TOKYO

Development of Water Services towards Ensuring Stable Water Supply in the Capital City Tokyo for the Future

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Sewerage systems of Tokyo, which support our life and create the future environment

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1. Introduction

The development of Tokyo’s world-class water supply system has been achieved by unremitting efforts through more than 100 years of service operations since the establishment of a modern water supply system in 1898.

We have greatly contributed to the development of the capital city Tokyo by conducting measures that time requires and bringing about improvement in the living standards of Tokyo citizens. Such measures include responses to the rapidly increasing water demand along with urban growth and measures against infectious diseases, sophistication of water treatment to respond to the deterioration of raw water quality and the strengthening of water quality standards, measures against non-revenue water (e.g. water leakage prevention), and development of various measures based on customer needs.

We are, however, required to respond appropriately to the possibly emerging issues and risks such as the arrival of a society in which population reduction and climate change-induced impacts on the water environment are expected, in addition to the issues we currently face such as renewal of aging water facilities that were intensively developed in the high economic growth period and improvement of preparedness for large-scale natural disasters including a large earthquake and torrential rainfall.

In such circumstances, Tokyo Waterworks has promoted various measures aiming to provide water services appreciated by customers, by promoting high-quality water services into over the future while building a more reliable water-supply system in both tangible and intangible manners.

2. History of Tokyo Waterworks

The beginning of Tokyo Waterworks dates back to more than 100 years ago.

At that time, we had issues such as pollution of resources and decay of wooden sluices for letting water run; in addition, in 1886, many citizens fell victim to a cholera outbreak. This led to the launch of development of a detailed survey design to establish Tokyo’s modern waterworks in 1888. The waterworks were designed to lead the water of the Tama River via the 43 km long, 360 years old Tamagawa Channel to...
the Yodobashi Water Purification Plant (hereinafter, WPP) to carry out sedimentation and filtration, and to distribute pressurized water in the metropolis through iron pipes. Starting with the water distribution to Kanda and Nihombashi areas on 1 December 1898, the waterworks service area was gradually expanded and completed in 1911.

After two years of the completion of the modern waterworks, we launched expansion projects focusing on construction of reservoirs and water purification plants and WPPs.

After the Great Kanto Earthquake of 1923, waves of urbanization expanded to the suburbs of Tokyo, and thus the water demand increased along with the expansion of city areas. Consequently, such expansion projects were further promoted. In the high economic growth period that followed the Post World War II Reconstruction Period, the water supply became tight due to the rapid urbanization (e.g. urban concentration of industries and population, expansion of sewage system, increase in nuclear families, diversification of lifestyles and construction of large buildings). In order to deal with this, we proceeded with new expansion projects to utilize the Tone River as a water source, thereby developing a trunk line network for water transmission and distribution.

In recent years, in order to respond to the growing needs of safe, good-tasting water, we have not only achieved the introduction of the advanced water treatment (hereinafter, AWT) system for all the water along the Tone River System but also promoted measures for stable supply of such water (e.g. promotion of directly-connected water distribution).

3. Current status of water services in Tokyo

Tokyo Waterworks has become one of the largest water operators in the world, which supplies water to about 13 million citizens living in water-supply areas of approximately 1,235 km² including the 23 Wards area, and 26 municipalities in the Tama area.

The annual total amount and the daily maximum amount of distribution water were 1.52349 billion m³ and 4.63 million m³, respectively, in FY 2013.
3.1 Water resources

Almost all the water used in Tokyo is taken from rivers: 78% from the Tone and Ara River Systems and 19% from the Tama River System.

Until the early half of the 1960s, we had been highly dependent on the Tama River System as water resources. Afterwards, in order to respond to the rapidly increasing water demand, we have increased our reliance on the Tone River System along with the water resources development of the System.

Currently, the amount of water resources owned by the Tokyo Metropolitan Government (hereinafter, TMG) is 6.3 million m³ per day.

3.2 Schematic diagram of water resources and water supply areas by river system

3.3 Water purification plants

Tokyo Waterworks has 11 main WPPs with the total capacity of about 6.86 million m³ per day.
These plants have introduced the AWT system by the ozonation and the biological activated carbon (hereinafter, BAC) adsorption treatment as well as filtration systems by rapid sand, slow sand, and membrane, and disinfection only, depending on raw water quality.

<table>
<thead>
<tr>
<th>Water system</th>
<th>WPP</th>
<th>Treatment capacity</th>
<th>Purification plant</th>
<th>Water system</th>
<th>Treatment method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tone and Arakawa</td>
<td>Kanamachi</td>
<td>1,500,000</td>
<td>21.9</td>
<td>79.9</td>
<td>Rapid sand filtration, advanced water treatment (1.5 million m³)</td>
</tr>
<tr>
<td>Rivers</td>
<td>Misato</td>
<td>1,100,000</td>
<td>16.0</td>
<td></td>
<td>Rapid sand filtration, advanced water treatment (1.1 million m³)</td>
</tr>
<tr>
<td></td>
<td>Asaka</td>
<td>1,700,000</td>
<td>24.8</td>
<td></td>
<td>Rapid sand filtration, advanced water treatment (1.7 million m³)</td>
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<tr>
<td></td>
<td>Misono</td>
<td>300,000</td>
<td>4.4</td>
<td></td>
<td>Rapid sand filtration, advanced water treatment (0.3 million m³)</td>
</tr>
<tr>
<td></td>
<td>Higashimurayama</td>
<td>880,000</td>
<td>18.4</td>
<td></td>
<td>Rapid sand filtration, advanced water treatment (0.88 million m³)</td>
</tr>
<tr>
<td>Tama River System</td>
<td>Ozaku</td>
<td>280,000</td>
<td>4.1</td>
<td>17.0</td>
<td>Rapid sand filtration</td>
</tr>
<tr>
<td></td>
<td>Sakai</td>
<td>315,000</td>
<td>4.6</td>
<td></td>
<td>Declining-rate filtration</td>
</tr>
<tr>
<td></td>
<td>Kinuta</td>
<td>14,500</td>
<td>1.7</td>
<td></td>
<td>Declining-rate filtration, membrane filtration</td>
</tr>
<tr>
<td></td>
<td>Kinutashimo</td>
<td>70,000</td>
<td>1.0</td>
<td></td>
<td>Declining-rate filtration, membrane filtration</td>
</tr>
<tr>
<td></td>
<td>Tamagawa</td>
<td>(152,500)</td>
<td>-</td>
<td></td>
<td>Declining-rate filtration, rapid membrane filtration</td>
</tr>
<tr>
<td>Sagami River</td>
<td>Nagasawa</td>
<td>200,000</td>
<td>2.9</td>
<td>2.9</td>
<td>Rapid sand filtration</td>
</tr>
<tr>
<td>System</td>
<td>Suginami</td>
<td>15,000</td>
<td>0.2</td>
<td>0.2</td>
<td>Disinfection only</td>
</tr>
<tr>
<td>Ground water</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>6,859,500</td>
<td>100.0</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>

Figure 4: Outline of Water Purification Plant

Note 1. The above facilities include those with decreased treatment capacities due to aging.
Note 2. The Tamagawa WPP is currently not in operation due to raw water deterioration and thus excluded from the total facility capacity. (This WPP currently transmits water to the Misono WPP for industrial water services.)
3.4 Water distribution facilities

A water supply station (hereinafter, WSS) consists of a distribution reservoir and pumping equipment, which takes major roles in water distribution control. The Water Supply Operation Centre conducts remote control operations of all the pumps and reservoirs of WSSs.

The total length of water distribution mains (with a bore diameter of 400-2,700 mm) and small distribution pipes (with a bore diameter of 50-350 mm) amounts to 26,613 km, which is equivalent to about two thirds of the way around the globe.

<table>
<thead>
<tr>
<th>Item</th>
<th>Total (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water distribution main</td>
<td>2,401</td>
</tr>
<tr>
<td>Small distribution pipe</td>
<td>24,212</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>26,613</strong></td>
</tr>
</tbody>
</table>

3.5 Water quality control

Tokyo Waterworks always supplies safe, good-tasting water by carefully controlling the water quality from water resources to faucets.

Also, in terms of eight items such as trichloramine and residual chlorine that cause chlorine odour, musty odour substances, and organic substances, we have voluntarily set the “water quality targets for good-tasting water” which are more stringent than those set out in the national water quality standards and worked on achieving the targets. Moreover, we have introduced the AWT system and carried out the “Tokyo High Quality Management Programme.”
3.6 Water supply operations

In order to ensure stable water supply, we have to make the most of our limited water resources by comprehensively promoting measures such as water facility development as well as carrying out efficient operations of raw water and careful control of water distribution.

Tokyo Waterworks has established the Water Supply Operation Centre to collect various data from each facility, thereby carrying out the around-the-clock monitoring of the entire Tokyo including major facilities in the Tama area.
4. Challenges for and efforts by Tokyo Waterworks

4.1 Middle-and long-term facility development

In recent years, the circumstances surrounding water services are different from those at the time when facility expansion was continuously carried out. That is, there are many factors of concern that may affect water services in the future, including the weakness of water resources owned by TMG and environmental burdens due to water services operations.

In such a situation, many of our WPPs intensively developed in the 1960’s will come to the end of their renewal periods nearly at the same time. We will thus face the time of reconstruction. In addition, we envisage various risks and issues that may affect future water services, including the urgency of a Tokyo Inland Earthquake, growing risks of heavy rain and drought associated with the progress of climate change, deterioration of raw water quality, and the arrival of a society in which population is expected to decrease.

Tokyo Waterworks has set up schemes for future facility development including the “Tokyo Waterworks Principal Vision STEP II” (November 2006) that shows the direction of measures for overall water services for the next quarter century, and the “Basic Concept for Renewal of Tokyo Waterworks Facilities” (March 2012) that compiles ideas on facility renewal from a long-term perspective for the future 50 or 100 years out.

Due to its extraordinary scale, the facility reconstruction that will serve as the basis of Tokyo Waterworks is a project that takes over a half century and requires huge cost. In order to effectively and efficiently promote the project, in April 2014, we formulated the Master Plan for Construction of Tokyo Waterworks Facilities that concretizes the ideas indicated in the abovementioned schemes and, on that basis, summarizes tasks for the next decade (FY 2015-24) which are intended to be incorporated into future project plans.

Summarizing the ideas on water demand, facility capacity and facility renewal that will be important factors in future facility development, the Master Plan clarifies the directions of three major policies: “ensuring of stable water supply,” “promoting earthquake countermeasures” and “potable delicious water.”

4.1.1 Ideas of facility capacity, facility renewal and water demand

Prospects of water demand

We estimated the water demand for the next 25 years until the completion of the first WPP renewal. As a result, in light of water leakage and variations in water distribution amount, the amount of the maximum daily water distribution may reach about 6 million m³ at the peak time during 2018-27.
In addition, we are going to conduct estimation of water demand as required based on the future socioeconomic circumstances, policy developments, demographic changes, etc.

**Facility capacity to be secured**

Although the total capacity of all the water purification plants is 6.86 million m$^3$ per day, we can currently supply only about 6 million m$^3$ of water per day due to the decrease in the water supply capacity associated with repairing works of aged facilities, which is tight in light of the planned water demand. On the other hand, in order to keep stable water supply into the future, we are required to retain facility capacity that can keep water supply even in the circumstances where water purification plants are forced to stop due to a disaster.

Thus, we decided that the facility capacity to be secured is about 6.8 million m$^3$ that includes water demand (the planned maximum water distribution per day) and the decreased capacity due to repair works, thereby keeping the capacity at the level of the daily average amount of water distribution and avoiding adverse impacts on the lives of Tokyo citizens and urban activities to the extent possible even in emergencies (i.e. water purification plants of the largest scale are stopped).

![Figure 10: Illustration of Details of Facility Capacity](image)

**Responses to facility renewal**

Most of large-scale WPPs will come to the end of their renewal periods almost at the same time from around 2020. Thus, in order to avoid significant capacity decrease due to renewal work, we will launch the work based on prior development of an alternative water purification facility of the equivalent capacity. This will allow us to promote systematic renewal work while ensuring stable water supply. In this regard, as the renewal of all the WPPs will take long period of time (about 60 years) to complete, we will reconstruct facilities at appropriate scales while taking account of water demand and risk responses as required.

Also, in cases where the in-service period of a facility will be long by the time of renewal, we will make use of asset management to understand the facility condition and prolong its operating life by appropriate repair in the future.
4.1.2 The direction of major policies and detailed tasks

Based on the basic ideas, we decided to steadily promote facility development by setting three main policies (i.e. “ensuring of stable water supply,” “promoting earthquake countermeasures” and “potable delicious water.”), 18 projects and 15 indexes that should be worked on during the next decade.

**Ensuring stable water supply**

In light of the occurrence of droughts that lead to water restriction once in three years and the concern about adverse climate change impacts on water resources, Tokyo Waterworks will work on ensuring stable water resources that can respond to droughts.

Also, we will improve the backup functions covering our water facilities as a whole by promoting development of alternative facilities, double-pipelines, and their networks so that we can continue to supply water even when waterworks facilities are...
forced to stop operations due to a disaster or an accident.

In areas with insufficient capacity of distribution reservoirs, we will continue to promote construction of new WSSs or expansion of existing ones.

**Promoting earthquake countermeasures**

Based on the lessons learned from the Great East Japan Earthquake and the TMG’s new earthquake damage assumptions, Tokyo Waterworks will promote earthquake resistance of facilities (e.g. WPPs and WSSs) and, particularly in terms of water pipelines, the “10 Year Project for the Use of Earthquake-Resistant Joints in Pipelines” so that we can effectively reduce damage due to water outage.

We will also promote water conveyance facilities, use of double pipes for water transmission and distribution, and their networking in order to strengthen the backup functions. Moreover, we will promote our own energy self-sufficiency by building and enhancing non-utility power generation facilities at WPPs and WSSs.

In addition, based on the flood assumptions by the government and TMG, we will enhance measures against floods for WPPs and WSSs.

**Potable delicious water**

Aiming to efficiently remove and reduce substances that cause musty or chlorine odours, Tokyo Waterworks has promoted the introduction of the AWT system in all the purification plants along the Tone River system that is the main water source for Tokyo, thereby achieving 100% water supply with advanced treated water in 2013.

On the other hand, we have enhanced the powdered activated carbon treatment of water to deal with musty odour substances that have occurred in raw water in the upper basin of the Tama River through the year. In this connection, we will consider the introduction of more efficient water treatment systems in facility renewal.

Also, it is important to avoid water quality deterioration in water pipes and receiving tanks. In particular, we will continuously work on promoting proper management of water supply facilities with receiving tanks – the subject of concern about water quality.
deterioration therein – and shift to the direct water supply system.

4.1.3 Details of tasks and indexes for improvement

4.2 Energy and environmental measures

The purpose of water services is the steady delivery of safe drinking water to consumers by utilizing valuable water generated by the earth. That is, the services are closely related to the global environment. Putting “energy and environmental measures” as one of its main policies, Tokyo Waterworks has worked on further promotion of environmental measures through various efforts considering the environment: management of water conservation forest, efficient use of energy, natural resources saving, recycling, etc.

Tokyo Waterworks, however, uses approximately 0.8 billion kWh of electricity that accounts for about 1% of Tokyo’s total power consumption through the processes of water intake, conveyance, purification, transmit, and distribution. Thus, we have to make efforts to reduce energy use as a large-scale business entity.
In this regard, in addition to effective use of water resources, we have strived to take measures to prevent water leakage, introduce renewable energy, and improve efficiency of pump equipment, which have significant effects on the reduction of energy use. Yet, our water leakage rate is already 2% that is at the top level in the world, the further reduction of which is thus difficult. That is, the conventional approach has faced limitations in seeking an additional reduction in energy use.

By seizing this opportunity of facility renewal based on the abovementioned Master Plan for Construction of Tokyo Waterworks Facilities (April 2014), we need to establish a highly energy efficient water system by making efforts to develop facilities in consideration of energy efficiency while thoroughly exploring and expanding the possibility of further promotion of existing measures such as employment of renewable energy and improvement in pump efficiency.

Tokyo Waterworks has formulated the Tokyo Waterworks 10 Year Plan for Energy Efficiency to aim for further improvement in energy efficiency of the waterworks services. Taking the stable supply of safe and good-tasting water as a given requirement, we have made utmost efforts to actively promote energy-related measures based on this Plan and pass the nature-rich environment of the earth on to the next generation.

4.2.1 Past efforts and future challenges towards higher energy efficiency

**Promotion of measures to prevent water leakage**

Measures to prevent water leakage are intended to contribute to the reduction in power use for the purpose of delivering tap water to our customers as well as the effective use of valuable water resources. Tokyo Waterworks has realized the world-leading low water leakage rate by promoting measures to prevent water leakage such as strategic water pipe replacement since before FY 2000.

Through the measures to prevent water leakage taken by FY 2013, we have reduced our annual power usage by 45 million kWh relative to the FY 2000 level, which is equivalent to about 6% of our power usage in FY 2000.

**Improvement towards high efficiency of pump equipment**
In installing or renewing pump equipment at WPPs or WSSs, Tokyo Waterworks has promoted the enhancement of energy efficiency, for example, by changing from the liquid rheostat method that decreases energy efficiency in the low-speed rotation range to the inverter control method that involves less energy loss.

**Introduction of the cogeneration system**

At large-scale WPPs, Tokyo Waterworks has in turn introduced continuous power generation equipment that employs the cogeneration system\(^1\). The continuous power generation equipment generates power using city gas; we have made efforts to save energy such as by utilizing the steam generated from the recovered exhaust heat for generating electricity and for warming the sludge generated from the effluent treatment process.

**Introduction of renewable energy**

WPPs and WSSs have generated clean energy by introducing the hydraulic power generation system that uses excess pressure generated when conveying and transmitting water, or solar power generation in order utilizing the upper part of distribution reservoirs.

**Efficient water supply operations**

Tokyo Waterworks have operated the total energy management system in which the energy usage in the processes of water conveyance, purification, transmission and distribution can be identified. By using this system, we have made efforts to make water supply operations efficient by adding an energy perspective to as by distributing water to routes that consume less energy.

As a result, the aforementioned measures have brought about the effect of streamlining energy use to be equivalent to about 15% (relative to FY 2000), relative to the case where no measures were taken.

**4.2.2 Policy on plan formulation**

In order to further improve energy efficiency of all the water facilities for responding to the social demand for energy (e.g. contribution to the targets set by the Government or TMG), Tokyo Waterworks need to proceed with consideration from every perspective, including the expansion of the measures taken so far.

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\(^1\) A system that generates power using city gas as fuel while effectively utilizing the recovered exhaust heat therefrom.
Thus, we decided to implement each measure by setting the following policies.

- By seizing the opportunity of construction or renewal of waterworks facilities, we will restructure them to be highly energy efficient by sufficiently utilizing the potential energy of water in the processes of water intake, conveyance, purification, transmission and distribution.

- To the extent possible, we will improve the existing measures such as the streamlining of pump equipment, and introduction of cogeneration systems and renewable energy sources.

### 4.2.3 Targets of the Plan

The Plan is to cover a ten year period from FY 2015 to 2024, which sets out targets as follows.

**Target 1**

Due to the introduction of the AWT system, it is unavoidable that there will be an increase in the use of energy that is necessary for ensuring stable supply of safe and good-tasting water. Putting this aside, we will streamline the energy usage in the conventional water system by at least 20% or more by FY 2024 relative to FY 2000.

Due to the introduction of the AWT system since FY 2000, energy usage is estimated to increase by about 16% by FY 2024. Thus, in terms of the total usage that includes the increase in energy use, the rate of streamlining of energy use will be about 10%.

**Target 2**

As well as promoting the use of renewable energy (e.g. solar and small hydraulic power) and of exhaust heat by using the cogeneration system, Tokyo Waterworks will increase the ratio of the use of renewable energy by reducing the purchase of electricity by promoting energy efficiency.

Specifically, we will introduce the system to water facilities and the upper part of buildings, thereby increasing the total solar generation capacity to 8,000 kW or more by FY 2020 and 10,000 kW or more by FY 2024.
As of end of FY 2013 | Total in FY 2020 | Total in FY 2024
--- | --- | ---
Targets for TMG facilities | 10,000 kW | 22,000 kW | -
Tokyo Waterworks | 5,600 kW | 8,000 kW | About 38% of the Targets for TMG facilities | 10,000 kW*

*TMG’s target for introduction in 2024: 1 million kW for the entire Tokyo

**Figure 22: Targets for Introduction at TMG Facilities**

Also, we will introduce the cogeneration system to all the large-scale WPPs, thereby expanding its total generation capacity up to 54,000 kW by 2014.

**Figure 23: TMG’s Targets for Introduction**

In water services, we have the mission to stably supply safe, good-tasting water, whereas we consume a huge amount of energy through the processes of water purification, transmission and distribution.

In order to realize further energy reduction in addition to various efforts already made, what is necessary for us is a fundamental shift to measures that improve energy
efficiency of our water system itself, rather than being confined to the expansion of conventional measures.

Based on this Plan, Tokyo Waterworks aims to construct a highly energy-efficient water system by undertaking services from the perspective of improving energy efficiency in every field from development planning to operations and maintenance of water facilities.

4.3 Diversified water quality issues

The basic policy of our services is to supply safe, good-tasting water. It is therefore important to keep the good quality of water resources to realize the policy.

In recent years, however, the circumstances surrounding water resource quality are becoming complicated and diverse such as due to the issue of radioactive materials caused by the accident at the Fukushima Daiichi Nuclear Power Plant, and social issues including the water quality accident due to formaldehyde in the Tone River System, musty odour occurring in water resources, cryptosporidium (i.e. pathogenic organism), dioxins, and endocrine-disrupting compounds. Also, the problems of foul smell and taste in reservoirs have become a common water quality problem in lakes and reservoirs across the country.

On the other hand, along with diversification of values among people, Tokyo citizens’ needs now require not only safe water but better-tasting water.

In response to these issues, Tokyo Waterworks has introduced the AWT system as well as promote careful water quality control and development of water treatment technology based on thorough water treatment, and water quality surveys and experiments, thereby realizing the supply of safer, better-tasting water.

4.3.1 AWT system

*Background of the introduction*

Since 1965, the basin area of the Edo River – a branch current of the Tone River System – was rapidly developed as Tokyo’s dormitory towns, while its river water quality drastically deteriorated due to the delay in sewage development. At the Kanamachi WPP that takes raw water from the Edo River, musty odour substances had occurred during the summer time since around 1972; we received nearly 1,000 complaints a year. Also, the high concentration ammonium nitrogen became a critical issue in water quality management in the winter time.

For this reason, we started the powdered activated carbon treatment at the Kanamachi WPP, which had a certain effect. It was, however, difficult to carry out stable treatment with this method due to the difficulty in dealing with the rapid changes in concentration of musty odour substances and due to the concern about leakage of microscopic particles of activated carbon when increasing its injection rate.
In light of this situation, in 1984, Tokyo Waterworks started the AWT experiment by the ozonation and the BAC adsorption treatment aiming for the reduction in the potential of ammonium nitrogen and trihalomethane formation as well as for the stable and efficient removal of musty odour substances.

**Progress of the introduction**

Because of the favourable results obtained from the five-year plant experiment, Tokyo Waterworks decided to introduce the AWT system using the ozonation and the BAC adsorption treatment to the Kanamachi WPP. The construction was started in 1989; the first-phase AWT facilities with the capacity of 260,000 m³/day were completed in June 1992. Afterwards, in light of the construction status of sewage systems in the upper basin of the Edo River, the daily-fluctuating raw water quality and the growing needs of Tokyo citizens, we have in turn developed AWT facilities.

In such a circumstance, we completed the construction of the 2nd phase facilities at the Asaka WPP in March 2014, thereby completing all the AWT systems at all the WPPs along the Tone River System. Since then, we have become able to supply safe, good-tasting water through AWT systems even in summer – the season with high water demand.

After a quarter of century, the large-scale project was completed, with the cost of 230 billion yen and the total capacity of 5.48 million m³/day.

**Mechanism of treatment**

The AWT is a method of water treatment that aims to remove and reduce musty odour substances that cannot be sufficiently dealt with by any method of ordinary water treatment, ammonium nitrogen that causes chlorine odour, and various organic substances such as formaldehyde. Tokyo Waterworks has placed the ozonation and the BAC adsorption treatment in-between the coagulation-sedimentation treatment and the rapid sand filtration.

The ozonation is a method to remove the chromaticity, and foul smell and taste from raw water, and carry out decomposition of organic matters by using ozone’s strong oxidizability that is only second to fluorine. Also, this method can be expected to improve the treatment ability of the BAC adsorption treatment in the later step of the treatment process because ozone decomposes organic matters in raw water into low-
molecular matters.

The BAC adsorption treatment is a method to remove organic matters and ammonium nitrogen by utilizing the decomposing action of microorganisms grown in the activated carbon bed, in addition to the adsorbent action of granular activated carbon.

The BAC adsorption basin that was developed by Tokyo Waterworks consists of a 2.5 meter thick layer of granular activated carbon and its lower catchment, which carries out water treatment by allowing gravity flow of ozonated water.

An effect of the AWT

In order for citizens to be widely aware of its high-quality tap water, Tokyo Waterworks organizes campaigns so that they can compare advanced treated tap water with commercially available bottled mineral water during the Water Week or at various events in towns.

As a result of the comparison made by about 58,000 customers in FY 2013, more than half of them answered that they preferred the tap water, which proved that Tokyo’s tap water bears comparison with bottled mineral water in taste.

4.3.2 Membrane filtration treatment

The membrane filtration treatment is a method to separate and remove impurities using the principle of filtering raw water through a membrane with ultrafine pores, which can remove suspended substances and microorganisms (e.g. cryptosporidium) in raw water.

In March 2007, Tokyo Waterworks introduced the then domestically largest membrane filtration facility (capacity: 40,000 m³/day) to WPPs. Also, eight small water purification facilities in the Tama area operate the membrane filtration treatment.
4.3.3 Trends in treatment methods and improvement of facility capacity

4.4 Responses to climate change (e.g. global warming)

According to the World Meteorological Organization (WMO), atmospheric greenhouse gases (GHGs) have continued to increase, the global average concentration of which hit a record high in 2012. The Fifth Assessment Report* of the Intergovernmental Panel on Climate Change (IPCC) shows that the increase in global average temperature by 0.85 degrees Celsius (from 0.65 to 1.06) during about 130 years (1880-2012) was caused by the increase in GHG concentration. The report also says that each of the last three decades has been warmer than any preceding decade since 1850.

Also, the Earth’s surface temperature is expected to rise by up to 4.8 degrees Celsius by the end of the twenty-first century.
In recent years, due to the impact of climate change, extreme weather events have frequently occurred around the world (e.g. heat waves, heavy downpours and tornados) while such events have become increasingly evident also in Japan (e.g. frequent local torrential rain that is called Guerrilla rainstorm).

In order to control the risks of such weather events within allowable range, we are required to limit the temperature increase to less than 2 degrees Celsius by 2100, compared to pre-industrial levels.

It is concerned that climate change such as global warming may have a large impact on water services (e.g. changes in water resources amounts and their quality). Thus, in order to maintain and operate water services into the future in a favourable manner, we need to conduct studies on and consider measures against the impacts of climate change on water services and their degrees.

Tokyo Waterworks will continue to ensure the implementation of the GHG reduction obligations, and to work on the effective use of resources and the conservation of the water environment.

4.4.1 Maintenance and management of water conservation forests

Rain water that falls on forests is temporally stored in the soil and then runs off to rivers while being filtered and purified through the soil. Forests trees supply oxygen by absorbing CO2 in the air, which takes a role in preventing global warming.

In order to maintain and improve these forest functions, Tokyo Waterworks has formulated the Water Conservation Forest Management Plan in almost every decade, thereby carrying out long-term maintenance of the water conservation forests (about
22,000 ha) that spread in the upper basin of the Tama River. We will continue to work on water resource conservation by growing forests that can sufficiently provide public service functions such as the water resource recharge function.

As for the management of water conservation forests, we have specified the artificial forests that are to be renewed by the alternation of generations as the exploitable multi-layered forests, thereby shifting them to multi-layered forests with mixture of needle- and broad-leaf trees that are formed by two generations of planted trees and natural broad-leaf trees, and carrying out various types of conservation work at growing stages of trees throughout the year.

Also, private forests in the upper Tama River basin are deteriorating due to such as the prolonged slump in forestry. For the purpose of management of water conservation forests, we will purchase the private forests which the owners intend to sell so that such forests can perform full functions.

### 4.4.2 Mitigation of the heat-island effect (development of roof greening)

The heat-island effect (i.e. temperature increase in central urban areas) is caused by green area loss and exhaust heat associated with urban activities. Roof greening produces effects equivalent to those of insulation, thereby mitigating the heat-island effect and leading to cooling cost reduction as well as energy-saving.

Having promoted roof greening for water facilities, Tokyo Waterworks will continue to carry out roof greening, taking the opportunities of construction or refurbishment of such facilities and government buildings, to expand green areas.
4.4.3 Promotion of waste control and recycling

Tokyo Waterworks will promote waste control and recycling through the effective use of WPP sludge, promotion of recycling of construction by-product, and office activities that take account of resource circulation.

Climate change is a phenomenon that affects various aspects of water services, and its impact is immeasurable. Water is essence of life, and thus water services are so important that they cannot be allowed to stop operations. Waterworks operators are responsible for taking measures to ensure stable services into the future.

Also, we have to take measures against climate change risks from a long-term perspective.

Given the serious challenges from climate change, Tokyo Waterworks will make every possible effort considering various measure options as well as collecting and analysing information through the cooperation of domestic and overseas water operators.

4.5 Wide-area services operations

Japan has entered the era of depopulating society and is highly likely to experience decline in the water supply population and amount. In this situation, Tokyo Waterworks has faced challenges such as the proper restructuring of facilities that are coming to the end of the renewal period and the retaining of experienced engineers that has become difficult due to mass retirement of such staff.

As a solution for such challenges, we have focused on the promotion of active wide-area cooperation and public-private partnership. On the one hand, in cases where
small waterworks operators encounter limitations in taking individual responses, it is necessary to cooperate regardless of respective positions of neighbouring waterworks operators, drinking water supply operators, related administrative bodies and private companies. On the other hand, prefectures and core waterworks operators are expected to actively participate in the cooperative framework from the perspective of optimizing the entire region.

The water services in the Tama area used to be individually operated by each municipality. Due to the rapid population increase and urbanization since 1960, however, they faced the serious difficulty in securing water resources and the significant disparities in rate levels and water supply coverage between the ward area and the municipalities in the Tama area. Hence, the cities and towns have made strong requests for correction of such situations.

In response to this, Tokyo Waterworks in 1973 announced a plan for the centralization of the TMG-run water services, thereby in turn integrating the municipality-run water services in the Tama area into the TMG-run water services.

In this connection, TMG delegated the duties to the municipalities based on the Local Autonomy Act, without transferring the relevant staff of municipalities to Tokyo Waterworks. Consequently, the water services in the Tama area became subject to the operations under the dual-structured system: “securing of water resources, wide-area development and management of facilities, and administration of public finance” by TMG and “management and execution of services that are necessary for water supply to residents” by municipalities.

### 4.5.1 Problems caused by, and threshold for cancelling, the duty delegation

**Problems caused by the duty delegation**

The duty delegation has caused various problems because the operations of water services within municipalities are basically delegated to respective municipalities.

As for the service operations, because TMG has delegated the authority of collecting water charges to each municipality, the municipal offices that deal with bill payment, notification and inquiries are available only to the customers who live therein, which has prevented external municipalities from providing these services.

Also, it takes the municipal water office long to know bill payment information because such information is transferred from financial institutions in each municipality via municipal treasurers to Tokyo Waterworks, which has prevented Tokyo Waterworks from providing accurate services to its customers based on the latest information.

As for facility management, the maintenance and check services for WPPs and WSSs are carried out on a municipal basis. Thus, we have not established a wide-area and efficient service execution system. Also, we have been unable to establish appropriate
service areas beyond municipal boundaries because pipeline management is carried out on a municipal basis. Moreover, small municipalities have been in circumstances where it is difficult to continue to accept the delegation from TMG because they have faced difficulties in keeping their technical capabilities to meet high technical requirements for water services.

**Threshold for cancelling the duty delegation**

If the duty delegation is cancelled, the abovementioned problems will be resolved. The delegated duties (i.e. those carried out by about 1,100 municipal staff as of 2003), however, will be returned to and must be undertaken by Tokyo Waterworks.

There was, however, continuing pressure to reduce staff numbers at the time. There was a sweeping trend within the government towards regulatory reform aiming to realize a simple and efficient government, while TMG had long worked on administrative reform. In this connection, Tokyo Waterworks had to limit the future increase in the staff numbers.

**4.5.2 Utilization of supervising organizations**

In order to cancel the duty delegation while restraining the increase in staff numbers, Tokyo Waterworks – as an outsourcee of duties for about 1,100 municipal staff – had to seek to build an efficient system of services operations while ensuring fairness that must be ensured by the public sector in carrying out services.

In this connection, Tokyo Waterworks sought to build a system for wide-area services operations while utilizing supervising organizations that had experience and knowhow through their long experience of services entrusted by Tokyo Waterworks.

**4.5.3 Services undertaken by supervising organizations and their effects**

**Integrated reception (Tama Customer Service Centre)**

Customers who are moving had to give notification twice to the municipality they move out of and that they move in, but it now suffices to notify the Centre only once. They can also continue their bill payment through financial institutions.

In addition, we have developed a system through which to respond to emergencies on a 24 hour a day, 365 days a year basis.

**Services related to payment receipt and water supply equipment (Tama Service Station)**

Customers are now allowed to make payment, enquiries, and consultation at any 12 service stations established in the Tama area.

**Monitoring of WPPs and WSSs, and control of water supply operations**
Tokyo Waterworks have promoted efficiency of water supply operations by making WPPs and WSSs unmanned at normal times through the integration of operation control services, which used to be undertaken by municipal staff, into four Centralized Control Rooms for remote monitoring and control.

**Development of facility management system and services concerning water supply equipment**

Tokyo Waterworks has realized efficient facility management, a wide-area and stable water supply operation system, and integrated facility management, beyond municipal boundaries.

**4.5.4 Effects of utilizing supervising organizations**

The supervising organizations have brought the service standards in the Tama area up to those in the ward area, through their contribution to not only restraining the increase in the number of staff of Tokyo Waterworks but also improving the water supply stability by wide-area service provision, facility development and facility management, beyond municipal boundaries by cancelling the duty delegation.

As mentioned above, the municipalities in the Tama area faced the challenges for retaining experienced engineers, operating services on a municipal basis and ensuring a system to execute services operations for 1,100 municipal staff for whom TMG was to be responsible as a result of the cancellation of the duty delegation. That the supervising organizations were delegated with tasks which comprehensively cover such challenges, and that a system for wide-area services operations was successfully built, contributed to the smooth cancellation of the duty delegation to the Tama area.

Also, it can be said that our efforts were effective, in that we restrained the increase in the staff numbers, ensured fairness, contributed to the establishment of an efficient system for services operations, and utilized supervising organizations.

Now that the long-standing duty delegation is completely cancelled, and in order to further bring out the strength of the TMG-run wide-area water services based on our past achievements, we will strive to work focusing on challenges for restructuring water services in the Tama area and strengthening our disaster response capability, as well as continue to work on challenges towards efficient operations and strengthening of cooperation with the municipalities.

**5. Conclusion**

It is said that there is 1.4 billion km³ of water on the earth, 97.5% of which is sea water, that almost all the fresh water is ice, and that the water easily accessible to humans is only 0.01%. In this sense, water is limited and valuable natural resources. Tokyo
Waterworks has built a world’s pre-eminent “water culture” as an actor to deliver this limited water through its everlasting quest and unremitting effort.

Currently, the roles of water services in Japan are diversified; they are essential as a basis for socioeconomic activities, to say nothing of improving public health and the living environment.

Along with its mission to daily deliver safe, good-tasting water, Tokyo Waterworks has responsibility to maintain and develop water services as a good social foundation, and pass it onto the next generation.

In 2018, Tokyo will host the International Water Association (IWA) World Water Congress & Exhibition – one of the world’s largest international conference on water. Moreover, in 2020, the Olympic and Paralympic Games will be held in Tokyo.

Taking advantages of these valuable opportunities, Tokyo Waterworks will disseminate information on our water technology and knowhow of system operations widely inside and outside Japan, thereby contributing to improving the water environment in the world. In addition, we will do our best to get prepared to “welcome” overseas visitors through our “stable supply of safe, good-tasting water.”
Sewerage systems of Tokyo, which support our life and create the future environment

1. Introduction

Sewerage system plays an important role of cleaning water generated from use in the daily life and activity of the citizens of Tokyo which is over 13 million population, and speedily rainwater drainage on the road and city area to rivers or sea; their activities are important in maintaining safe and comfortable environment and forming good water circulation. These days, it is also required to create a good city environment by recovering the resource and energy such as ash, reclaimed water and wastewater heat, etc.

The total length of sewers owned by the Bureau of Sewerage Tokyo Metropolitan Government (TMG) is so long that the length of only the sewers in the 23 wards of Tokyo (the Ward Area) reaches 16,000km, nearly equal to the distance between Tokyo and Sidney in Australia by round-trip. 5.56 million m³/day of wastewater is treated in 20 wastewater treatment plants (WWTPs), 13 of WWTPs in the Ward Area and 7 of WWTPs in Tama Area. However, sewers and WWTPs which have 130-years history have aged and need some rehabilitation. Simultaneously, TMG has to take measures to control increasing floods, CSO, energy and global warming problem.

For these reasons, TMG has progressed repair of various facilities and has planned to manage the steady operation making much of preventive maintenance and manage the operation to save energy and improve the quality, as a result protecting the safety of citizens of Tokyo, supporting their safe and comfortable life, and creating good water environment.

2. History

Since Tokyo has expanded its land by landfill from Edo period (17th century), there are a lot of low-lying lands. Drainage as well as wastewater treatment has been an important issue.

In 1884, an epidemic of cholera and other diseases triggered the construction of “Kanda sewer” which is the beginning of the modern sewerage system of Tokyo and still functioning. In 1900, the Sewerage Act was enacted and the first Tokyo sewerage plan has made. The objective of the plan was to eliminate both rainwater and wastewater.

In 1922, Mikawashima WWTP which is the first modern WWTP in Japan began its operation. A part of the Sewerage Act was amended to solve various environmental
problems including water pollution and air pollution caused by the economic boom followed by the end of World War II. To preserve the quality of the public water was defined as one of the roles of the sewerage system.

Since then, the water quality of the rivers in urban area has been improved, owing to development sewerage works. The sewered population ratio has reached approximately 100% in the Ward Area in 1994, and the ratio in Tama Area is also 99%, as of FY2014 (Fig.1).

3. Current situation of the Tokyo Sewerage services

3.1 Outline of Tokyo Metropolitan area (FY 2014)

Tokyo is the Japanese capital, where political and economic functions are highly concentrated. Tokyo covers 2,188 km², with population of about 13.29 million. It is consisted of 23 Wards Area, Tama Area with 26 cities, 3 towns, and 1 village located in the western part, and islands with 2 towns and 7 villages.

3.2 Sewerage works in Tokyo (excluding islands)

Sewerage works in the Ward Area is managed independently from the one in Tama Area. Sewerage works is usually managed by city or town governments in Japan, but sewerage works in the Ward Area is managed by TMG, taking the role of the “city.” On the other hand, in Tama Area, sewerage works is operated by each city and TMG.
Outline of sewerage works of Tokyo Ward Area is below (Table 1, Fig. 2).

### Table 1  Outline of sewerage works in Ward Area (FY2014)

<table>
<thead>
<tr>
<th>Items</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Planned population</td>
<td>8.692 million</td>
</tr>
<tr>
<td>Planned area</td>
<td>57,839 ha</td>
</tr>
<tr>
<td>Total length of sewers</td>
<td>16,000 km</td>
</tr>
<tr>
<td>The number of treatment areas</td>
<td>10</td>
</tr>
<tr>
<td>The number of manholes</td>
<td>483,430</td>
</tr>
<tr>
<td>The number of pumping stations</td>
<td>84</td>
</tr>
<tr>
<td>The number of WWTPs</td>
<td>13</td>
</tr>
<tr>
<td>Total volume treated</td>
<td>4.62 million m$^3$/day</td>
</tr>
</tbody>
</table>

5km
3.3 Sewerage System components (Principally 3 facilities)

3.3.1 Sewers
Sewers are pipeline which collect sewerage from houses and commercial buildings and transport to WWTPs. They reticulate like leaf veins and total length of sewers in the Ward Area is 16,000 km. The sewer is made of various materials such as concrete, polyvinyl chloride (PVC), and clay, etc. And their internal diameter range of sewers is from 25 cm to 8.5 m.

3.3.2 Pumping Stations
Sewers have gentle slope so that wastewater flows naturally (gravity flow). Therefore, the sewers gradually get deeper in the ground. When it gets too deep to build sewers, wastewater is pumped and carried to near-surface and the gravity flow restarts. Pumping stations have the role of pumping wastewater. In this way, wastewater collected in the sewers is transported to WWTPs by way of pumping stations. Additionally, pumping stations fulfill an important role of flood prevention in case of heavy rain by promptly discharging rainwater, which has flowed into the sewers, to rivers and the sea.

3.3.3 Wastewater Treatment Plants (WWTPs)
WWTP has two main functions: one is for wastewater treatment function, and another is for sludge treatment function generated from wastewater treatment. Most of WWTPs in Tokyo use standard activated sludge process. Advanced treatment method can remove nitrogen and phosphorus.
In Tokyo, sludge before dewatering is sent to some centralized treatment plants. Sludge generated in WWTPs without a sludge treatment facility is sent through the pressure pipes to three WWTPs with a sludge treatment facility or two sludge treatment plants to treat them. In order to cope with the lack of capacity on restructuring, and to back up a WWTP in case it is damaged in earthquake disasters, etc. The pipelines among some plants to send sludge and wastewater are being constructed.
Sludge from the primary and secondary sedimentation tanks are thickened, dewatered, and finally incinerated to be reduced to ash. Ash is used for landfill and recycled as cement material, etc.
Additionally, the roof covering WWTPs are used as park or playground for neighborhood.
Table 2 13 WWTPs and 2 Sludge treatment plants in Ward Area (FY2014)

<table>
<thead>
<tr>
<th>WWTPs &amp; Sludge plants</th>
<th>Treated wastewater volume (10,000m³/day)</th>
<th>Sludge treatment volume (10,000m³/day)</th>
<th>Incinerated volume (ton/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shibaura</td>
<td>64.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mikawashima</td>
<td>43.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunamachi</td>
<td>37.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ariake</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nakagawa</td>
<td>17.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kosuge</td>
<td>23.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kasai (with sludge plant)</td>
<td>30.9</td>
<td>3.1</td>
<td>414</td>
</tr>
<tr>
<td>Ochiai</td>
<td>35.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nakano</td>
<td>2.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Miyagi (with sludge plant)</td>
<td>18.9</td>
<td>0.5</td>
<td>73</td>
</tr>
<tr>
<td>Shingashi (with sludge plant)</td>
<td>54.4</td>
<td>1.9</td>
<td>326</td>
</tr>
<tr>
<td>Ukima</td>
<td>14.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Morigasaki</td>
<td>118</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>Toubu-sludge plant</td>
<td>—</td>
<td>3.1</td>
<td>608</td>
</tr>
<tr>
<td>Nambu-sludge plant</td>
<td>—</td>
<td>4.5</td>
<td>1,008</td>
</tr>
<tr>
<td>Total</td>
<td>461.7</td>
<td>16.6</td>
<td>2,429</td>
</tr>
</tbody>
</table>

3.3.4 Collection system (combined and separate; Fig.4)

In the combined sewer system, both sanitary wastewater and rainwater are collected to the same sewer and sent to WWTP. On the other hand, in the separate sewer system, sanitary wastewater and rainwater are collected to the separate sewers. Eighty percentage of Ward Area adopts the combined sewer system, because it was cheaper and quicker than separate sewers to be introduced in old days.
3.3.5 Environmental Conservation

Water quality standard of effluent is defined by Sewerage Act, the Water Pollution Control Act, and local laws. WWTPs control the water quality of the influent and effluent to comply the standard (Table 3).

Additionally, measures such as covering the facilities with lids or adsorbing the odor with activated carbon are taken to prevent odor, because many sewerage facilities are located near residential areas and commercial facilities.

The emission gas from incinerators is controlled by selecting incinerators of appropriate specification and introducing exhausting gas removal devices.

![Fig.4 Outline of sewer system (Left; combined, Right; separate)](image)

<table>
<thead>
<tr>
<th>Items</th>
<th>Influent</th>
<th>Effluent</th>
<th>Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td>BOD</td>
<td>161</td>
<td>7</td>
<td>25</td>
</tr>
<tr>
<td>COD</td>
<td>86</td>
<td>9</td>
<td>35 (15)</td>
</tr>
<tr>
<td>T-Nitrogen</td>
<td>30.9</td>
<td>12.4</td>
<td>30 (20)</td>
</tr>
<tr>
<td>T-Phosphorus</td>
<td>3.3</td>
<td>1.0</td>
<td>3.0 (1.0)</td>
</tr>
</tbody>
</table>

( ): effluent water quality standards with advanced treatment facilities

3.3.6 Water Reuse

The secondary effluent is further treated by advanced treatment methods such as filtration and ozonation for water reuse. The reclaimed water is mainly used for toilet flushing, river flow augmentation, and recreational waters. 9% of effluent in Tokyo is intentionally recycled.
4. Challenges for Tokyo Sewerage works

Tokyo sewerage works faces various issues. They include the aging of sewers and WWTPs. The others are flood control, anti-earthquake, CSO control as well as energy efficiency for global warming.

4.1 Renovation of Sewers and WWTPs

Measures for aging sewers, WWTPs, and pumping stations, stable collecting and treatment of wastewater is maintained for the future by taking other measures of reinforcing the capacity of draining rainwater and tolerance to earthquakes, improving energy efficiency, and reducing GHGs.

4.1.1 Current Situation and Issues

Total length of sewers older than their legal useful life is as long as about 1,800km. Additionally, it is anticipated that another sewer installed in large quantities within short time, after the period of high economic growth reach their useful life all together. Therefore, the total length of the aging sewers is expected to be 8,900km in the next 20 years. However, various infrastructures are buried under the metropolitan roads, which make difficult to dig the road to replace aging sewers, or there are some sewers whose water level is too high to rehabilitate.

4.1.2 Solutions

By taking the asset management approach allows effective retrofitting by extending the regal useful life of pipes by 30 years. The branch sewers are rehabilitated in 3 phases, in order to level the annual expenditure of rehab works. The sewers installed earliest in 4 urban areas are reconstructed with priority. The sewer trunks with priority are the aging sewers which were built before 1955 and turned out to need measures thorough inspection. As rehabilitation method, trenchless technologies are often employed. It is usually to reconstruct sewer trunks with higher water level. In this case, TMG would needs to build for relief sewers in order to reduce the flow direction in advance.

Enhancement of the capacity to drain rainwater, improvement of earthquake proof,
advancing the energy utilization, and reducing GHGs emission are also planned in restructuring the aging WWTPs and pumping stations. The asset management method is utilized to extend the useful life to about twice as long as the legal life by planned maintenance, and then TMG is going to renovate them efficiently during the economic useful life.

Photo.3  The sewer trunk of reconstruction by rehabilitation method

4.2 Flood Control
Securing the urban function by advancement of flood control measures, citizens of Tokyo can live safety with peace in mind.

4.2.1 Current Situation and Issues
In these days, there are frequent local heavy rainfalls exceeding 50 mm/hr which is designed rainfall of Ward Area mainly. Moreover, there are some areas where rainwater drainage capacity of sewers is too small to run off as progress of urbanization.

4.2.2 Solutions
The sewerage system is developed for 50 mm/hr torrential rainfalls which is targeting at the completion of flood control in 30 years, based on the Tokyo basic policy of the measures for rainwater. Both soft and hard measures are taken for the rainwater over 50mm/hr to ensure the safety of citizens. As for the hard measures, control measures will be taken for 75 mm/hr torrential rainfalls for the areas having large underground shopping complex. As for the soft measures, TMG operates “Tokyo-Amesh (Rain-radar)”, which supplies rainfall information in and around Tokyo with radar and is shown the real-time. This Tokyo-Amesh is utilized in operation of our facilities, and you can see it on our web site. The citizens of Tokyo are alerted for the flood.
4.3 Measures against Earthquake Disaster

In order to protect sewerage systems and secure traffic function such as emergency transport road, TMG develops countermeasures against big earthquakes and tsunami.

4.3.1 Current Situation and Issues
Many damages are expected such as fracture of the joints between sewers and manholes, and suppress uplifting of manhole by liquefaction in case of large-scale earthquake such as “Tokyo epicentral earthquake”. As well as countermeasures of terminal stations and restoration hubs, it is necessary to secure toilet and traffic functions in the important facilities such as shelters and nursing facilities newly designed by the revision of regional disaster prevention plan, and to measure the stayed-in district residual areas.

Wide-area electric blackout would be likely as well as the damage to facilities and equipment in WWTPs and pumping stations. Therefore, countermeasures against earthquake to maintain the minimum necessary sewerage systems in case of the largest earthquake are important. Additionally, securing emergency power generation facility and securing fuel in order to keep the sewerage systems are also an issue.

4.3.2 Solutions
The joints between manholes and sewers are made flexible to prevent earthquakes damage for the targeted sewers accepting the wastewater from terminal stations and disaster control centers. Prevention technologies of manhole uplift caused by liquefaction on the emergency access roads connecting shelters or terminals stations are progressing. Sewerage systems can be secured by the countermeasures of earthquake proofing in case of the largest earthquakes. Installing emergency power generators at WWTPs and pumping stations is secured the electric power steady in case of emergency such as blackout electric with preparing for the power system fuel.
4.4 Sludge Disposal

Sludge generated from wastewater treatment process in Ward Area is centralized for treatment. Sludge is collected from WWTP without sludge treatment facility through pipelines to WWTPs with sludge treatment facility. After then, sludge is incinerated and recycled into material of cement or concrete product, in order to minimize the volume.

4.4.1 Current Situation and Issues

Some of the sludge pipelines in the Ward Area are more than 50 years old and consequently aging. Additionally, dual system of sludge pipelines in some area is not complete. If the sludge treatment facility stops from some disasters such as earthquake or breakdown, sludge treatment function of other WWTPs are also seriously affected.

4.4.2 Solutions

Connecting for sludge treatment facilities between WWTPs would enhance reliability so that the system can withstand earthquakes or breakdown. And then, to maintain the control center for sludge treatment in good condition and promote efficient sludge treatment would prepare for the backup function. Simultaneously, TMG is going to go forward with restructuring of the aging sludge pipelines.

4.5 Improvement of the Combined Sewer System

About 80% of the Ward Area has the combined sewer system. Because it is impossible to treat all wastewater in rainy weather in the combined sewer system, the sewerage system is designed to discharge part of the wastewater may be discharged from the pumping stations and sewers overflow structures. Pollution load through the combined sewer system to rivers and sea should be reduced in order to create good water environment.

4.5.1 Current Situation and Issues

Effluent water quality standards on rainy days will be tightened from 2024. It is
necessary to implement control measures for 14 stagnant river reaches from tide. Although it is necessary to build the storage facilities to retain CSOs in the beginning of rain, it is difficult to secure sites for storage facilities at the outlet along rivers.

4.5.2 Solutions
TMG should hurry to construct the CSO storage facilities for the 14 stagnant waters. Besides, TMG plans to build CSO storage facility with the capacity of 1.5 million m³ to prepare for the 2020 Tokyo Olympic and Paralympic Games. TMG plans to reduce the pollution load with these measures to the same level as separate sewers system in the future.

4.6 Advanced Treatment
4.62 million m³/day of wastewater is treated in 13 WWTPs and discharged by way of rivers to the Tokyo bay every day. It is necessary to further improve the quality of the effluent in order to create better water environment of Tokyo Bay, and it is also required to save energy.

4.6.1 Current Situation and Issues
Red tide occurs in Tokyo Bay on about 80 days a year. In order to reduce the red tide frequency, it is necessary to further reduce the concentration of nitrogen and phosphorus in the effluent. However, it needs a lot of time and high costs to install advanced treatment system (such as Anaerobic /Anoxia /Aerobic method; A2O method). Moreover, electricity consumption to maintain the advanced system is 3 times as high conventional system.

4.6.2 Solutions
TMG will install the semi-advanced treatment system to improve the effluent water quality. Treated water quality by semi-advanced treatment system is slightly poorer than the A2O method. But this system can be implemented in short time by modifying the existing structures. Its initial introduction cost and power consumption are lower than A2O method. Additionally, new type of advanced treatment system (Fig.5) with similar effluent water quality as A2O method and with lower power consumption should be developed and introduced in applicable facilities.
4.7 Appropriate Maintenance
It is important to keep the sewerage treatment function, and maintain the sewers and WWTPs appropriately as well as saving the maintenance cost.

4.7.1 Current Situation and Issues
It is necessary to replace the existing old laterals (the sewer pipe connecting house drain to sewer main) which are responsible for 70% of sewer subsidence cases to rigid PVC (polyvinyl chloride) pipe which is flexible. Since there are as many as 1.14 million laterals introduced, it takes very long time to replace all. It is also important to measure against corrosion of concrete of primary sedimentation tank and conduit in WWTPs. To save electricity cost is also necessary because the electricity bill is rising by increasing ratio of thermal power station after the accident of nuclear plant in the Great East Japan Earthquake.

4.7.2 Solutions
Preventive maintenance such as replacing the existing pipes in prioritized areas with lots of road subsidence should be taken. Additionally, regular inspection and systematic repair is important to use until their economic useful life. Power and fuel consumption is reduced by introducing energy-saving equipment and by operational measures.

4.8 Promotion of Measures for Energy and Global Warming
Wastewater and sludge treatment consumes 9.8 hundred million kWh, which is about 1% of the total power consumption of Tokyo, 86.0 billion kWh. TMG should contribute to the reduction of GHGs emission, which is becoming the world wide problem, as well as reduction of the total energy consumption.

4.8.1 Current Situation and Issues
Energy consumption is predicted to increase as sewerage system service improves. In addition to expand the use of renewable energy, it is necessary to promote energy
saving of each process and of entire system facility energy management.

4.8.2 Solutions
TMG has developed for their first global warming prevention plan “Earth Plan 2010” and basic energy plan “Smart Plan 2014”, and these plans are steadily implemented (Fig.6).
Renewable energies such as solar power and power generation with the heat of the incinerators are further utilized and obtain as possible energy by themselves. Sludge thickener and dehydrators of energy-saving type are introduced and further energy saving equipment is devised. TMG is going to introduce newly developed energy-independent incinerators to save the energy of sludge treatment (Fig.7).

Fig.6 outline of “earth plan 2010 ”and ”smart plan 2014”

Fig.7 Image of newly developed energy-independent incinerator system
4.9 Sewerage Service Operation

Tokyo sewerage works will be conducted by TMG, Tokyo Metropolitan Sewerage Service Corporation (TGS) and private companies to utilize each characteristic and enhance efficiency (Fig.8).

5. International Development and Contribution of TMG

TMG is advancing the international development of the Tokyo’s advanced technologies and know-hows of management with Ministry of Land, Infrastructure and Transport in Japan (MLIT), and Japan International Cooperation Agency (JICA), etc. Under the appropriate responsibility share with TGS, TMG currently follows three main projects.

- Promoting infrastructure development projects in overseas
- Strengthen of information transmission
- Promotion of personnel exchange and training

5.1 Promoting infrastructure development projects in overseas

In October 2014, TMG realized the first overseas project for building a sewerage system infrastructure in Malaysia by cooperation between public and private sector. TMG advanced the project towards the improvement of water environment in Malaysia. Currently, it is under construction of the WWTP and sewers. TMG plans to give technical advice and information to local engineers, and train them to maintain the facility to steadily transmit the knowledge of technology in the future. Furthermore, TMG, TGS, and private corporations jointly developed individual technologies originated in Tokyo as for the overseas development.

As an example;

- Gross solids controller; a device of control for CSO to reduce floatable gross solids in CSO

Fig.8 Support system of sewerage service operation
- Spiral Pipe Rehabilitation (SPR); a method of trenchless sewer rehabilitation
- Float less; a method of preventing manholes to rise up in case of ground liquefaction

5.2 Strengthen of information transmission
International Conference and Exhibition of the International Water Association (IWA) will be held in Tokyo in September 2018. In the conference, the knowledge in the fields of “water and sewerage works and water environment” is shared among experts all over the world. TMG is going to introduce our excellent and advanced technologies of Tokyo sewerage works.

5.3 Promotion of personnel exchange and training
TMG has received about 1,000 officials and researchers every year mostly from Asian cities. Through the exchange of information with friendship cities, the receiving of researchers and trainees, and dispatch the personnel staff, we plan to continue the personnel exchange and human resource development in order to solve the problem common among urban cities. Simultaneously, we plan to communicate with overseas engineers by active presentation in the international conferences held both inside and outside Japan.

6. Conclusion
Tokyo sewerage works has the history of 130 years. TMG has made efforts to enhance technologies. We will continue to solve various problems, challenge the improvement for safety and comfort of capital Tokyo, and