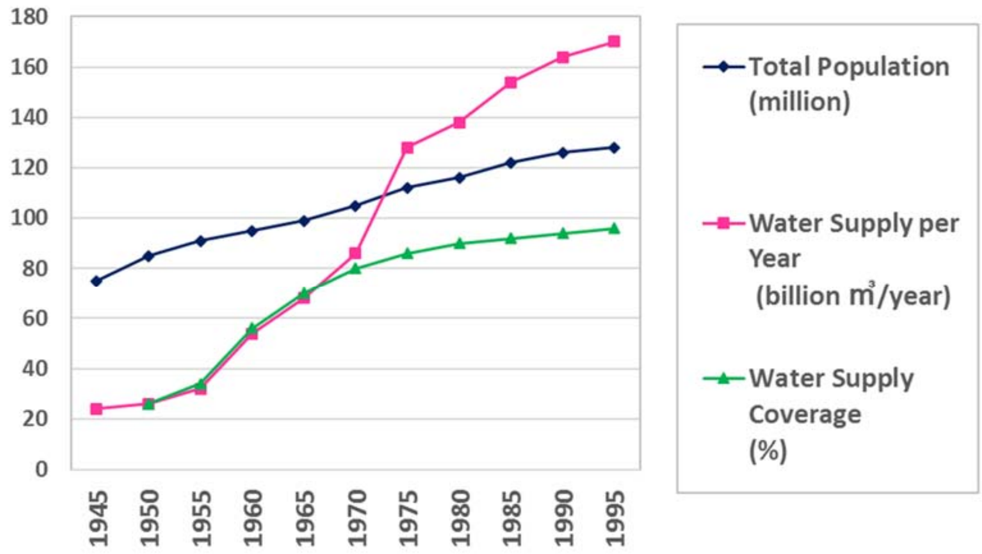
Theme 2. Water Supply System: from Water Resources to Distribution

Contents

1. Introduction

The water supply system is the infrastructure for the intake, transmission, treatment, storage and distribution of drinking water for water users. Development of water supply systems dramatically increased the coverage of drinking water distribution in Japan since the 1950s.



Source: JWWA, *Water Supply Services Overview*, 6th edition (2015) p.21

Figure 1. Water Supply Volume in Japan

This module describes Japanese waterworks' experience in securing water resource, selecting water treatment methods which corresponds to quality of source water, designing water supply system and managing technical standards by addressing the following frequently asked questions by participants from developing countries:

Q1. How did Japanese water utilities choose water sources and maintain facilities for stable and economical safe water supply?

Q2. How did Japanese water utilities develop water resources to meet increasing demand? How did they manage the conflicts with other water use? How do they share the cost with other stakeholders in water resource development?

Q3. How water sources were developed for water supply in wide areas? How the Bulk Water Supply, which only treats and supplies water to utilities and does not supply water up to consumers, is managed?

Q4. Water sources were polluted by wastewater through economic activities. Then large water demand forced water utilities to take large amount of water from polluted water sources. How did Japan control pollution of water sources?

Q5. How did Japan overcome land subsidence caused by excessive groundwater use in response to growing economic activities?

Q6. How did Japanese water utilities develop water distribution pipelines? What are characteristics of water distribution networks in Japan?

Q7. Why does Japan emphasize water supply plans for facility constructions? How do Japanese water utilities steadily develop water supply facilities in required level? How master plans are made and utilized?

The following sections attempt to provide answers to these questions:

2. Water Sources and Treatment System (Q1)
3. Development of Surface Water (1), (2), (3) and (4) (Q2)
3. Development of Surface Water (5) (Q3)
4. Treatment Process (Q4)
5. Groundwater (Q5)
6. Distribution Systems (Q6)
7. Engineering Design and Master Plans (Q7)

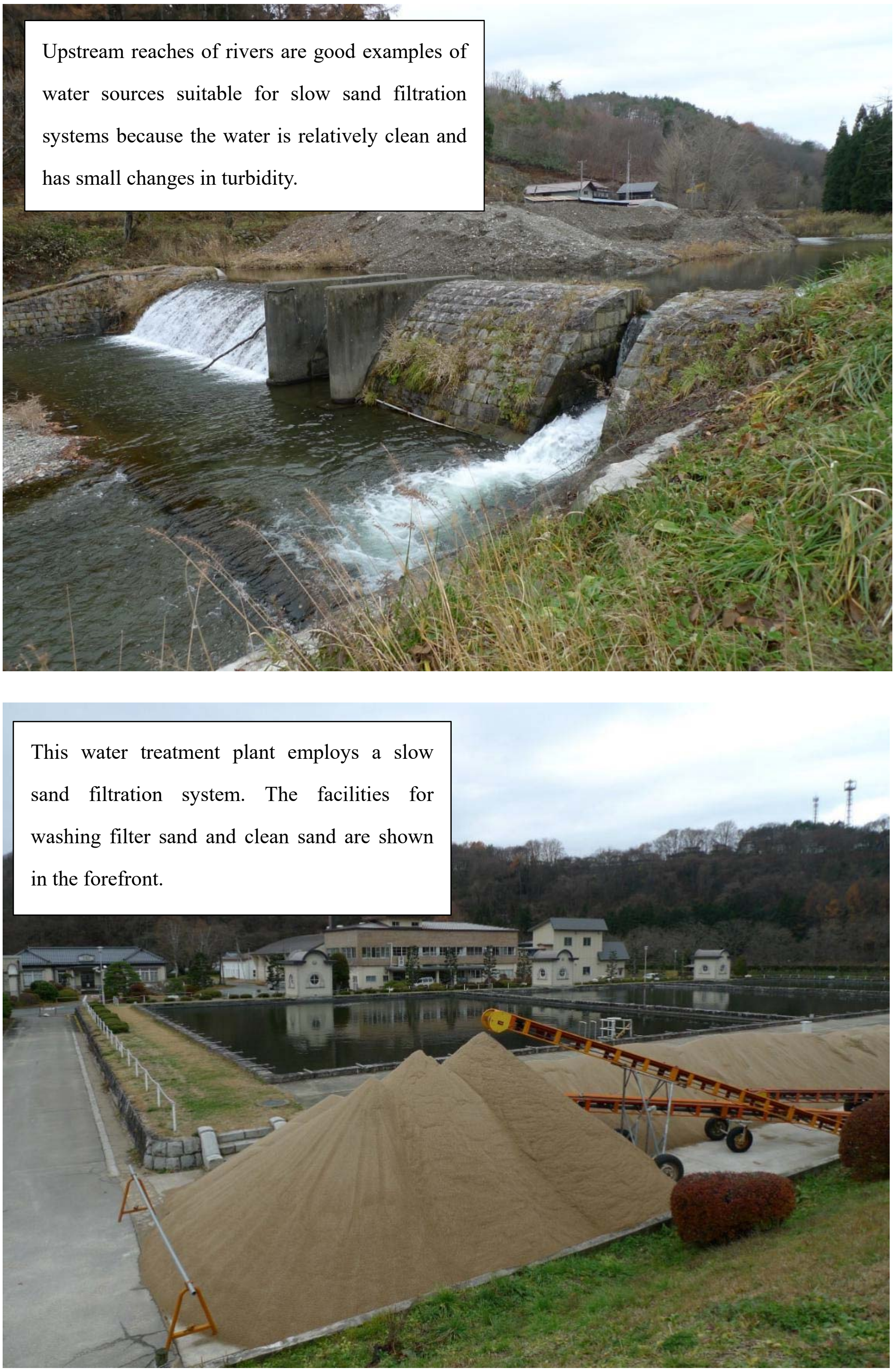
2. Water Sources and Treatment System

Water sources should be as clean as possible, taken from upstream areas without any pollutants. Small utilities can source good quality raw water to save on financial and technical resources for water treatment. Larger utilities do not always have the choice to start with unpolluted raw water because larger intakes are usually only available in downstream sections of rivers. Treatment processes are required to cope with the pollution load.

Ideally, water sources should be free from contaminants. The better water sources are usually in the upstream reaches of rivers, springs or groundwater. Before the high economic growth period, many utilities could use upstream surface water, spring water or groundwater and if necessary, treat the water with simple method such as slow sand filtration. Even today, small utilities (serving populations of 101 - 5,000) are still using this simple system if they can source good quality raw water, as they usually have insufficient technical capability to conduct advanced treatment processes.

Large utilities normally take their water close to urban areas from sources with substantial flow. They have to move their water sources downstream where large enough volume is available as the demand grows. These water sources are often polluted as human and industrial activities increase, and advanced treatment is required to cope with the pollution load. Urban development in the watershed raises the pollution risk to the water source and treatment plants have to deal with this risk. Rapid sand filtration is often used because it can treat a large amount of water with equipment that can be installed in a relatively small space.

During Japanese high economic growth period (from 1955 to 1973, the period while economic growth rate surpassed 10%), large water utilities shifted their water sources to downstream which is able to meet large demand. Rapid sand filtration came to often used because the process can treat large amounts of polluted water efficiently and can be combined with breakpoint chlorination. In addition, excessive pumping of groundwater caused land subsidence. For solving these problems due to increased demand of water by growing population, water utilities and other water users were turning to dam development. At present, about half of the raw water for waterworks is drawn from dam reservoirs.



Upstream reaches of rivers are good examples of water sources suitable for slow sand filtration systems because the water is relatively clean and has small changes in turbidity.

This water treatment plant employs a slow sand filtration system. The facilities for washing filter sand and clean sand are shown in the forefront.

Photo 1. Water source and intake of the Yonai Water Treatment Plant in Morioka, Iwate prefecture. Unpolluted water from the upstream reaches of the river is taken and treated by slow sand filtration (November 23, 2010).

Photo 2. Kanamachi Water Treatment Plant, Bureau of Waterworks, Tokyo Metropolitan Government. It is equipped with advanced water treatment facilities which include rapid sand filtration, high-speed coagulation, flocculation and sedimentation reservoir. It also has power generation facilities, constructed using private financing (April 4, 2004).

Column: Environmental Water Quality Standards for Public Water Bodies

In Japan, utilities must provide information on annual changes in the quality of raw water when they apply for their operating Approval (License). This information is the basis for the selection of appropriate treatment methods. Before, the oversight authority instructed the utility to make modifications on water source if the raw water quality and treatment methods are not satisfactory.

Raw water is categorized by the treatment needed to render it potable and to meet the legislated quality standards. Above mentioned instructions on Approval (License) procedure were made based on the category of water source as follows;

Class 1: water requires simple processes such as filtration;

Class 2: water requires treatment with sedimentation and filtration; and

Class 3: water requires advanced methods such as pre-treatment combined with filtration.

Water environment standards identify target water quality for drinking water sources and promote water quality conservation in public water bodies. It is recognized that the conservation of water sources and their environment go hand in hand.

Table 1. Environmental Water Quality Standards for Public Water Bodies

(1) Rivers (excluding lakes)

Item Type	Water use	Standard Value				
		Hydrogen-ion concentration (pH)	Biochemical Oxygen Demand (BOD)	Suspended Solids (SS)	Dissolved Oxygen (DO)	Total Coliform
AA	Water supply class1, Conservation of natural environment, and uses listed in A-E	6.5≦ pH≦8.5	1mg/l≦	≦25mg/l	≧7.5mg/l	≦50 MPN/100mL
A	Water supply class2, fishery class1, bathing and uses listed in B-E	6.5≦ pH≦8.5	2mg/l≦	≦25mg/l	≧7.5mg/l	≦1,000 MPN/100mL
B	Water supply class3, fishery class2, and uses listed in C-E	6.5≦ pH≦8.5	3mg/l≦	≦25mg/l	≧5mg/l	≦5,000 MPN/100mL
C	Water supply class3, industrial water class1, and uses listed in D-E	6.5≦ pH≦8.5	5mg/l≦	≦50mg/l	≧5mg/l	-
D	Industrial water class2, agricultural water, and uses listed in E	6.5≦ pH≦8.0	8mg/l≦	≦100mg/l	≧2mg/l	-
E	Industrial water class3 and conservation of environment	6.5≦ pH≦8.0	10mg/l≦	Floating matter such as garbage should not be observed.	≧2mg/l	-

(2) Lakes (Natural lakes or artificial reservoirs with 10 million cubic meters of storage capacity and retention time of 4 days or more.)

Item class	Water use	Standard Value				
		Hydrogen-ion concentration (pH)	Chemical Oxygen Demand (COD)	Suspended Solids (SS)	Dissolved Oxygen (DO)	Total Coliform
AA	Water supply class1, fishery class1, conservation of natural environment, and uses listed in A-C	6.5≦ pH≦8.5	1mg/l≦	1mg/l≦	≧7.5mg/l	≦50 MPN/100mL
A	Water supply class2 and 3, fishery class2, bathing and uses listed in B-C	6.5≦ pH≦8.5	3mg/l≦	5mg/l≦	≧7.5mg/l	≦1,000 MPN/100mL
B	Fishery class3, industrial water class1, agricultural water, and uses listed in C	6.5≦ pH≦8.5	5mg/l≦	15mg/l≦	≧5mg/l	-
C	Industrial water class2 and conservation of environment	6.0≦ pH≦8.5	8mg/l≦	Floating matter such as garbage should not be observed.	≧2mg/l	-

Source: Extracted from Environmental Quality Standards for Water Pollution.

3. Development of Surface Water

(1) Water Rights

In Japan, water right is a special license for exclusive use of a designated amount of water for a certain purpose. It is legally designated with consideration of customary uses. It has been effective in reconciling conflicts among stakeholders.

Surface water is suitable for intake in large quantities; therefore it is an extremely important water source for large utilities. Utilities often compete with other large scale users, such as agriculture and power generation, for the same water source. Some kind of coordination and cooperation is required. The system of water rights and coordination among water users has been functioning to avoid conflicts and complicated or contentious situations especially in large rivers.

Since Japan developed mainly agriculture with many paddy fields before it was replaced with industry and has a history of conflicts over water use, the importance of coordinating water utilization was recognized early on. The River Act established in 1896 conceptualized the rights for utilization of water in rivers. By 1961, the concept of existing water rights was already in place.

As rivers in Japan are relatively short and most are already exploited to the fullest extent, dam construction is the next effective means to increase capacity to meet growing demand. Dams need to serve multiple purposes so that the enormous investment can be shared among the various users. Coordination and cost allocation is required among users such as utilities, farming communities, flood control organizations and hydropower suppliers. Government authorities from different sectors are often involved.

Certain rights to use surface water for agriculture were recognized before the River Act was established in 1896. These customary water rights present challenges in water resource development. The customary rights become vested interests and it requires construction of new dam with enormous investment to acquire new water rights other than the customary rights in some cases.

Photo 3. Shiroyama Dam and Lake Tsukui for the water resource development along the Sagami River (December 19, 2009).

Authorities responsible for not only water use but also flood control, transportation and environmental maintenance are involved in the coordination of water use. It takes time to build consensus among the stakeholders. Sometimes small steps have to be taken one at a time to resolve conflicting interests. Support and intervention from downstream water users to water source area were also effective to reach consensus.

Example: Coordination of Water Use through Comprehensive Development: Kagawa Canal in Shikoku Region

Kagawa Prefecture initiated the project to build the Kagawa Canal as part of the Comprehensive Development of the Yoshino River, which runs through Tokushima, Ehime and Kochi Prefectures. For a long time, Kagawa had wanted to build a canal to access water from the Yoshino River to ease its chronic water shortage. Tokushima was reluctant to divert its share of water to Kagawa even though it suffered from flooding. Kochi where a dam would be built did not give a positive answer. The negotiation among stakeholders from various administrative agencies and watersheds was complicated and difficult. The four prefectures went through the following process to arrive at a consensus and Kagawa Canal was built as part of the Comprehensive Development of the Yoshino River.

(i) In 1950 Ministry of Construction[1] led the negotiation because the four prefectures could not settle the issues by themselves.

(ii) The considerations were elevated above the prefectural level. Water use for flood control, food production and hydroelectric power were discussed, together with the development of the entire Shikoku area beyond each prefecture. Shikoku island is located apart from the main island. There was a concern shared by all 4 prefectures that the economic developments on the main island during the period of high economic growth, would pass them by, and the concern became a foundation of discussion for economic development of the area.

(iii) The Shikoku Region Development Promotion Act was formulated in 1960. The Shikoku Regional Development Council was established consisting of Diet members, representatives from administrative organizations, prefectural governors and academics. The Council decided on water allocation arrangements, cost allocation, and the operating agency (today's Japan Water Agency). The consensus for the Yoshino River Comprehensive Development Project was achieved and Sameura Dam, Ikeda Dam and Kagawa Canal were completed in 1975.

(iv) The Yoshino River Council was established to manage water utilization through comprehensive consultation. It operates on the principle that adjustments have to be made regularly to accommodate changes in social demand and balance resource utilization with environmental conservation.

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[1] The Ministry of Construction was merged with the Ministry of Transport and two Agencies to form the Ministry of Land, Infrastructure, Transport in 2001.

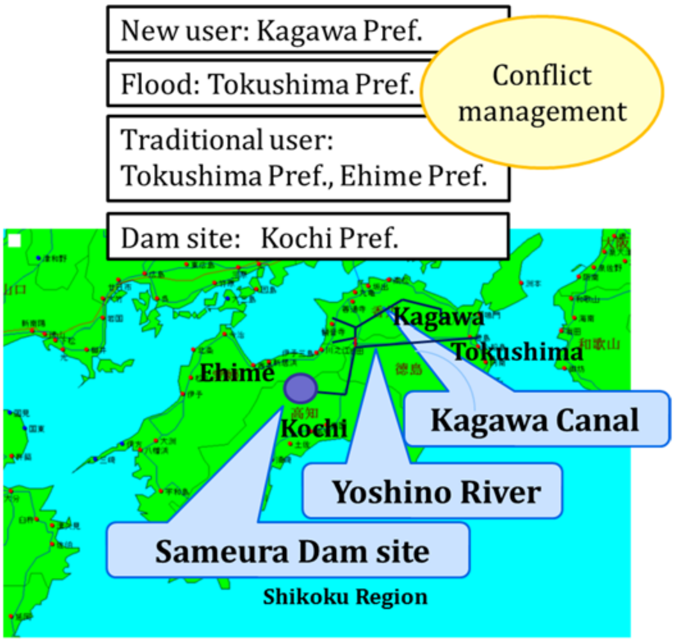

Figure 2. Kagawa Canal in Sikoku Region

(2) Development of Surface Water Source

In Japan, multipurpose dams were built to meet the increasing water demand under the Comprehensive River Development Projects conducted by the government, for water use, flood control and environment conservation. These projects enabled to reduce the cost burden for the utilities in securing the water sources.

The comprehensive river development was initiated by the Home Ministry[2] in the 1930s for comprehensive flood control, irrigation and power generation. The basic idea was to maximize the use of water resource by stocking variated river flow and to control the risk of flooding with dams and river improvement projects. River control projects began in 1937 following the examples of the Tennessee Valley Authority in the United States of America. After surveying the major rivers across the country, seven were selected for the first project. In 1951, the Comprehensive River Development Projects were implemented with taking over the initial projects and a series of legislation such as the Comprehensive National Land Development Act were developed in the same period.

These river developments focused on flood control, except for some cases such as the

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[2] The Home Ministry was changed to the Ministry of Home Affairs in 1947.

Ogouchi Dam (completed in 1957) which was developed exclusively for water supply by the well-financed Tokyo Metropolis. Most utilities were not financially capable of building dams exclusively for water supply; therefore, multipurpose dams were developed together with other users.

When the Japanese economy began to grow rapidly, construction of multipurpose dams was the only mean to meet the growing needs in a financially feasible way by sharing construction costs among users. The Water Resources Development Public Corporation (now Japan Water Agency) the implementing agency of the projects, was established with the enforcement of the Act on Advancement of Water Resources Development in 1961. Utilities shared the cost for construction and O&M in these dam developments. The Water Resources Development Basic Plan (Full plan) was formulated exclusively for seven water systems where there was increasing demand. The Basic Plans looked at the integrated construction and management of the dams, water channels, and other related facilities. In this way, independent water related policies and projects such as flood control by the Ministry of Construction, irrigation by the Ministry of Agriculture and drinking water by the Ministry of Health and Welfare[3] were integrated and securing water source was promoted in the whole country. This approach had to find a compromise between two competing goals: storage space for flood control and storage space for securing adequate water resources. Flood control requires a reservoir that has enough empty storage capacity to cope with a one in a hundred-year flood event (50 to 200 years depending on the river system). Water supply requires a reservoir capacity that can store enough water to avoid shortage during a prolonged drought event that occurs about once every ten years. The final reservoir capacity had to be worked out to meet both goals, and compromises were also needed in deciding the optimal operational rules for the dam.

Users that benefit from the dam have to share the construction expenses in accordance with the Specified Multipurpose Dam Act or the Water Resources Development Public Corporation Development Act, as well as under the provisions of the Minister of Land, Infrastructure, Transport and Tourism or a governor of the prefecture. There were environmental and social impacts including involuntary resettlement due to dam construction. To keep dam investment under control, utilities made efforts on leakage reduction and increasing the efficiency of the distribution system to economize the usage of water. Utilities distributed free “water saving tap washer” which is replaced with usual washer in tap and it can reduce water flow compared to the normal one, to customers to advocate economy of water use and to lower water consumption. This PR activity contributes to save on future investment. In addition, the sewerage tariff system

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[3] The Ministry of Health and Welfare was merged with the Ministry of Labour to form the Ministry of Health, Labour and Welfare in 2001.

which is calculated based on the amount of tap water consumed, raises consumer's awareness to save water and is the reason to purchase water saving devices, such as water saving toilets.

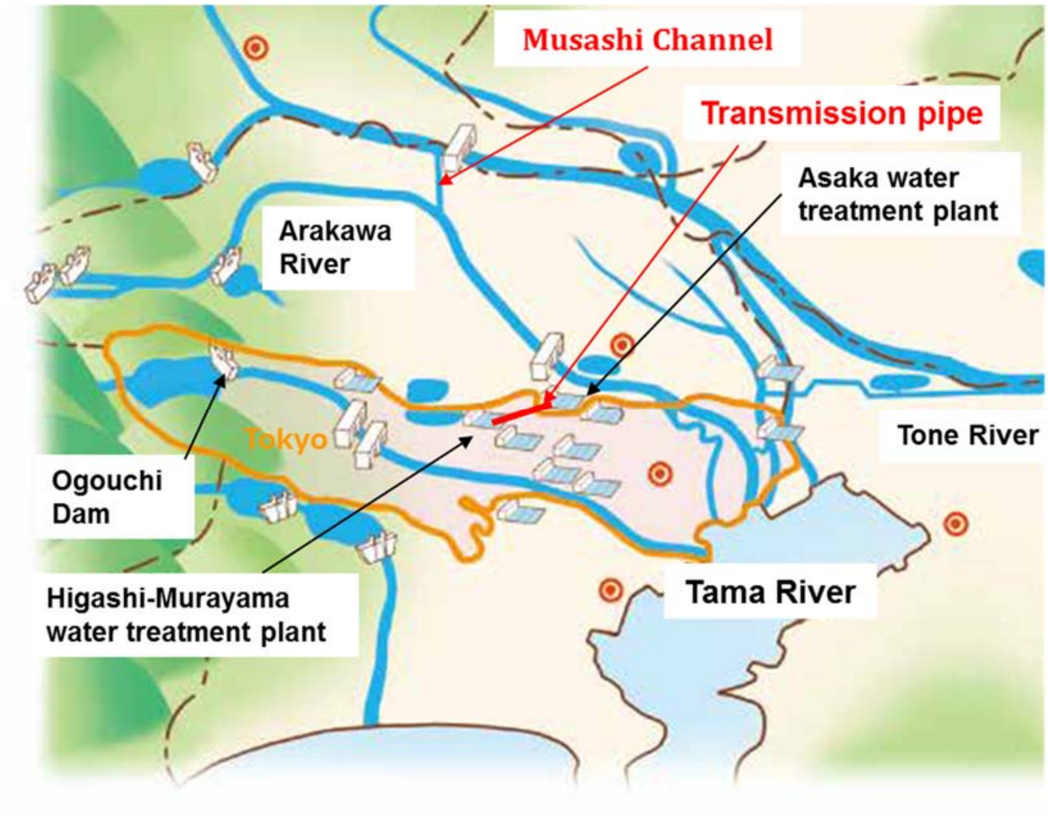
As the result of comprehensive water resource development and effective use of limited water resources, the frequency of intermittent supply and water use restrictions dropped significantly in many areas. As water demand declined after the 1990s, dam developments became contentious because of the huge investment and great environmental and social impacts. Some projects were stopped when the impacts became a concern. In addition, the share of dam maintenance cost based on the allocation of water rights became a serious financial burden for the utilities as water demand declines.

Example: Water source development by the Tokyo Metropolitan Government Bureau of Waterworks (Ogouchi Dam development and the drought during Tokyo Olympic Games)

A lot of damage was done by aerial attacks to the Tokyo Metropolitan Area during World War II. Water demand once had declined at the end of the war then increased significantly as the city recovered. Various types of water supply expansion projects supported by the government were carried out at a rapid pace after the war. The construction of Ogouchi Dam located in Tokyo, exclusively for drinking water supply for Tokyo Metropolitan Area, started in 1938, suspended by the war in 1943, was resumed and completed in 1957.

After the early 1960s, the Tokyo Metropolitan Area experienced high concentration of industries, population, and rapid expansion of flush toilets resulted in drastic increase in water demand. There were droughts every year and the most severe one was in 1964 when the Tokyo Olympic Games were held. In order to survive the crisis, Bureau of Waterworks, Tokyo Metropolitan Government tried to secure alternative water sources from surrounding prefectures. The arrangement was extremely difficult, however Higashi-Murayama water treatment plant was taking raw water from the Tone and Tama River systems and the Arakawa River. The Musashi Channel connecting the Tone and Arakawa Rivers was built in 1965. The Tone River system became the water source for Tokyo and solved the water shortage problem. (See Figure 3 and Photo 4)

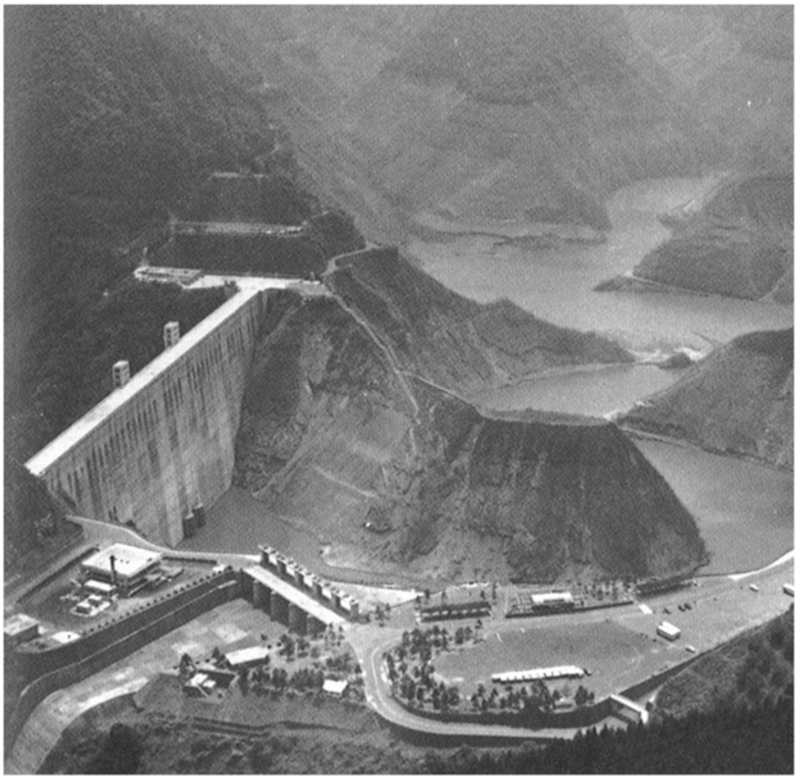
Tokyo shared a large amount of the cost for the multipurpose dam development led by the national government, and the cost was covered by public enterprise bonds. At one time, more than 60% of the revenue of the Bureau was applied to the repayment. Based on the experience, the Bureau sets the water tariff to cover water resource development and made effort to reduce water leakage.



Source: Bureau of Waterworks Tokyo Metropolitan Government
https://www.waterworks.metro.tokyo.jp/kids/study/images/study_13-14-15-16.pdf

Figure 3. Geographical Outlook of Tokyo Metropolitan and Its Water Sources

Photo 4. Tone Ozeki; Water intake facilities of the Musashi Channel (November 19, 2010).



Source: JICA, The Challenge of the Tokyo Waterworks, *Integrated Water Resource Management (A), Knowledge Co-Creation Program Textbook*.

Photo 5. Ogouchi Dam without Water during Drought

(3) Watershed Conservation

Good source water quality depends on sustained efforts to preserve the environment in the entire watershed. Japan has improved source water quality through wastewater effluent regulations, development of sewage treatment and the conservation of forests in the catchment area of the water source for a long period.

A clean water source is the starting point for securing safe drinking water. Therefore, watershed conservation is an important priority for the drinking water supply.

It is critical to regulate wastewater, including domestic, industrial and agricultural discharges containing pesticides and fertilizers, for preserving water quality, to manage the water source area properly and to be prepared for accidental water source contamination. Japan has long been engaged in various measures in this regard and these efforts are continuing today.

Effluent water quality standards for industries came into effect with the establishment of the Water Pollution Control Act in 1970. The Act contributed to reduction of total volume of discharged water, and significant improvement of water quality in the watershed. The Sewage Act was revised in the same year, with the added targets for watershed conservation. By the revision of the Act, wastewater treatment plants were newly constructed to reduce pollution load in household discharges. Two laws concerning water resources, the “Act on Special Measures concerning Water Quality Conservation at Water Resources Area in Order to Prevent the Specified Difficulties in Water Utilization” and the “Act on Advancement of Project for Quality Management of Raw Water” were established in 1994. Utilities are legally and directly involved in the protection of water sources under these laws.

Forests in the watershed are very crucial to the preservation of water source areas. Conservation of these forests is carried out continuously by specific efforts in each area. This is recognized in the Basic Act on Water Cycle established in 2014. The Act is expected to contribute to the systematic conservation of all stages of the hydrological cycle including groundwater.

Japanese government agencies are working hard to improve water quality even within their individual mandates. Dams are constructed in the upstream of rivers, wastewater treatment plants are constructed, industrial wastewater and domestic sewage are treated and reduced in the middle river basin, and various efforts to save water are taking place. These efforts together are bearing fruit; water quality has improved and the pollution risk reduced in the entire watershed.

Utilities are also making valuable contributions on early detection of accidents that can compromise water quality. They have hotlines for reporting on oil or chemical spills so that remedial actions can be taken immediately. They also work together on water safety plan to analyze and reduce risks in the entire system.

(4) Salt Water Intrusion

Estuary barrages prevent salt water intrusion at intakes in coastal areas.

It is easier to obtain large quantities of water from downstream sections of rivers. Sometimes it is the only option for utilities in coastal regions. However, when the intake is in an estuary there is the risk of saltwater intrusion.

Estuary barrages are set up to prevent saltwater intrusion and stabilize the flow at the intake.

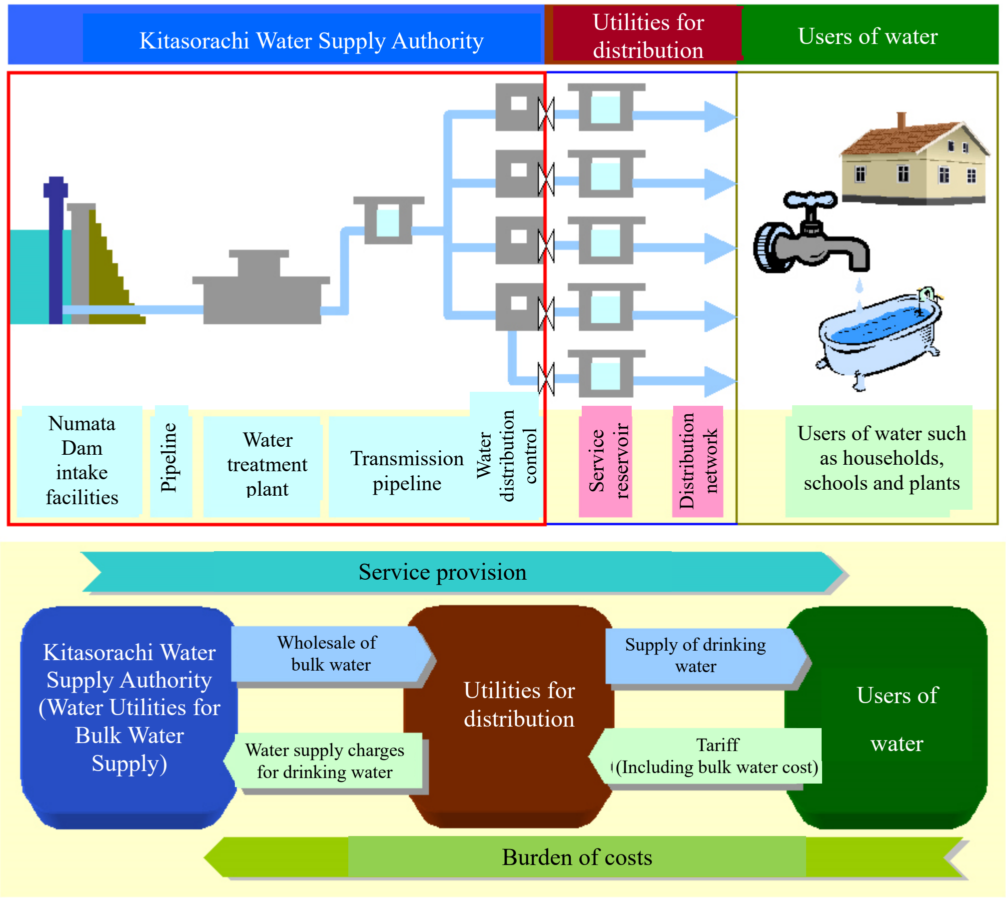
Since most of the urban utilities in Japan take water from downstream, estuary barrages are common in these areas. Discussions with the river administrator and coordination with maritime traffic and fisheries activities are necessary when installing such facilities.

Movable rubber dams or temporary dams are used in some places where other facilities are not suitable (such as Yura River in Kyoto and Imari City, Saga Prefecture).

(5) Bulk Water Supply

In Japan, utilities working together and/or a prefecture would take the lead to establish a Bulk Water Supply Authority for large scale water source development to secure water, to save huge investment costs for the utilities.

Each municipal government on its own was unable to cope with the expense of participating in a large dam project. Therefore, they jointly organized a Bulk Water Supply Authority to participate in dam development and secure their water as bulk supply. National subsidies pay for one half or one third of the expenses for the water resource development. Since public funds are used, the operators of the bulk water supply have to be public institutions, unlike in developing countries where sometimes private financing is involved. There are no private bulk water suppliers in Japan.



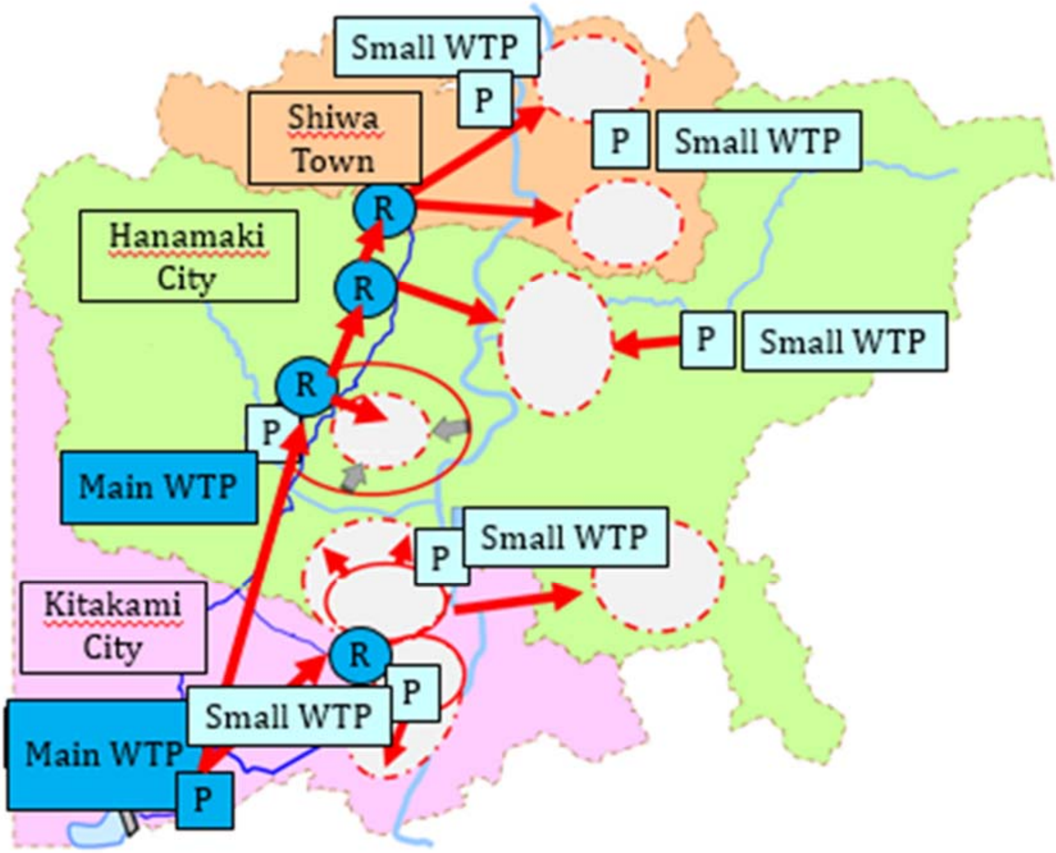
Source: Kitasorachi Water Supply Authority, *About tariff of Bulk Water Supply in Japan*, http://www.kitasorasui.or.jp/ryoukin.html

Figure 4. Bulk Water Supply and Water Tariff

Bulk water supply was initially started to improve management efficiency and the quality of service. Benefitting from economies of scale, participating utilities can deliver the water supply at a higher service level. It emulates the British system which consolidates operations for sustainability. However, the system is not practical when utilities have huge gaps in water source availability and are run independently by their own municipal governments as in Japan. Therefore, partial consolidation in terms of securing water resource and supplying bulk water was promoted. Bulk Water Supply Authorities were founded accordingly.

Bulk water supply improves the long-term management of the water source, stabilizes source water and cuts operational and maintenance costs. On the other hand, the distribution is not a part of this operation and does not benefit from these advantages. When the water demand does not increase as initially projected, the investment cost for the dam and water treatment plants becomes a financial burden to the entire organization. Small scale utilities could lose critical mass of their technical staff because of the segmentation of the operation. It is desirable to manage bulk water supply and distribution in an integrated way to avoid these pitfalls.

Regional collaboration of water utilities used to be initiated by the Bulk Water Supply Authorities in Japan. Recently, some water utilities, such as the Iwate Chubu Water Supply Authority, have been merged into one water utility through voluntary discussions among some municipalities, to review and revise their overall operation and distribution system to look for more efficiency in water source management and water supply service.



Source: JICA, Extensive Waterworks System in Iwate Central Region by vertical and horizontal integration, *Integrated Water Resource Management (A), Knowledge Co-Creation Program Textbook.*

Figure 5. An Example of Water Supply Integration

*Iwate Chubu Water Supply Authority is an example of the consolidation of utilities. The Authority closed and merged some facilities and selected the best water source. It also reduced risks of transmission pipeline accidents by the introduction of pipeline looping.

4. Treatment Process and Water Quality Control

(1) Chlorination

Access to safe drinking water is essential to public health. Utilities successfully use chlorination to control microorganisms in tap water to prevent the spread of waterborne diseases.

Safe drinking water is one of the most important factors in preventing outbreaks of waterborne diseases. Chlorination eliminates pathogenic microorganisms in drinking water to safe levels without requiring sophisticated skills or large energy input. It is an extremely important technology for developing countries.

In Japan in the early 1900s, waterborne diseases were spread by the water supply before disinfection was practiced. Yodobashi Water Treatment Plant of the Tokyo Metropolitan Government Bureau of Waterworks introduced chlorination for the first time in Japan in 1922. The practice was not widely adopted at that time and was only used when there were disease outbreaks.

The effectiveness of chlorination was recognized after World War II (WWII) when the hygienic status became poor. The General Headquarters at the Supreme Commander for the Allied Power (GHQ[4]) enforced and supported the practice by providing chlorine agent.

During the same period, soldiers returning from overseas after the war brought back dysentery which spread across the country. Believing that the epidemic was caused by water, there was opposition against the development of water supply. The Water Supply Act was enacted in 1958 and established drinking water standards. The Ordinance for Enforcement of the Water Supply Act made chlorination mandatory and promoted the public water supply as a safe measure. Outbreaks of waterborne diseases reduced dramatically, and the foundation of public health was established.

Flush toilets became commonly used even in rural areas and Johkasou (Japan's on-site treatment systems for domestic wastewater) were installed during high economic growth period. However, Johkasou treated only night soil and not grey water at that time. As population increased rapidly, this rudimentary wastewater treatment was insufficient and the discharge of highly polluted wastewater into the environment was contaminating surface water. There were

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[4] GHQ is an agency established in Japan by the Allies to enforce the Potsdam Declaration at the end of the World War II on August 1945.

incidences of diarrhea, food poisoning and waterborne diseases mainly in areas without water supply system. Water supply in these areas was urgently needed to overcome public health concerns.

Disinfection by chlorination has contributed the drinking water supply but can be problematic. Chlorine can react with naturally occurring organic compounds and form disinfection by-products. It can also stimulate corrosion of water distribution facilities such as pipes.

Handling and storing of chlorine in the gas phase is dangerous because of its strong corrosive potential and can be fatal for the workers if it is inhaled. Therefore, sodium hypochlorite is generally used in Japan. Sodium hypochlorite should be stored below 20°C to reduce its rate of decomposition.

Customers may find the odor of residual chlorine in the tap water unpleasant. Residual chlorine in the water supply may produce carcinogenic by-products such as trihalomethanes, so the countermeasures are necessary.

In spite of the drawbacks, chlorination contributed to the significant decrease of waterborne diseases and infant mortality after WWII. There is no doubt that chlorination plays an important role to acquire safe water in Japan.

On the other hand, the legal requirement to chlorinate the water supply created an over-reliance on one particular disinfection method at the expense of other treatment processes. In 1996 there was an outbreak of cryptosporidium, whose oocyst was highly resistant to chlorine disinfection.

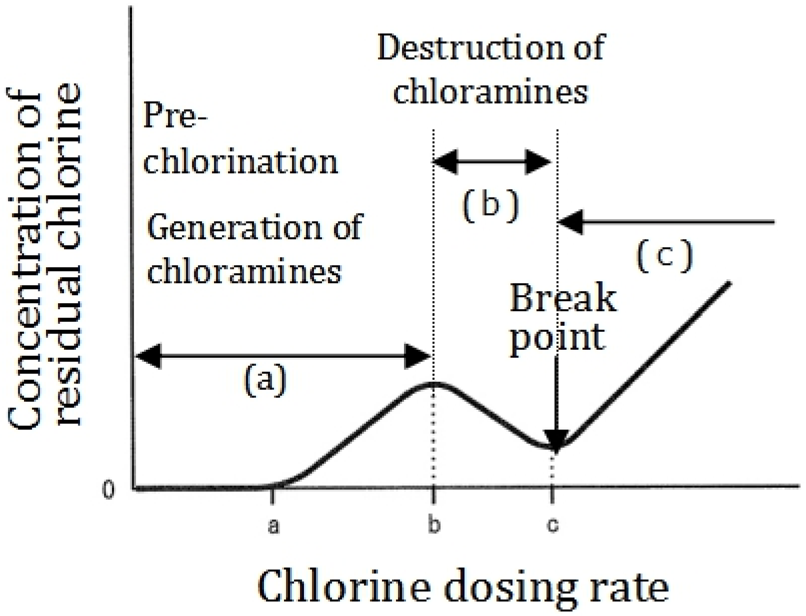
A research study around 2000 looked at alternative disinfection methods. Ultraviolet light and chlorine dioxide were introduced in the last couple of decades. However, their application is limited because chlorination is still the legal requirement for drinking water safety.

Column: Water Treatment Using Chlorine Prior to Filtration

While chlorine is mainly used for disinfection, it is also effective for the removal of algae and ammonia. When chlorine is injected in water containing ammonia, chlorine is consumed rapidly and chloramine is generated. The treatment method to inject chlorine at a higher dose to degrade chloramine and generate free chlorine is called break point chlorination. Due to the degradation of source water quality after the mid-1960s, large utilities adopted pre-chlorination to remove ammonia and algae.

Osaka City experienced a large consumption of oxygen in the slow sand filtration system because of the high concentration of ammonia in the source water. The city shifted to rapid sand filtration, break point chlorination and disinfection by chloramines.

Manganese can also cause water quality problem. Manganese can be eliminated almost completely through oxidation using chlorine and rapid sand filtration. The sand is coated with a layer of manganese dioxide.



Source: Ministry of the Environment, Government of Japan, *Testing Method Set by the Minister of the Environment Based on Item 2 of Article 5 of the Ordinance for Enforcement of the Act on Special Measures concerning Water Quality Conservation at Water Resources Area in Order to Prevent the Specified Difficulties in Water Utilization,* http://www.env.go.jp/hourei/05/000188.html

Figure 6. Break Point Chlorination

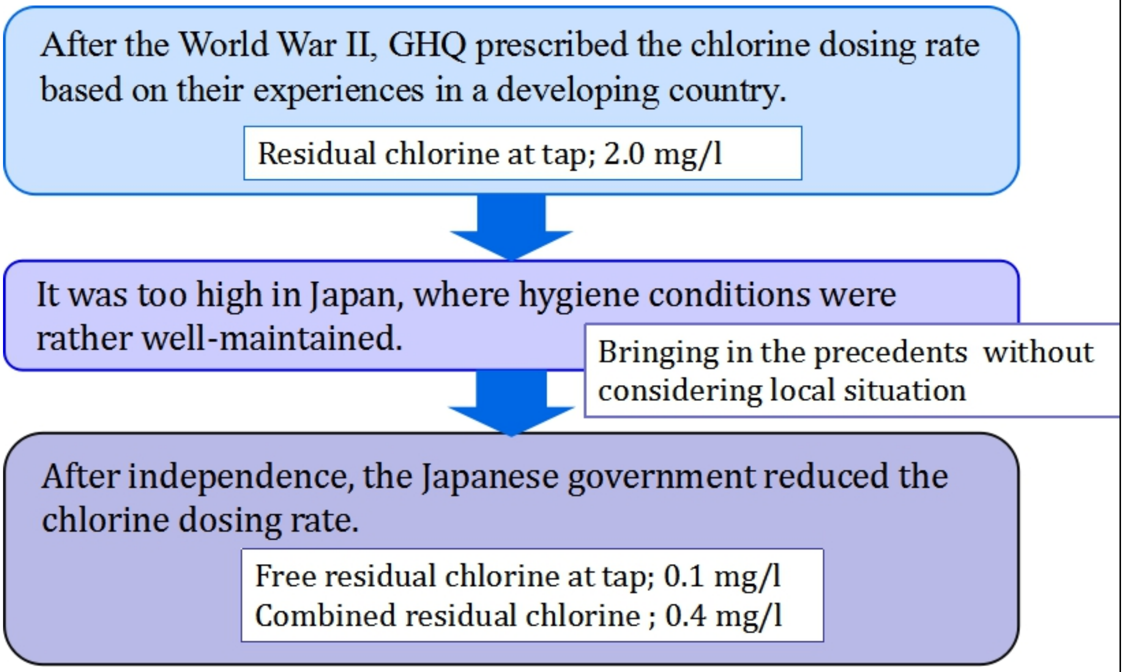
Column: Standards for chlorine concentration

The third clause of Article 17 of the Ordinance for Enforcement of the Water Supply Act establishes the following standards for chlorination:

Chlorination must achieve a residual concentration of free chlorine of ≥ 0.1 mg/l (0.4 mg/l in chloramines) for effective disinfection at the point of use. In case there is the risk of contamination by pathogenic organisms, large number of organisms or substances suggestive of pathogenic organisms, the residual free chlorine should be 0.2 mg/l or higher (1.5 mg/l or higher for chloramines) to eliminate the risk.

The injection dose of chlorine proposed by GHQ immediately after WWII was for residual chlorine at ≥ 2.0 mg/l. This was extremely high and was gradually reduced to the current standard as the quality of treated water improved.

The exceptionally high concentration of residual chlorine was proposed by the US Navy based on sanitation management in a developing country. This is a reminder that conditions in one country can be very different from another. Adopting a practice from another country must be carefully considered and adjustments may be necessary.



After the World War II, GHQ prescribed the chlorine dosing rate based on their experiences in a developing country.

Residual chlorine at tap; 2.0 mg/l

It was too high in Japan, where hygiene conditions were rather well-maintained.

Bringing in the precedents without considering local situation

After independence, the Japanese government reduced the chlorine dosing rate.

Free residual chlorine at tap; 0.1 mg/l
Combined residual chlorine ; 0.4 mg/l

Figure7. Determining an Appropriate Standard for Residual Chlorine

(2) Selection of Treatment Process

Water may be treated differently in different places depending on the quality of the water that enters the treatment plant. Adaptation to environmental conditions, technical knowledge and training skilled workers are essential considerations in choosing the appropriate treatment processes and for managing their operations.

It is important to assess and characterize source water quality, identify the treatment options accordingly and finally select the appropriate treatment method.

Japanese utilities study the volume and quality of water sources to select the most appropriate intake point. Data collection over 5 or more years is conducted with considerations for seasonal variation throughout the year. Utilities also work with treatment facility construction companies to set up pilot facilities to evaluate treatment processes. They also monitor the effectiveness of the treatment processes up to a year after completion of plant construction, making adjustments if necessary to achieve optimal performance.

The quality of raw water has a direct impact on the smooth operation of the treatment processes. Water quality and temperature in dam reservoirs can be different at various depths. When it rains, turbid water can flow onto the reservoir surface. Depth adjustable intake facilities are a practical design solution for selecting less turbid water. Intakes should be located upstream of wastewater discharges and oil booms should be deployed around the intake for stable source water quality and water treatment.

Water treatment must be designed for local conditions and the technical capability that is available. Small utilities in rural communities with limited capabilities must start with a good water source to minimize treatment requirements. In addition, education and training of engineers are also important to understand the natural condition of the place of operation and to be able to select suitable treatment processes.

(3) Slow Sand Filtration

Slow sand filtration is an adequate treatment process if the raw water is relatively clean and stable but it requires a large area for the facilities.

Slow sand filtration uses biological treatment and is also known as the “Ecological

Purification System”. It is different from the physical separation in rapid filtration. It is simple and requires little chemicals or electrical and mechanical equipment. It was the most commonly used treatment system when modern waterworks were introduced in Japan.

The basic processes of slow sand filtration system are removal of suspended solids by gravity in the sedimentation tank and sand filtration at slow velocity, around 4 – 5 m/day in Japanese standards. The filtration rate can be faster if the raw water turbidity and viscosity are low and the biological film is more active such as in tropical/subtropical areas. Miyakojima City Waterworks Bureau operates slow sand filters at 7 m/day, as it is located on the southern island in a subtropical area. When biological activity is not inhibited, the filter can remove not only suspended matters and bacteria but also a certain amount of ammonia nitrogen, odor, iron, manganese, synthetic detergent, and phenols.

Slow sand filters differ from all other filters in that they have a complex biological film that grows naturally on the surface of the sand filter. The surface biofilm is a gelatinous layer that provides the effective purification. The underlying sand and particles of foreign matter trapped on the surface of sand filter provides the support medium. Sludge is formed with organic substances and nutritious salts which are adsorbed into the suspended solids on the surface, as the water passes through the sand. Then, algae, soluble organic material and nutrient salt are trapped and adsorbed in the biofilm. The contaminants are metabolized by the bacteria, fungi and protozoa and these together form a filtration filter. This filter has functions of screening, absorption and biodegradation. In addition, the biofilm is effective for removal of odor. As it is principally biological treatment, the facility should be designed so that sunlight can reach the surface of biofilm and sufficient oxygen must be available. In operating the system, flow should be carefully controlled and inflow of toxic matters and mud should be minimized. A pre-filter can be used if the turbidity of the raw water is too high.

This method requires long treatment time, large area, and low turbidity in the water source. The treatment process has to be suspended periodically to scrape off the surface layer of sludge when the filtration resistance becomes high. Many utilities switched to rapid sand filtration when land acquisition became difficult because of urbanization. Other reasons for switching include pollution of raw water and increasing water demand.

But slow sand filtration system still has its advantages. In 2011, Public Enterprise Bureau of Shimane Prefecture constructed the Mijiro water treatment plant with slow sand filtration at 35,000 m^3/day.

Example: Yanagasaki Water Treatment Plant, Otsu City Public Enterprise Bureau

Otsu City Yanagasaki Water Treatment Plant, the principal water treatment plant of the city, was constructed in 1948. It has a 15,000 m^3/day slow sand filter. This was expanded to 27,000 m^3/day during 1960-1965. With growing water demand, a 30,000 m^3/day rapid sand filter was completed in 1973.

There is no complaint in the area served by the slow sand filtration system even though raw water from the Lake Biwa tends to cause odor because of water quality deterioration. Biological contact filtration was added to the rapid filtration system in 1998 to control odor.

Source: Otsu City Public Enterprise Bureau, Main water supply facilities

http://www.city.otsu.lg.jp/kigyo/about/water/1454032216393.html

Photo 6. Yanagasaki water treatment plant, Otsu City Public Enterprise Bureau

(4) Rapid Sand Filtration

The basic method for water treatment is solid-liquid separation, which removes turbidity from water. In the early days of construction of water supply systems in Japan, slow sand filtration was used for treatment of small volumes of relatively clean raw water. Coagulation, sedimentation, and rapid sand filtration became the mainstream treatment technology when demand increased.

The basic method for water treatment is solid-liquid separation, which removes turbidity from water.

In the past when utilities used groundwater or water from the upper watershed that had less turbidity, chlorination was often the only treatment required in Japan. Many utilities sourced from groundwater that have less turbidity and distribute it after chlorination.

It was common for the water utilities, which could intake surface water from upstream, to choose slow sand filtration process, because upstream water contained less turbidity.

As utilities required larger intakes to meet increasing demand, their intakes shifted downstream. Treatment processes were introduced to deal with more polluted and turbid water sources. These include coagulation, flocculation, sedimentation, and rapid sand filtration. Rapid sand filtration is a physical purification method that provides rapid and efficient removal of relatively large suspended particles. The factors for determining the treatment process of choice include: ability to treat fluctuating levels of turbidity; area available for setting up the treatment facility; and if the treatment process can work with break point chlorination for the removal of ammonia. The advanced water treatment systems are introduced for the urban areas where rivers are more polluted.

Example: Application of Rapid Sand Filtration for Lake Biwa Aqueduct

The rapid sand filtration together with coagulation, flocculation and sedimentation were introduced for the first time in Japan at the Keage Water Treatment Plant in Kyoto City in 1912. The Lake Biwa Aqueduct Projects [with the first aqueduct (1890) and the second aqueduct (1912)] were extremely ambitious projects which introduced various new challenges such as bulk water, canal, and power generation for the first electric trams in Japan. It was also the important turning point for the waterworks by being the first to use rapid sand filtration system.

Source: Waterworks Bureau, City of Kyoto http://www.city.kyoto.lg.jp/suido/page/0000158305.html

Photo 7. Keage Water Treatment Plant

Many large utilities use the coagulation-flocculation-sedimentation and rapid sand filtration process for various reasons:

- Land cost in major cities became high. It was also difficult to acquire a large land. That was why water treatment plants with slow sand filtration in Tokyo were mostly located outside the city. Rapid sand filtration requiring less space became the method of choice.
- Around 1960, river water had high turbidity and the river channels where affected by sedimentation. Extraction of construction materials from river beds also caused high turbidity. Rapid sand filtration is suitable for the removal of high turbidity. With the development of dams and the prohibition of gravel extraction, turbidity is now less of a problem.
- The Yodo River system experienced increased levels of ammonia in its source waters due to contamination in 1958. The large oxygen demand created anaerobic conditions in the slow sand filtration, causing iron and manganese to re-dissolve. Water turned red and black when chlorine was added. Break point chlorination was introduced to remove ammonia and odor when slow sand filtration no longer worked. Rapid sand filtration became the most common treatment technology. Developing countries may have to deal with similar situations when the pollution of water sources worsens.
- Coagulation-flocculation-sedimentation technology was regarded as the most advanced technology after WWII. The leading waterworks introduced the technology together with rapid sand filtration when water sources became more polluted. Other utilities adopted the technology to keep up with the advances.

The coagulation and sedimentation process has evolved through trials and errors. The following part explains about high-speed coagulation-sedimentation system, which has been less used as the water treatment methods change, and development of coagulants.

In the high-speed upflow type coagulation-sedimentation process, large flocks are formed efficiently with the presence of existing flocks in the source water. This makes the sedimentation process more effective in the sedimentation tank where the main water flow is upwards. This method was introduced in the 1950s because it is compact and it can treat a large quantity of water at relatively low cost. The operation of the high-speed process requires highly skilled workers compared to the horizontal flow sedimentation process. The high-speed process has lost some of its appeal after the introduction of inclined plate and tube-type settling equipment for horizontal flow sedimentation. At present, high-speed upflow coagulation sedimentation is rarely used, because more strict turbidity removal is needed for removal of cryptosporidium which is resistant to chlorination.

The choice of coagulants has changed with technology development. In Japan, polyaluminium chloride (PAC or PACl) developed around 1967, is effective over a broad pH range. This quickly replaced for aluminum sulfate, domestically and around the world. Organic polymer coagulants, often used overseas, are not popular in Japan because the safety of the product was not confirmed when it was introduced. Although its safety has now been proven, its use never picked up.

Example: Changes from Slow Sand Filtration to Rapid Sand Filtration in Osaka Municipal Waterworks

The water supply system of Osaka City was built in 1895. Its water source was the Yodo River. It was the fourth modern water supply system at that time after Yokohama, Hakodate and Nagasaki. 51,240m^3/day at 80l/capita/day was supplied without water treatment. To meet increasing demand, Kunijima water treatment plant (151,800m^3/day) with slow sand filtration was built in 1914. Water quality was very good (general bacterial concentration was less than 100 cfu /100 ml) and chlorination was not needed before WWII.

After WWII, chlorination was introduced. The destruction of upstream forest during the war caused landslides when there was heavy rainfall. High turbidity in the river became a problem. To solve this problem, Osaka Municipal Waterworks Bureau examined some types of coagulants and improved valves for dosing coagulants. Then, the problem was eased with the restoration of the upstream forest.

Around 1955, organic matters and ammonia in the water started to increase. Water intake was suspended when water suddenly turned black and there were fish die-offs in 1958. From 1960 to 1962, water quality worsened. At first, the mechanism of this situation was not clear but later turned to be that heavy rain had flushed out large amounts of anaerobic, decayed organic contamination from the bottom. At first, there were objections to introducing chemical treatment because all the filters at that time were slow sand systems. However, by 1958, small amounts of chlorine and aluminum sulfate were regularly injected into sedimentation tanks as a pre-treatment to slow sand filtration to stabilize the water quality.

10 mg/l of dissolved oxygen (DO) is required for the nitrification of 1 mg/l of ammonia. When ammonia nitrogen is high, nitrification occurs in the filtration layer and the oxygen becomes depleted, making the bottom of the filtration layer anaerobic. Under such conditions, the iron and manganese become reduced, ionized and re-eluted. The addition of chlorine produced ferrous oxide and manganese dioxide causing the red and black colored water.

In 1962, break point chlorination was introduced as a treatment prior to slow sand filtration, and solved the problem of the odor and taste, iron and manganese. Before this, chlorine in rapid sand filtration was only used for disinfection.

The elution of manganese and iron accumulated in the slow sand filtration tank can be an issue, when oxygen level dropped due to the rise of water temperature and worsening of water quality in summer. The city investigated and considered aerating the raw water. However, as it was unclear how the water quality may change, rapid sand filtration was used instead during 1969 to 1974, after discussions with the water and sewerage utilities. The system was introduced together with pre-chlorination to remove manganese and iron.

(5) Advanced Water Treatment

Serious pollution causes musty odor which is difficult to remove with conventional water treatment processes. Japan developed advanced water treatment systems that use a combination of technologies.

As the pollutant load increases, eutrophication occurs and the deterioration of water source quality accelerates. When ammonia and nitrogen loads become significant in the initial stage, break point chlorination and other treatments offer certain level of removal. As eutrophication continues and odor caused by algae becomes serious, it becomes difficult to treat water with conventional water treatment. Advanced water treatment technologies have been introduced, which combine processes such as activated carbon treatment (adsorption removal), ozone pre-treatment and biodegradation mainly for the treatment plants, which source in downstream river.

Column: Introduction of Advanced Water Treatment Technology

The Yodo River System faced pollution of water sources after the war. The increase of pollutant load in the Yodo River system was due to insufficient sewage treatment, characterized by the rise in ammonia concentration. Break point chlorination was used to remove the ammonia.

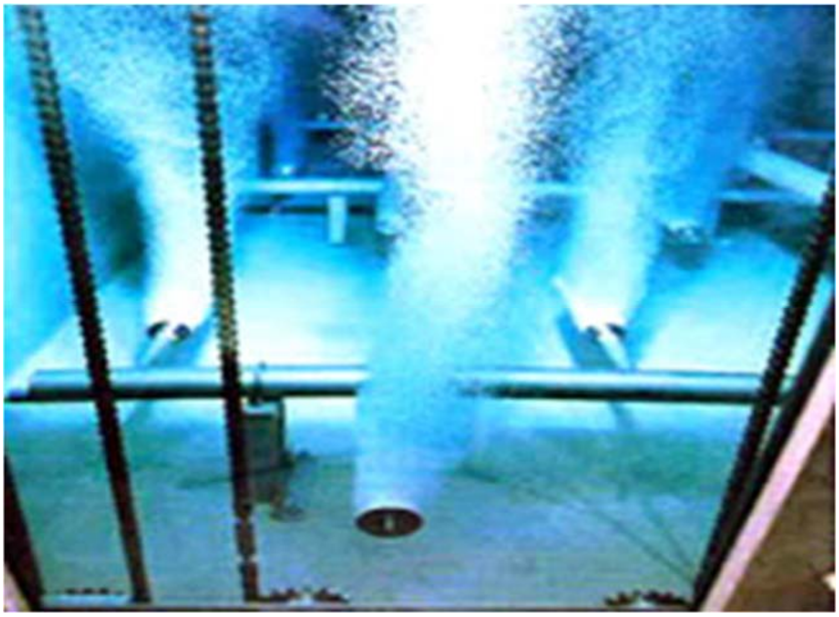
At that time, eutrophication of lakes became a serious problem in Japan, Biwa Lake, the source of the Yodo River System, was no exception. In 1971, algae bloom caused eutrophication in the river flew down all the way to the water intake. The moldy taste came from abnormal growth of algae, caused by eutrophication of the entire watershed. Break point chlorination alone could not treat it, and degradation or adsorption process had to be employed.

To tackle the problem, research was carried out on biological treatment and ozonation. In 1973, the first ozonation plant was built in Amagasaki City. Activated carbon was introduced and used in combination with ozonation to ensure complete removal of taste and odor.

In the Kanto region, the combination of ozonation and activated carbon treatment was introduced at the Kashiwai water treatment facility in Chiba Prefecture in 1980. These cases initiated the research on advanced treatment processes.

The high investment cost held back the use of advanced treatment processes at the beginning. However, as social concerns over carcinogenic by-products of chlorination emerged, utilities discussed applying advanced treatment processes only for drinking water and distributing the drinking water separately from water for other use. They also discussed about supplying bottled drinking water.

In the end, advanced water treatment was used because it was deemed important to reduce the organic substances in the water purification process to minimize by-products of chlorination. Nowadays, the comprehensive efforts in water resource conservation have stabilized water source quality. The advanced treatment methods considered earlier were attractive when at the time, it was difficult to know if the source water quality could be improved or not.



Source: Tokyo Metropolitan Government Bureau of Waterworks,

https://www.waterworks.metro.tokyo.jp/suigen/topic/13.html.

Photo 8. Ozone contact basin

Advanced water treatment improves odor and taste of the treated water and reduces the risks caused by organic substances. Safe and tasty water plays a critical role in winning the citizens’ trust in the water supply.

(6) Membrane Filtration

Membrane filtration can be easily automated, thus requires less labor input. It is mainly introduced at small and medium utilities in Japan. It is assumed that application of the method will increase around the world.

The principle of membrane filtration is the removal of substances by a pressure driven membrance separation process. Coagulants are added as a pre-treatment in some cases. The advantages of membrane filtration technology include: requiring less space, little maintenance and manpower, easy to control, and automate. In Japan, they are ideal for mountainous areas, where the raw water has low turbidity but is contaminated with protozoa from wild animal excrement. On the other hand, no economy of scale can be expected as it is joining membrane modules.

There are different types of membrane filtration for water treatment: microfiltration (MF), ultrafiltration (UF), and reverse osmosis (RO). Microfiltration and ultrafiltration are physical separation of suspended matters. They are differentiated by the size of the pores of the membranes. Ultrafiltration uses smaller pores and can remove viruses, but requires higher pressure than microfiltration. Reverse osmosis is used for desalination.

Source: Waterworks Bureau, City of Kyoto

http://www.city.kyoto.lg.jp/suido/page/0000160981.html

Photo 9. Membrane filtration facilities,
Water supply system for Kuroda area in Kyoto City

In Japan, industry, government and academia collaborated in developing the next-generation of water supply technologies under the MAC21 (Membrane Aqua Century 21) research project (1994-1996). Establishing membrane filtration technologies was one of the projects implemented under the plan.

Desalination of seawater or brackish water is expected to increase around the world, because it has already defused especially in areas such as the Middle East where water resources are scarce, or where there are not many trained workers. If membrane filtration is broadly promoted and the cost comes down, this technology is expected to become one of the main options for water treatment in developing countries.

(7) Water Reuse

In Japan, reuse of treated wastewater for flushing toilets or for industrial purposes is widely employed. Water reuse can be an option for developing countries where water resources are scarce.

Water reuse is use of recycled water such as sewage water treated with advanced water treatment process.

Sewage water is treated and discharged to the watershed for natural purification and used again in a downstream basin. This type of "indirect reuse[5]" is common and widely used. On the other hand, the element technologies of treating sewage water for "direct reuse[6]," such as biological treatment and ozonation are already established and technically possible. However, it is not practical to achieve drinking water quality because of the high energy cost. There is also some non-acceptance by users because of cultural and religious constraints, so its use is still extremely limited on a global basis.

In Japan, "direct reuse" is not in place for drinking water purpose. Uses for industrial purposes and for toilet flushing are reasonable targets. Especially in regions where groundwater use is strictly regulated (e.g. Tokyo) because of land subsidence or where water resource is scarce (e.g. Fukuoka City), reusing water is enforced and proactively utilized as "middle water" (the water quality is in the middle of potable water and wastewater, not for drinking but can be used for other purposes).

Many countries experience extreme water shortage. In China for example, it is estimated that they require water for "indirect reuse" five times more than in Japan to meet the demand. Advanced water purification such as microfiltration (MF) / reverse osmosis (RO) membrane can be options in such cases. For water to be fed in boiler, treated water with RO could be of better choice than drinking water. In Japan, as there are relatively rich water resource, these options are considered to be extremely rare. But water shortage will force developing countries to explore various options.

(8) Wastewater Treatment

In Japan, utilities have to comply with the effluent regulations for discharging treated wastewater to public waters. Water treatment plants have processes to treat sludge from sedimentation facilities and backwash from filtration units. The treatment system usually consists of thickening, dewatering and drying processes. Wastewater is now rarely discharged to public waters. It is usually treated and reused.

Sludge is produced from suspended solids removed from raw water. Backwash from cleaning the filters is another source of waste from the water treatment process. In Japan, the water treatment plants which have a capacity larger than 10,000m^3/day, with sedimentation and filtration systems are regulated by the Water Pollution Control Act. They have to install a

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[5] An example of "indirect reuse" is taking treated wastewater, which was discharged into a river, as raw water.

[6] An example of "direct reuse" is using wastewater from flush toilet for flushing again.

wastewater treatment system to meet standards for effluent discharges to surface waters.

First, the sludge concentration of wastewater is adjusted at the filter backwash clarifier or the gravity thickener, then turned into thicker sludge so to make the following dewatering process easy. The skimmed water can be sent back and used as raw water again, but the water quality should be tested carefully as it may contain concentrated dissolved matters which may have an impact to the treatment process.

The thickened sludge is dewatered mechanically or naturally. Mechanical methods include vacuum filtration, pressure filtration and centrifugal separation. Solar sludge drying beds utilize natural wind and/or sun for dewatering.

The dewatered sludge cake or water treatment generated soil, is used for landfill or for manufacturing cements, reclaiming playgrounds or producing agricultural compost.

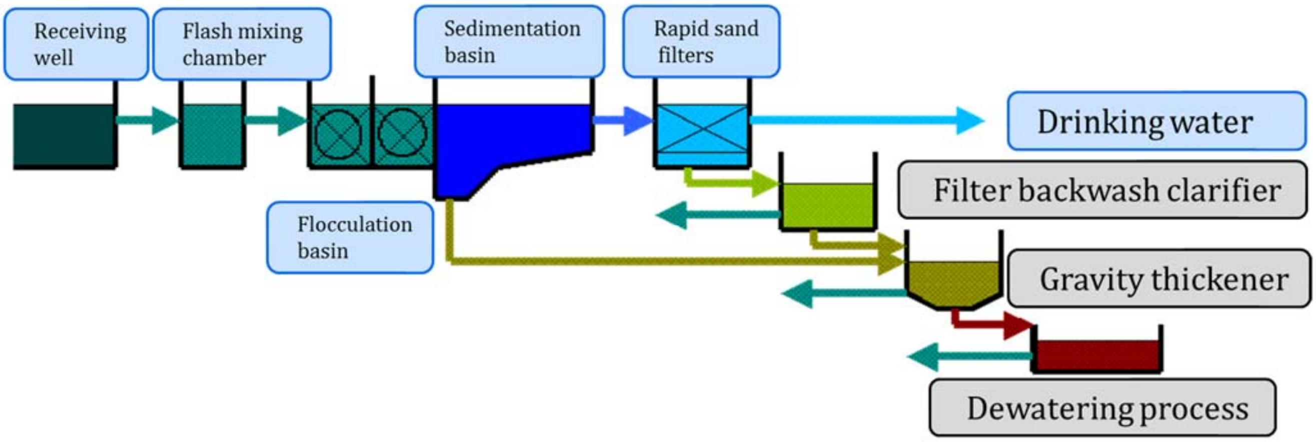


Figure 8. Wastewater Treatment System

5. Groundwater Use and Prevention of Land Subsidence

(1) Groundwater Use

Clean good quality groundwater is an excellent water source. However, quality of groundwater and the operation and maintenance requirements must be carefully assessed.

Japan has relatively abundant water resources, and spring water and groundwater has been utilized since ancient times. Many utilities, especially small scale ones use groundwater sources. But surface water has taken the place of groundwater in urban area which is located on alluvial plain, to avoid land subsidence.

There are wells that draw shallow groundwater and artesian wells that tap deep aquifers. Japan has developed unique techniques for digging deep wells without machines, radial collection well that extract shallow groundwater efficiently, and some excellent strainer and screen products for efficient intake from wells.

Photo 10 shows an example of rich groundwater as the source of drinking water. Photo 11 shows an example of traditional water grids, which is not a source for water supply utility, but is utilized as a community water source from springs for drinking, and other domestic purposes.

In many cases groundwater is an excellent water source. Kumamoto City and other many utilities distribute groundwater after only chlorination. However, in some cases, utilities have problems such as contamination from the surface of the ground, or pollution of iron and manganese. Some groundwater contains pollutants which may cause serious problems such as arsenic poisoning. Water quality testing before intake must be carried out to avoid utilization of such sources. In case there is no other water source, appropriate water treatment process should be adopted and water quality should be managed carefully.

In using groundwater as source, maintenance cost is required for well washing and monitoring for groundwater level. Well screens will be clogged up by changeover time.

Photo 10. Takizawa Village, Iwate Prefecture.
Ubayashiki Water Sources (December 2, 2010).

Photo 11. This spring water is currently used in Morioka City.
Traditional water grids which are separated for drinking, washing and other purposes from the upstream (November 23, 2010).

(2) Prevention of Land Subsidence

Some areas of Japan experienced serious land subsidence. This is under control mainly by introducing strict regulations for pumping groundwater and providing alternative sources by development of surface water and industrial water supply.

Land subsidence occurs naturally but can also be induced by human activities. The mechanism of land subsidence can be determined from hydrogeological surveys. It is important to determine the cause. If it is human-induced, measures must be taken to prevent its occurrence, such as: (1) investigate the hydrogeological features for clay layer which will cause consolidation and settlement; (2) monitor water level and pumping volume of every aquifer; and (3) avoid pumping more than the amount of natural recharge. Japan has a broad observation network and strong regulations to restrict over abstraction of groundwater. In establishing the regulations, efficiency and social acceptance are also considered by restricting pumping only large amount pumping from the layer which has the greatest impact on land subsidence.

In addition, it was important to develop alternative water source such as industrial water supply to reduce the reliance on groundwater. Land subsidence is well controlled by implementing these measures.

Column: Land Subsidence in Japan

Larger quantities of groundwater were extracted with the development of pumps and drilling technologies, causing land subsidence. Land subsidence was recognized for the first time during the survey after the Great Kanto earthquake in 1923. Similar findings were reported in Osaka and Nagoya. The problem was not much reported again until after the end of World War II (1945) as the pumping discharge of groundwater declined during the period. Land subsidence caused many social problems in eastern Tokyo, Osaka City and eastern Saitama Prefecture, etc. in the 1950s. Strengthened groundwater use regulations and development of alternative sources for industrial water has successfully prevented most land subsidence and the groundwater level recovered. Land subsidence is no longer a serious issue but still occurs in some areas.

6. Distribution Systems

In the early days, water distribution systems were developed as dendritic (tree) systems in a disorganized manner with little or no documentation of their locations and connecting points. Pipeline capacity was not clearly understood. The poor management became a serious problem when the system had to be expanded. Therefore, new pipelines were constructed to go around old networks and unitedly formed pipeline network in response to the expansion of urban area. This provided stable service with equal water pressure and fewer water stoppages.

After the 1970s, distribution networks become more sophisticated with the block system. The system allows the adjustment of water pressure in the distribution pipelines and flexible water supply operation. It is desirable to design the system from the earlier stage with future vision of developing the block system.

(1) Water Distribution System

Distribution systems such as service reservoirs, pumping stations and pipelines are very costly, adding up to 2/3 of the total investment of the water supply facilities. Therefore, planning with long-term vision and efficient design are very important.

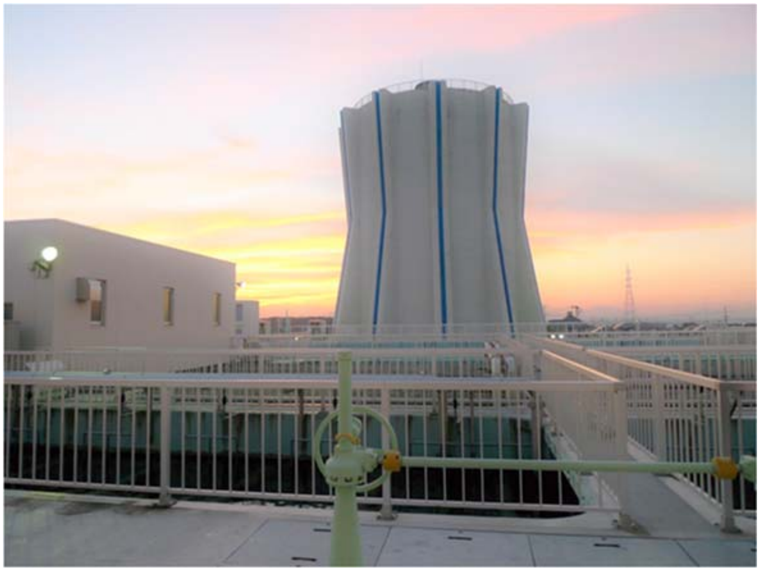


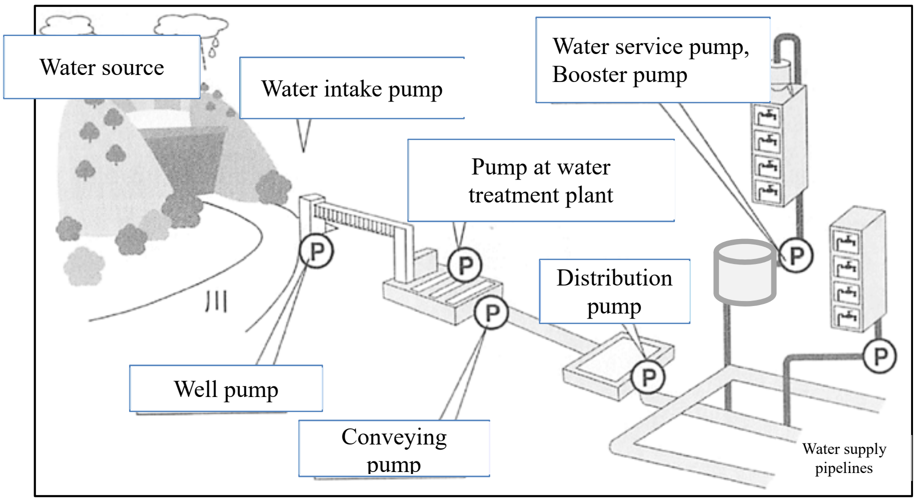
Photo 12. An elevated tank at the Hakusan Water Treatment Plant Hachinohe Region Water Supply Authority. (October 29, 2010).

Ideally, distribution reservoirs should be built on hillsides to take advantage of gravity. Otherwise pumping is required for flat areas.

For vast flat areas it is necessary to use elevated tanks with storage capacity that can provide the required water pressure in the distribution network. The facilities should also be earthquake resistant in Japan, making their construction rather expensive. Elevated tanks are less used nowadays, because pumping technology has been improved and the water supply system has been equipped with enough capacity of distribution reservoirs. Water distribution systems can now send water under pressure with constant pumping without serious problems.

Distribution tanks must be designed with careful estimation of long-term demand and the appropriate distribution system, since their water level ranges are fixed once they are built.

It is necessary to understand pumping technology and water hammer control to distribute large volume of water. Water hammer can cause serious damage to the distribution system. Therefore, surge tanks, pumps with flywheels and other surge prevention measures should be considered in the design phase.



Source: Water Partners Jp Co., Ltd., “Fundamental knowledge of water supply pumps”, Water Solution and Technologies, No.15, 2012.

Figure 9. Example of Water Distribution System and the Use of Pumps

(2) Pipeline Configuration

Water distribution pipeline gradually evolved from the facility, which simply distributes water, to the system, which has the function of controlling water flow and pressure forming organic network and consisting with distribution blocks.

The requirement for water distribution pipelines has been evolved by 3 stages: (1) investment cost efficiency (the most effective diameter for dendritic (tree) system that pipes are arranged in a tree-like form), (2) operational efficiency (network systems which enables flexible operation and minimizes the impact of accidents), and (3) management efficiency (block system with remote monitoring and control called Supervisory Control And Data Acquisition, SCADA).

At first, distribution pipelines were constructed as simple dendritic system. This system is relatively inexpensive, and it is easy to locate leaks. However, as it follows a single route, water pressure fluctuates depending on the demand. In addition, service stoppage can be long as repairs must be done before service can be restored.

The concept of distribution network existed before the 1940s, but it became widespread after the 1960s when water supply was promoted and expanded. Houses were firstly constructed near main roads and rivers, and then spread into a wide area including hilly terrain. Network system was formed through interconnecting existing service areas with other pipelines when distribution capacity was expanded for the service areas spread widely. The other reason of introducing network system was limited capacity of tree system. In Japan, a fire-hydrant is required for every 2,500 habitants. The pipe sizes in a dendritic system were not enough to handle water for firefighting.

Other events that prompted the shift to better distribution networks include liquefaction observed after the Niigata earthquake in 1964, Fukuoka City drought in 1978, and water pressure problems in Sendai City and Kobe City with undulating landscape. Every utility had its own reason to introduce the block system.

With the cost of information technology declining rapidly, water distribution management can make use of remote monitoring and control (or SCADA) to regulate the water flow in pipelines and to detect leakage.

On the other hand, still many utilities do not have the sufficient management capacity to deal with pipeline information, such as pipe age, type, repair and accident records. Improvement of network management by further applying information technology will be implemented with mapping system, asset management based on assessment of soundness of network and smart meters.

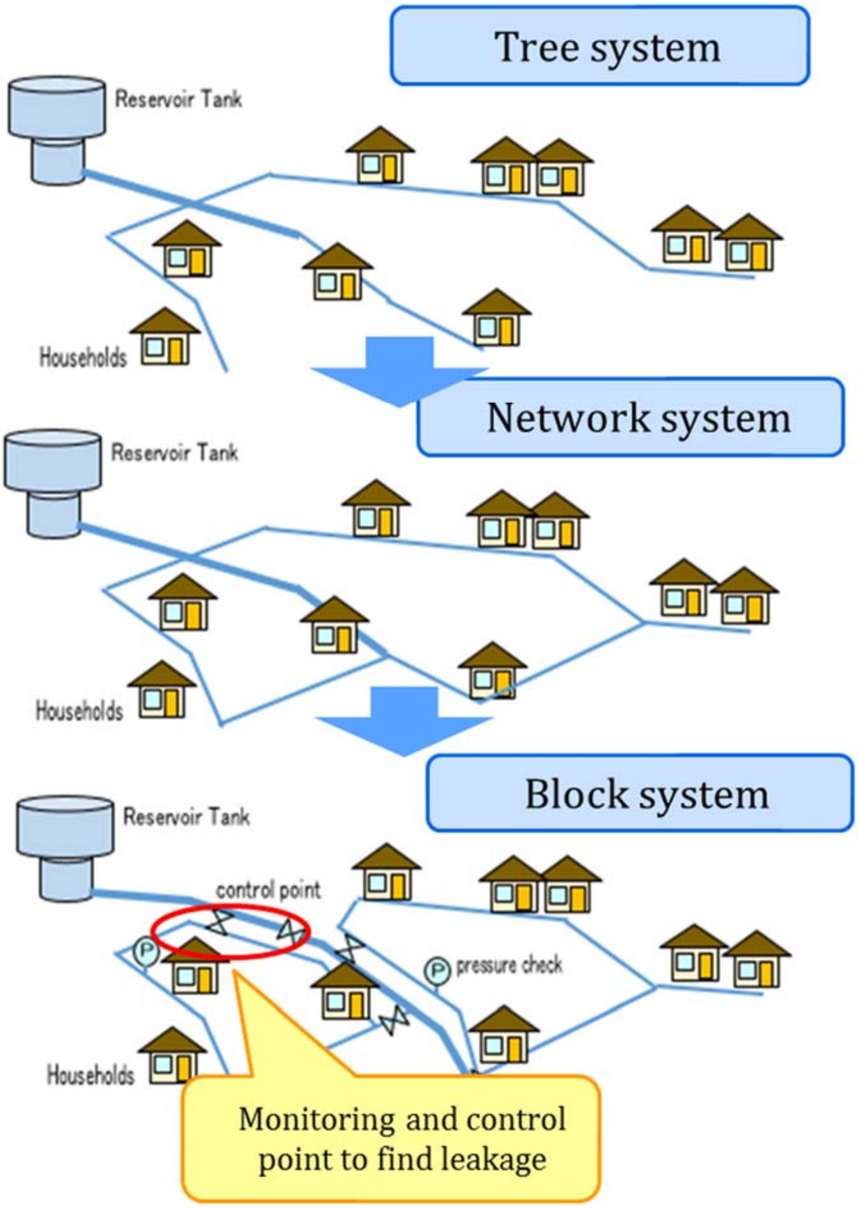


Figure 10. Dendritic System, Water Distribution Network and Block Distribution System

7. Engineering Design and Master Plans

(1) Importance of Engineering Design Standards

The core idea of water supply is to secure safe water supply by properly operating and maintaining facilities, which are properly designed and constructed. Standards for water supply facilities are specified in the Water Supply Act.

In Japan, engineers had frequently faced difficulties in designing water facilities when the network started to be established. Utilities needed to share their experiences with others. Japan Water Works Association (JWWA) played a central role in the initial development of the water supply systems. It became the repository of accumulated technical knowledge from its member utilities, and was instrumental in the preparation of the design criteria and facility standards.

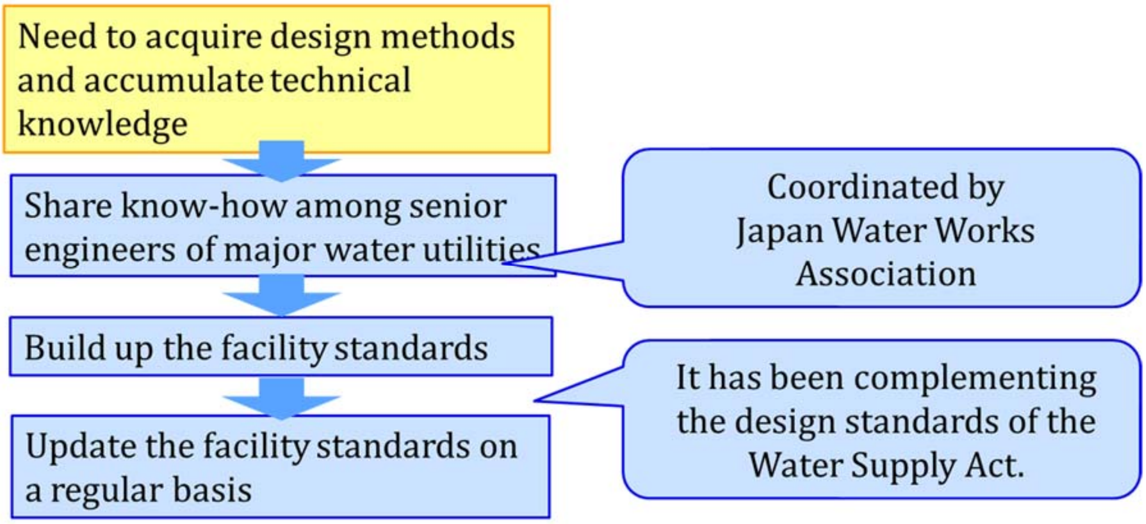


Figure 11. Engineering Design Development in Japan

(2) Updating Design Concepts

Design philosophy of water supply facilities should fit the social and physical environment of the country. As Japan is an earthquake prone country, the design of water supply facilities and equipment has been improved based on experience with past earthquakes.

In Japan, technical standards for public facilities originally focused on constructing substantial structures, which were earthquake resistance such as ability to withstand 5 intensity earthquakes (Japanese earthquake scale). However, after the Niigata earthquake in 1964, there were extensive liquefaction and severe damages to water supply pipelines. Since then, many technical studies were carried out on earthquake resistance of water pipelines. In 1973, the studies on preparedness for the Minami Kanto earthquake prompted the design of a chain-like structure with connectors that can flex with ground movements, leading to the standardization of earthquake-resistant pipelines.

Following the Hanshin-Awaji Earthquake in 1995, which occurred directly underneath a metropolis, various ingenious attempts were made to develop earthquake-proof water supply facilities. This experience brought improvement of seismic design based on classification of ground motions into two levels, and minimum amount of water to be stocked for drinking and firefighting even in water outages, then they became a part of the guidelines for earthquake countermeasures thereafter.

As a result of these efforts, not many water supply structures were damaged during the Great East Japan Earthquake in 2011 considering its intensity and multiple impacts from the tsunami. While the damages were as anticipated, the destruction of aged pipelines which were not earthquake resistant was quite extensive. It is very difficult to preserve the integrity of pipelines buried in the ground over a broad area. More discussion is still taking place to decide how to make pipelines earthquake-proof.

(3) Importance of Expansion with Proper Planning

The development of water supply requires enormous investment and funding is always limited. The master plan is a very useful tool for managing funds and forecasting revenue for expansion. In Japan, a master plan is required for obtaining the Approval (License) for operating the utility and for securing financial resources.

To expand the water supply coverage, it is necessary to broaden the distribution area. More facilities have to be built continuously. Public funds must be procured from governments, and revenue will cover the expense on facility expansion once operations started.

Investment in urban water supply in Japan has been funded by municipal bonds and investment, and subsidies from the national government.

A master plan is needed to secure the investments through an approval process involving the local assembly and also requiring the understanding and support of the residents. The master plan is also needed to gain national subsidies or funds.

The master plan is also critical for determining the cost recovery of the entire operation (from securing water sources, to treatment, transmission and distribution). In Japan, a water supply system was first developed in relatively small urban centers due to the financial constraints with establishing a complete set of facilities and management system including tariff collection to secure management foundation. Then it was gradually expanded to the surrounding areas. The planning and management of every expansion must be worked out in the master plans to ensure cost recovery and sustainable operations.

Development of urban water supply can be constrained by the scarcity of water sources and progress can only be made as water sources are allocated, in spite of demand pressures. Plans have to be reviewed frequently as water resource, urban planning as well as industrial development can change. Gradual expansions in accordance with demand growth and the concept of cost recovery to cover the construction cost by tariff revenue enabled continuous investment to maintain a sustainable water supply.

Rural utilities use their limited funds for renewal of facilities. The financial constraints force them to use inexpensive materials. They do not use the public enterprise accounting system and have to manage their operation with the assistance of the prefectural government. They are necessary for universal coverage but their sustainability is a big issue at present.

(4) Approval (License) System and Complementary Frameworks

The Water Supply Act stipulates that utilities must obtain Approval (License) to operate water supply systems. The approval process requires the submission of a master plan. In the early stage of expansion when utilities were not yet technically sophisticated, the approval process contributed to prevail appropriately designed water facilities.

The facility standards and the Approval (License) system specified in Article 6 of the Water Supply Act are important pillars in the development and management of the water supply systems. The Approval (License) process clearly states that utilities serving populations of over 50,000 have to be approved by the Ministry of Health, Labour and Welfare, and those serving populations of less than 50,000 by prefectural governments.

The application must provide information on demand projections, facility plan and fiscal plan (including proposed tariff structures), i.e. the preparation of a master plan is always required. The application for Approval (License) for small scale utilities is also used to determine eligibility for national subsidies.

Each prefectural government had special divisions in charge of Small Scale Public Water Supply, with staff devoted to the design and approval process. There was not enough technical expertise to manage the responsibilities even with personnel transfers of engineers from a construction division to a public health division. Later, affiliated organization and private companies were contracted for planning and designing, but their workforce was insufficient to meet the demand of Small Scale Public Water Supply at that time.

Small utilities prepare their plans based on the assumption that they have limited human resources and that they must seek good quality water sources. They also have to secure the services of local businesses for the repair of water supply pipelines. The Plumbing Constructor's Association was established in various regions as a result of this development.

The Approval (License) process is very effective for small scale utilities which have insufficient technical ability to maintain good quality of the service. It is essential that developing countries take the initiative to develop their own plans and not just follow proposals led by donors.

It is noted that Approval (License) is required only for new or expansion projects. Since Japan has achieved nationwide coverage, this process is taking place less frequently. Therefore, the national government urges water supply utilities to prepare Water Supply Vision and Water Safety Plan, and implement asset management, by introducing guidelines and tools for them, emphasizing operation and maintenance and facility renewal. Water Supply Vision defines the method to assess utilities and their challenges, forecast future business environment, determine future vision for local waterworks, set operational targets, monitor performance and conduct reviews.

Utilities have to prepare annual management plans (annual budget), based on the Local Public

Enterprise Act. The local assembly has to scrutinize and approve these plans, as a means to validate the efficient and effective operation of the water supply business. These plans and their monitoring complement the Approval (License) system, which is effective for the era of construction and expansion and not for the era of operation and maintenance.

8. Lessons Learned

The following Japanese experience could be useful for other countries.

- **(Selection of Water Source)** It is ideal if pristine water sources can be used for drinking water supply. This is especially important for small- and medium-scale utilities that are in short of human resources and technical capabilities.
- **(Surface Water Development)** The water rights system and Comprehensive River Development are effective for developing water resources. It requires cooperation of stakeholders, negotiations and sometimes conflict management. Dam construction is expensive, so that municipalities needed to get together and work with other users and river authorities on multipurpose dam construction. They also organized to secure bulk water supply.
- **(Chlorination)** Chlorination contributed a lot to the supply of safe drinking water. However, it has some disadvantages including: production of disinfection by-products, formation and corrosion of equipment.
- **(Rapid Sand Filtration)** The coagulation, flocculation, sedimentation and rapid sand filtration process is often used to treat highly polluted raw water. The choice depends on the quality of the raw water and water demand. Many utilities use this method to treat large volumes of polluted water especially in urban area, which usually located at downstream.
- **(Dealing with Source Water Deterioration)** Japan developed technologies and new approaches to deal with challenges of water source pollution and drought. These include advanced water treatment, membrane filtration and wastewater reuse. Although new technology development requires large investments, it can produce high quality waters to win public support for the water supply.
- **(Prevention of Land Subsidence)** Japan faced serious land subsidence due to over-pumping of groundwater in some regions. This problem is under control by strictly regulating groundwater abstraction, providing alternative water sources, and monitoring ground and groundwater levels.
- **(Transmission and Distribution Systems)** The investment for transmission and distribution systems accounts for two thirds of the total investment cost of the water supply system, so that it is important to plan and construct distribution reservoir, pumps and pipelines efficiently based on the long-term plans. Japan has taken advantage of its

hilly terrain to build gravity flow systems to save money and energy and for easy control of water distribution.

- **(Block Distribution System)** Distribution pipelines have evolved from dendritic systems, to network and block distribution systems as cities expand. The advanced designs provide better control of water distribution and minimize supply disruptions.
- **(Master Planning)** Japan expanded its water supply systems by well-planned and stepwise expansion to keep pace with population growth and water demand. This approach is effective for sound financial management of the utilities. Formulation of a master plan, which includes long-term projection of demographic and social changes, is effective in developing water supply system and improving water supply coverage.
- **(Approval(License) System)** The Water Supply Act stipulates the requirement for Approval (License) of utility operations, adherence to facility standards and appointment of a qualified technical administrator. These requirements set the high standard for water supply quality and sound business management. In addition, the national government is encouraging the preparation of Water Vision and Water Safety Plan to ensure technical stability of utilities. The preparation of annual business plans, which include budget plan based on the Local Public Enterprise Act, and the approval by the local assembly ensure sound business management.