Water Supply System:
from Water Sources to Distribution

Amagasaki Water Treatment Plant,
Hanshin Water Supply Authority

No. T2 Ver. 1

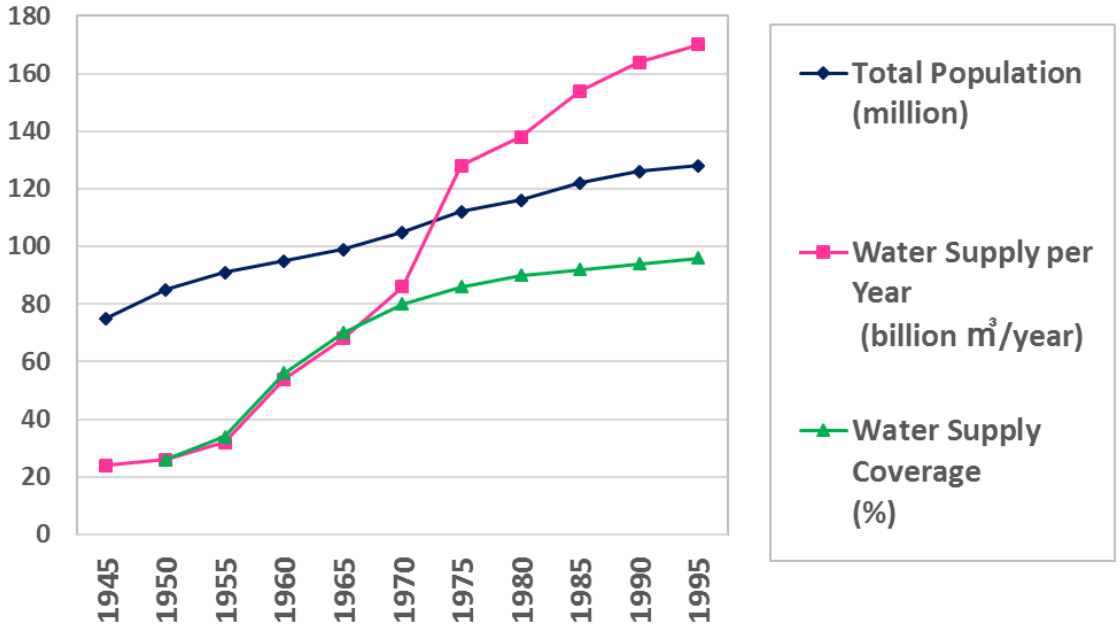
Contents

1. Introduction

What is the water supply system?

- Securement of water sources
- Water treatment facilities suitable for different water sources
- Water transmission and distribution system
- Engineering Design

Development of water supply systems raised the amount of drinking water supply in Japan sharply since the 1950s.



Annual water supply volume in Japan

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

1. Introduction

Frequently asked questions from participants of the water supply training courses

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

Q2. How did they develop water sources 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 source developed for water supply in wide areas? How the Bulk Water Supply is managed?

Q4. How did Japan control pollution of water sources?

Q5. How did Japan overcome land subsidence?

Q6. How did Japanese utilities develop water distribution pipelines? What are characteristics of them?

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

2. Water Sources and Treatment System

It is better to select clean and safe water sources without microbial contamination.

Water source from mountain stream

Quantity

Meteorological water (rain water)

Spring water, stream water, groundwater

Need to prevent microbial contamination.

Surface water from dam reservoirs and rivers

Plentiful but contaminated

River water has been used in response to increased water demand.

3. Development of Surface Water

(1) Water Rights

In Japan, water rights has been established pursuant to state law for the orderly allocation of water and to manage conflicts among stakeholders, with due considerations to customary water rights.

- 1896　Former River Act included the concept of water rights system.
- 1961　Current water rights system was established.

- Multi-purpose dam for cost efficiency
- Coordination of the interests of stakeholders
- Watershed conservation

The Shiroyama Dam and Lake Tsukui

3. Development of Surface Water

(2) Comprehensive River Development

In Japan, in order to meet increasing water demand, water sources were developed mainly by multipurpose dams planned under the Comprehensive River Development Projects, which covered and coordinated water use, flood control and environmental conservation.

- 1951 Comprehensive River Development Project started.
- 1961 Act on Advancement of Water Resources Development enacted.
- For financial efficiency, multipurpose dams are constructed by sharing the burden with other water users and river administrators.

Water saving and leakage reduction were proactively promoted in order to reduce the cost of water resources development.

Ogouchi Dam

3. Development of Surface Water

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

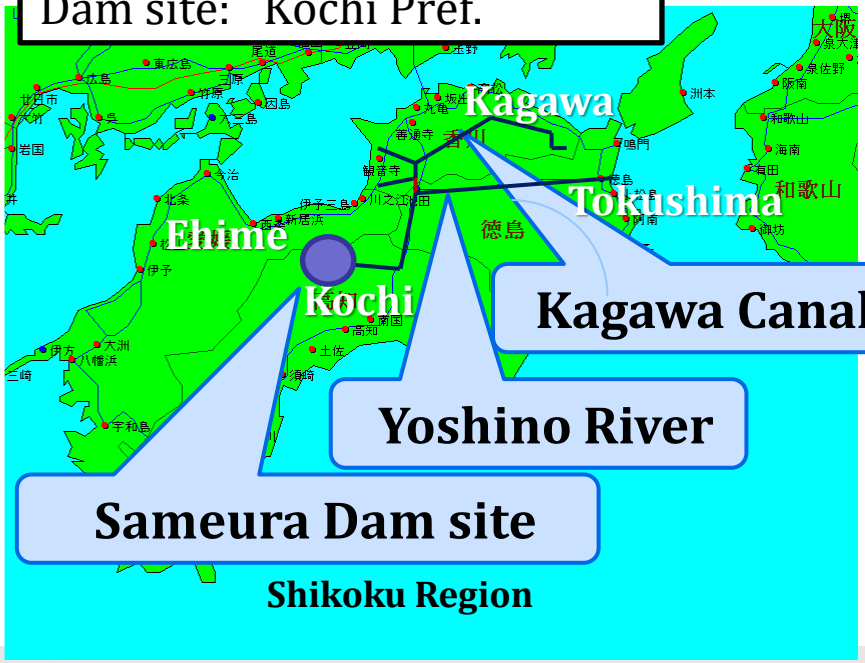
New user: Kagawa Pref.

Flood: Tokushima Pref.

Historic user:
Tokushima Pref., Ehime Pref.

Dam site: Kochi Pref.

Conflict management



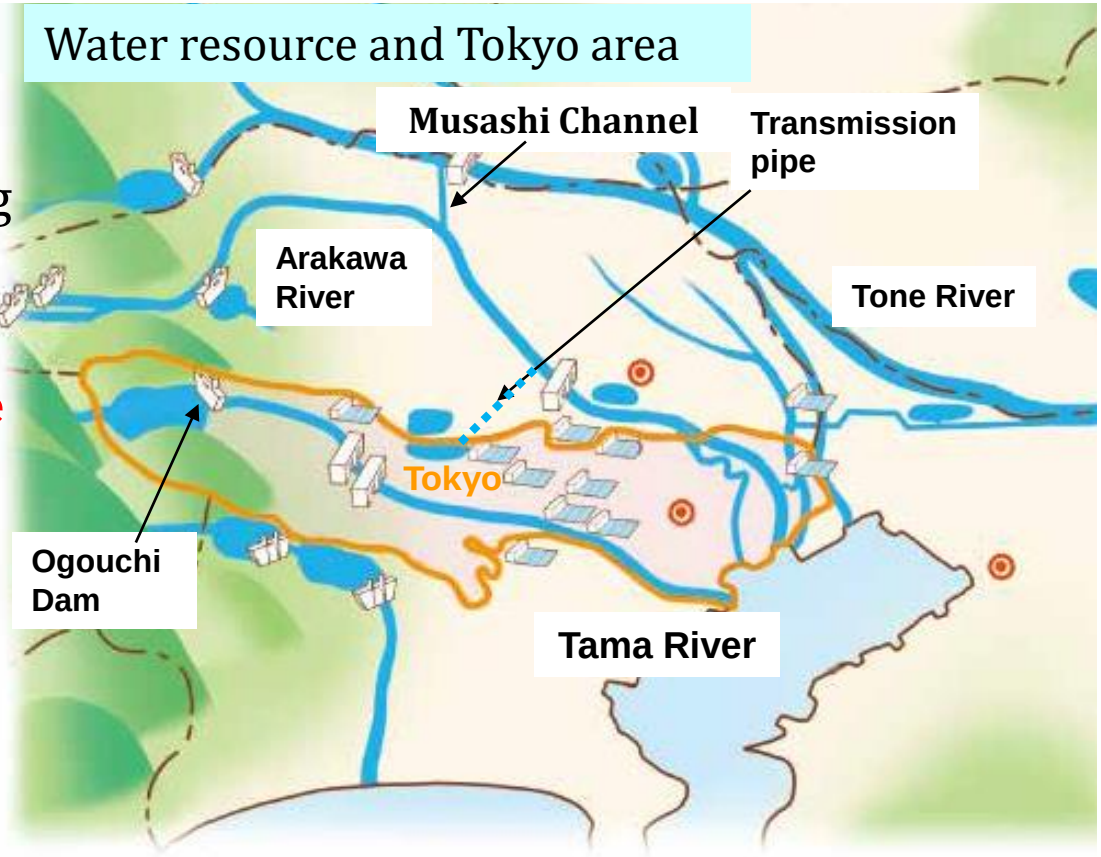
National government steps in by:

- Bringing together key stakeholders in planning how to develop the entire Shikoku Region
- Making a special act for the plan
- Transparent and fair sharing of hydrological data set by the initiative of the national government
- Discussing comprehensive river basin management, covering not only water use by Kagawa Pref., but also flood control needs of Tokushima Pref.
- Providing compensation for negatively-affected Kochi Pref., where dam site is located, from the beneficiary, Kagawa Pref., such as subsidy for forestry

3. Development of Surface Water

Example: Water source development by the Tokyo Metropolitan Government Bureau of Waterworks

- 1957 Commissioning of the Ogouchi Dam in Tokyo
- 1964 Serious drought during Tokyo Olympics
- 1965 Commissioning of the raw water transmission pipe connecting the Tone River (outside of Tokyo) and the Tama River (in Tokyo)
- 1965 Commissioning of the Musashi Channel to bring more water from other prefectures to Tokyo



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

3. Development of Surface Water

(3) Watershed Conservation

In Japan, steady and long-term efforts were made not only for the purpose of water supply, but also for the improvement of water quality in the entire watersheds.

River cleaning campaign

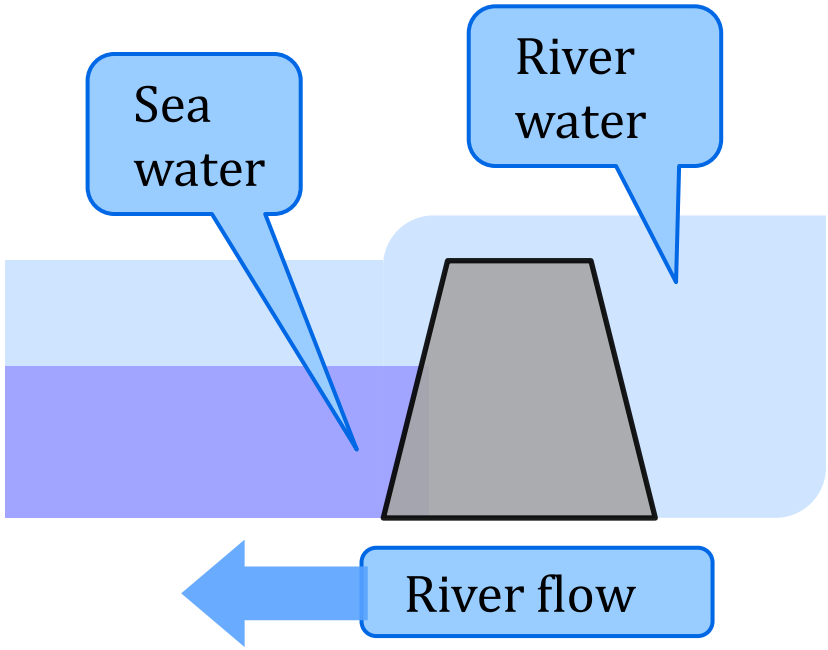
Wastewater Treatment Plant

- Effluent regulation
- Wastewater treatment plants
- Conservation of forests in water source areas

3. Development of Surface Water

(4) Salt Water Intrusion

Intake of water in the downstream of rivers can aggravate salt water intrusion. Japan dealt with this issue by installing estuary barrages.



Simple estuary barrage in Okayama city

3. Development of Surface Water

(5) Bulk Water Supply

Bulk Water Supply

↓

Large-scale water sources for the project in a wide region

↓

Securing of water sources

↓

Reduction of investment costs

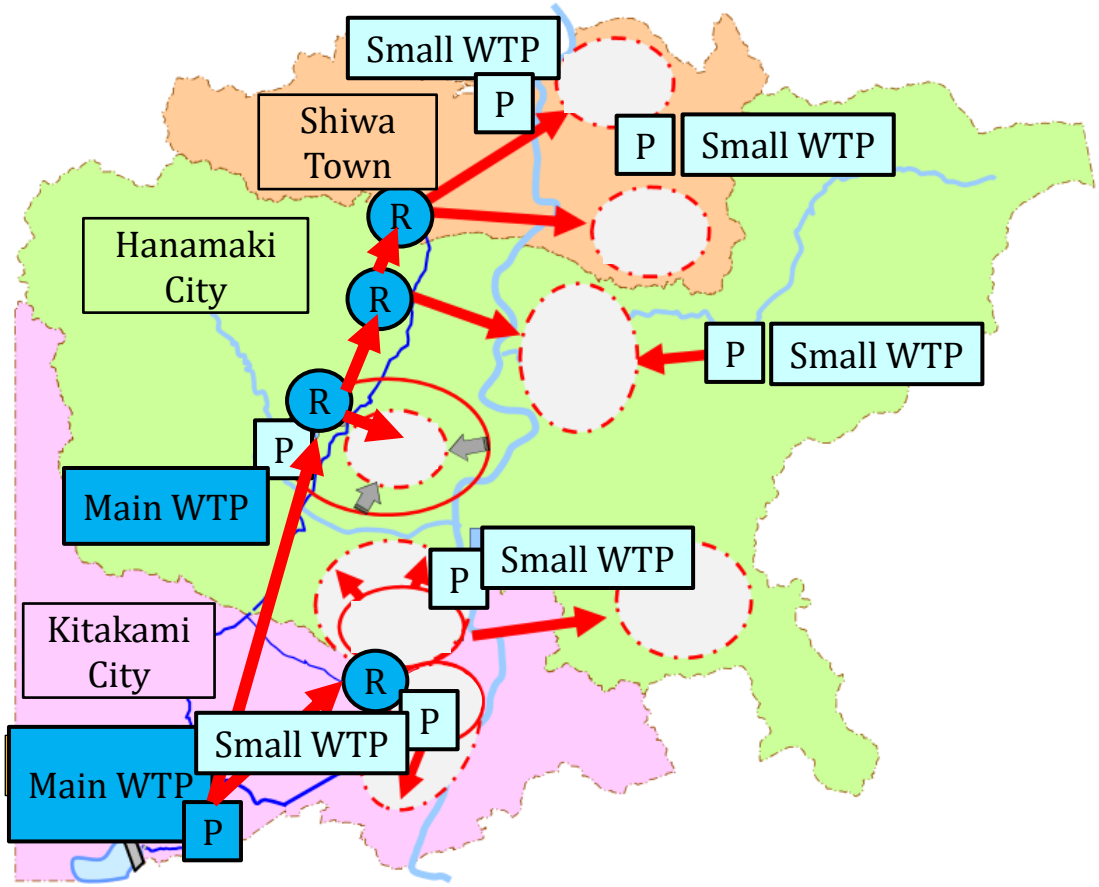
Note: Bulk Water Supply in Japan are operated by public institutions, and different from the private bulk water supplies often seen in developing countries.

3. Development of Surface Water

(5) Bulk Water Supply

Main water treatment plant is connected to other small water treatment plant

Stable water supply.



An example of water supply integration (Iwate Chubu Water Supply Authority)

4. Treatment Process

(1)Chlorination

Chlorination is the most effective disinfection method for the drinking water supply.

The effectiveness of chlorination was recognized as countermeasure against deteriorated public health in Japan after World War II .

Chlorination has prevented waterborne diseases, which were caused by contamination of water sources.

Advantages

- Very effective against waterborne diseases
- Reliable disinfection
- Easy to operate
- Simple injection device
- Low cost

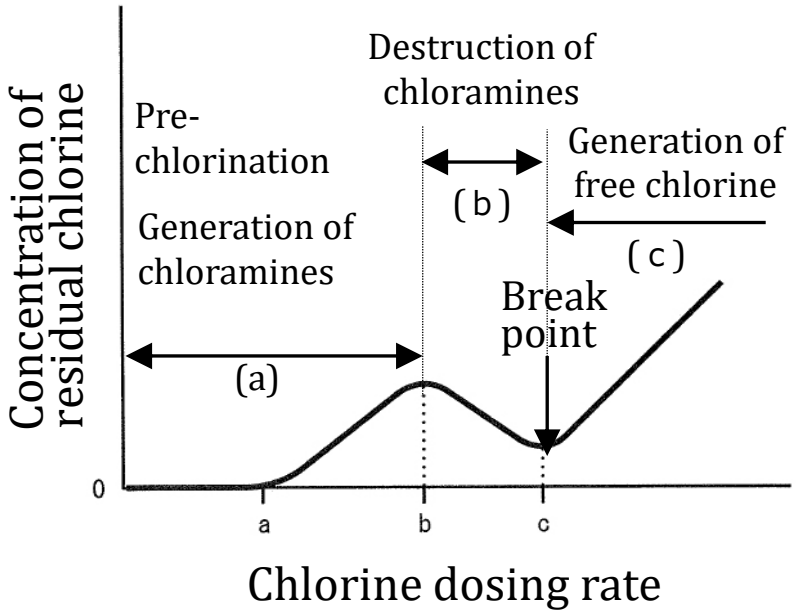
Disadvantages

- Toxicity
- Generation of disinfection by-products
- Corrosion of equipment
- Over-reliance on chlorination may lead to neglect of water purification technology

4. Treatment Process

Water Treatment Using Chlorine

Ammonia Removal (Break point chlorination)



Source: Ministry of the Environment, Government of Japan, http://www.env.go.jp/hourei/05/000188.html

Pre-chlorination to remove algae and ammonia(a)

Generation of chloramines (a)

Destruction of chloramines (b)

Break point chlorination
High injection rate to
reduce the chloramine
generate free chlorine (c)

Manganese Removal

Oxidation of manganese by chlorine

Rapid and certain removal by filtration of manganese sand, which has manganese dioxide coating.

4. Treatment Process

The Standards of Chloride Concentration

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

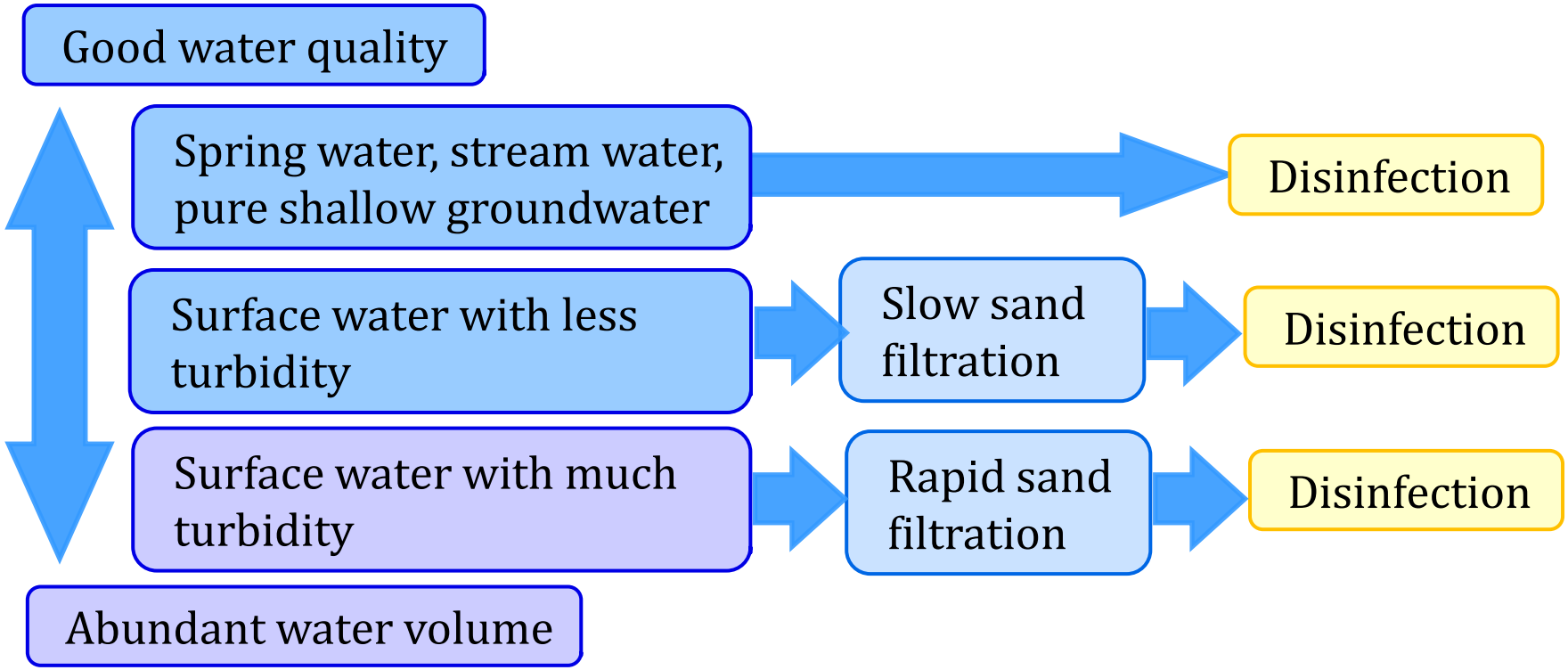
After independence, the Japanese government reduced the chlorine dosing rate.

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

4. Treatment Process

(2) Selection of Treatment Process

Water treatment facilities play a central role in water supply systems and its performance has a direct impact on the quality of the water supplied.



4. Treatment Process

(3) Slow Sand Filtration

Slow sand filtration is suitable for relatively clean raw water.

It provides biological treatment when water passes through a gelatinous layer (or biofilm) which consists of algae and bacteria, etc.

Gravity settling in sedimentation tank

↓

sand filtration with filtration velocity 4 – 5 m/day (Japanese standards)

↓

chlorination

Advantages

- Simple facilities
- Less chemicals and electricity
- Removal of odor

Yanagasaki water treatment plant, Otsu City Public Enterprise Bureau

Source: Otsu city Public Enterprise Bureau, *Main water supply facilities*
http://www.city.otsu.lg.jp/kigyo/about/water/1454032216393.html

4. Treatment Process

(4) Rapid Sand Filtration

In the early days of construction of water supply systems in Japan, slow sand filtration was selected for treatment of small volumes of relatively clean raw water. In response to the increasing demand, coagulation, sedimentation, and rapid sand filtration became the mainstream treatment technology.

Economic growth caused a huge water demand

↓

Intake points were moved downstream to get larger water volumes

↓

High in contaminants and high turbidity

Advantages of RS filtration

- Adjusts to changes in turbidity
- Less space for facility
- Removal of highly concentrated ammonia

The first plant using rapid sand filtration in Japan(Keage WTP, Kyoto City)

4. Treatment Process

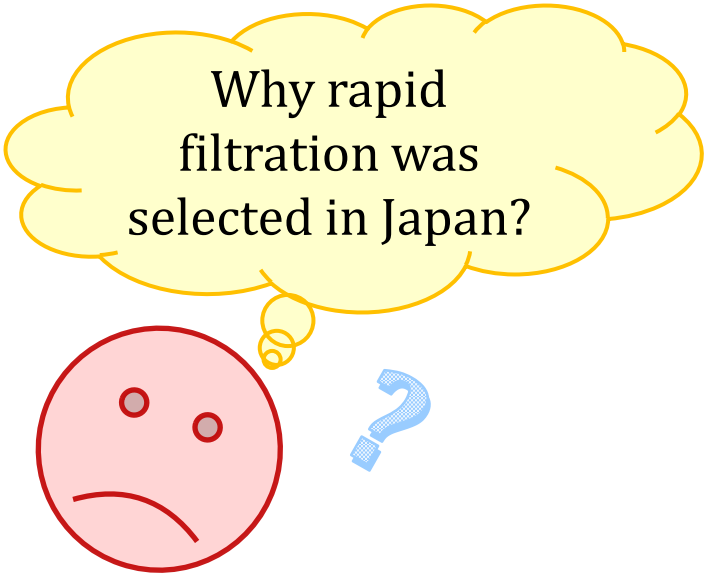
The Background of Widespread Application of Rapid Filtration

Smaller footprint than slow sand filters, making it possible to built in a small plots.

Disruption of river bed caused by digging for construction materials.

Increased levels of ammonia in source waters due to contamination beyond the ability of slow sand filtration.

It may be only a trend; it was the most advanced technology at that time.



4. Treatment Process

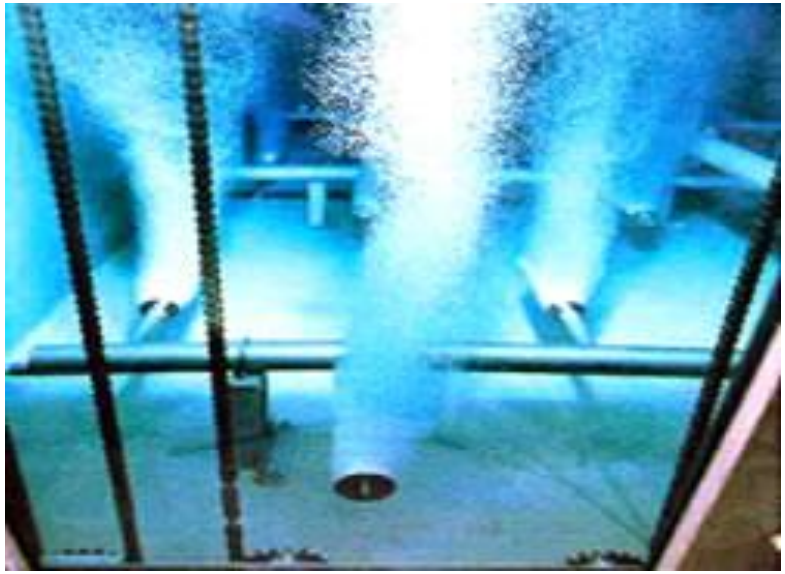
(5) Advanced Water Treatment

Exacerbating pollution of source waters has reached to the levels that made it difficult to treat source waters by conventional water treatment processes designed for the removal of turbidity and disinfection. Japan has carried out a series of studies for the combination of various water treatment technologies to develop advanced water treatment technologies.

Ozonation
=Oxidize organic matter

Activated carbon adsorption
=Biological reactor

Removal of odor and organic substances improves drinking water quality.



Ozone contact basin

Tokyo Metropolitan Government Bureau of Waterworks：
https://www.waterworks.metro.tokyo.jp/suigen/topic/13.html

4. Treatment Process

(6) Membrane Filtration

Advantages of membrane filtration technology requires less land areas, low maintenance and minimal manpower because it is easy to control automatically.

The use of membrane filtration is expected to increase around the world in the future.

1994-1996 MAC 21 research project; Industry-government-academia collaboration

Membrane filtration technology continues to be developed.

Membrane filtration facilities, Water supply system for Kuroda area in Kyoto city, Waterworks Bureau, City of Kyoto

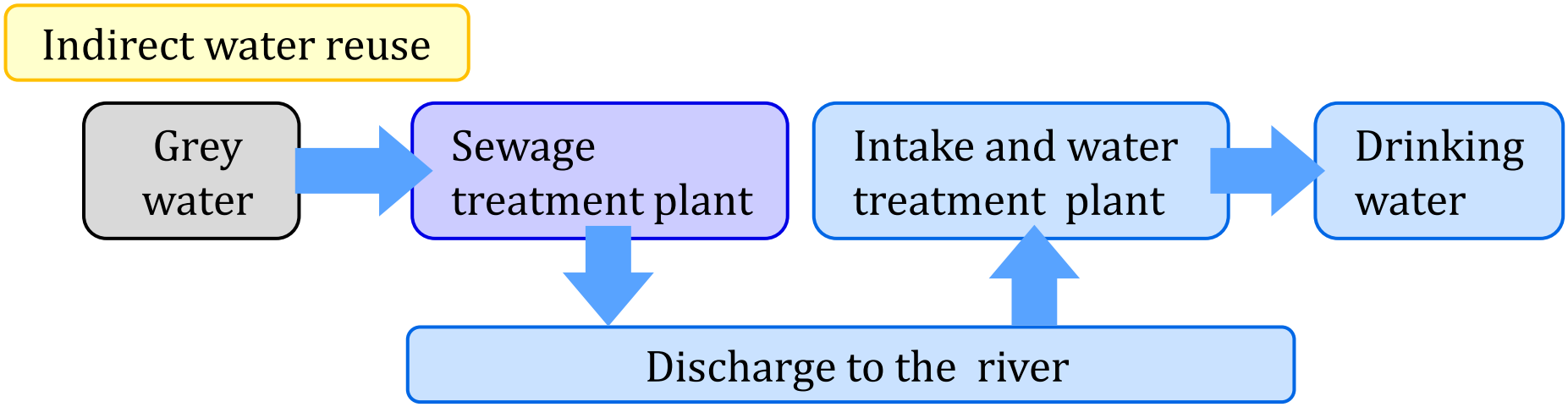
http://www.city.kyoto.lg.jp/suido/page/0000160981.html

4. Treatment Process

(7) Water Reuse

Water reuse can be an option even in developing countries, when water resources become too scarce or degraded to be handled with ordinary water supply systems.

In Japan, reused water is not used directly for potable use. It is used mainly for industrial process water and toilet flushing in regions where the use of groundwater is strictly regulated (ex. Tokyo) or in regions where water resources frequently run short.



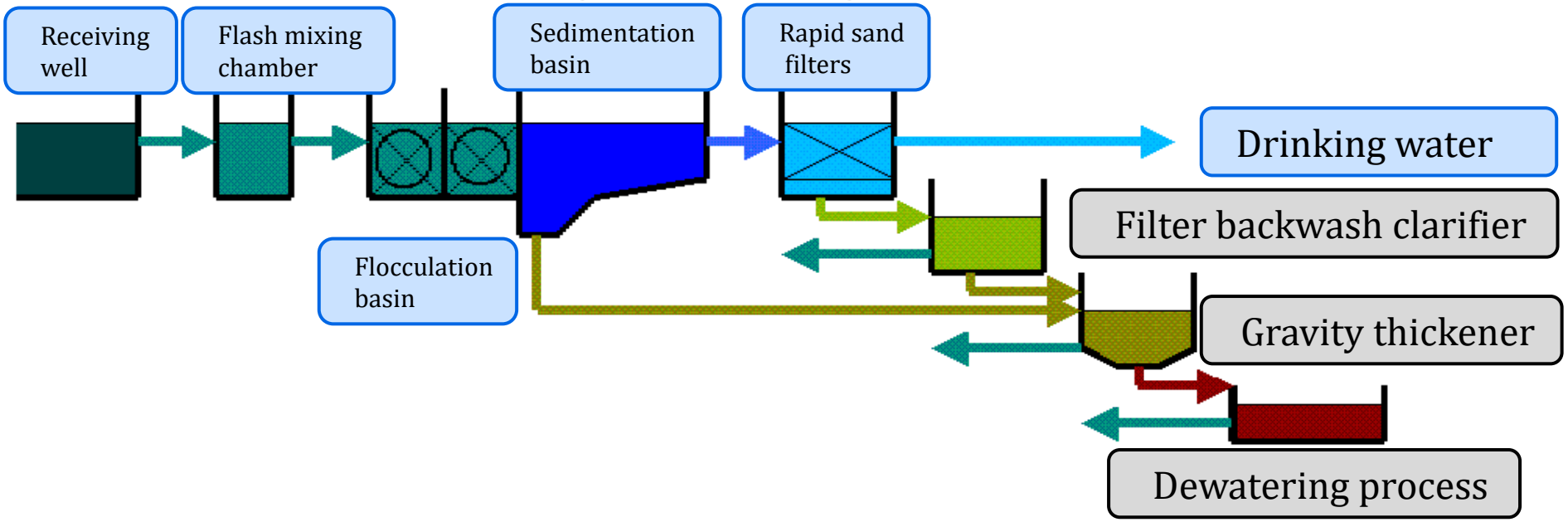
4. Treatment Process

(8) Wastes from Treatment Plants

The sludge from the sedimentation system is sent to gravity thickener and condensed by gravity thickener.

The filter backwash water is sent to filter backwash clarifier then it is sent to gravity thickener.

The dewatered sludge is often disposed but it is sometimes utilized for materials for cements, playgrounds and agricultural compost etc.



5. Groundwater Use and Prevention of Land Subsidence

(1) Groundwater Withdrawal

In general, groundwater is clear and suitable as a drinking water source.
But in some cases, it requires treatment to meet water quality guidelines.

Check water quality carefully because some groundwater is not good for drinking water.

Contaminated by Fe, Mg, As…or *E. Coli.*

Maintain and monitor the well regularly.

Groundwater source
(Takizawa Village, Iwate Prefecture)

5. Groundwater Use and Prevention of Land Subsidence

(2) Land Subsidence

Japan experienced serious land subsidence in some regions, but has brought it under control by introducing strict regulations for use by industries and large buildings, and supplying alternative sources such as surface water and reclaimed wastewater.

Monitoring of the levels of ground and groundwater tables

Preventing overuse of groundwater to avoid negative effect of land subsidence

- Introduce regulations for pumping groundwater to restrict water withdrawal
- Provide other water sources instead of groundwater
- Monitor groundwater levels, land subsidence and groundwater withdrawal regularly

5. Groundwater Use and Prevention of Land Subsidence

The Background of Land Subsidence in Japan

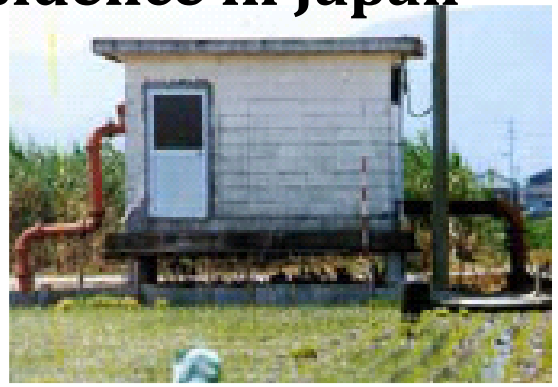
1930s-40s The cause of land subsidence was found to be excessive groundwater pumping.

No countermeasures, economic recovery was priority

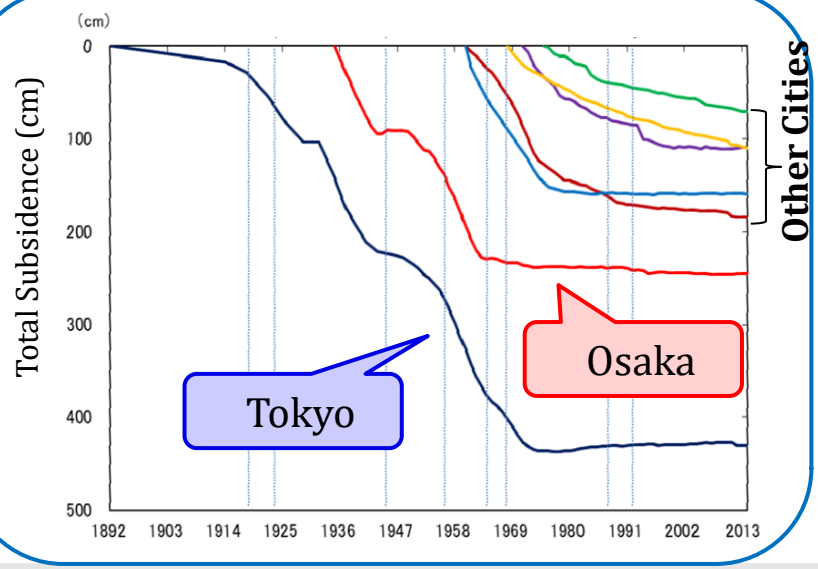
1950s Land subsidence became recognized as a serious social problem causing flooding and lifting of buildings.

Various countermeasures

Today Japan has almost stopped land subsidence.



Lifting phenomena at pumping facility



6. Distribution Systems

(1) Distribution Systems

The investment in distribution infrastructure such as service reservoirs, pump stations and pipelines is very costly and it accounts for 2/3 of the total capital cost of all the water supply facilities. Therefore, good planning of the distribution system based on the long-term perspective is very important.

Elevated tank,
Hachinohe Region Water Supply Authority

For good planning,

- Construct service reservoirs in high places
- Use elevated tanks when there is no suitable high place
- Plan the capacity of service reservoirs and distribution network based on the long-term water demand projection
- Understand pump technology and water hammer pressure to prevent critical damages to the system

6. Distribution Systems

(2) Pipeline Configuration

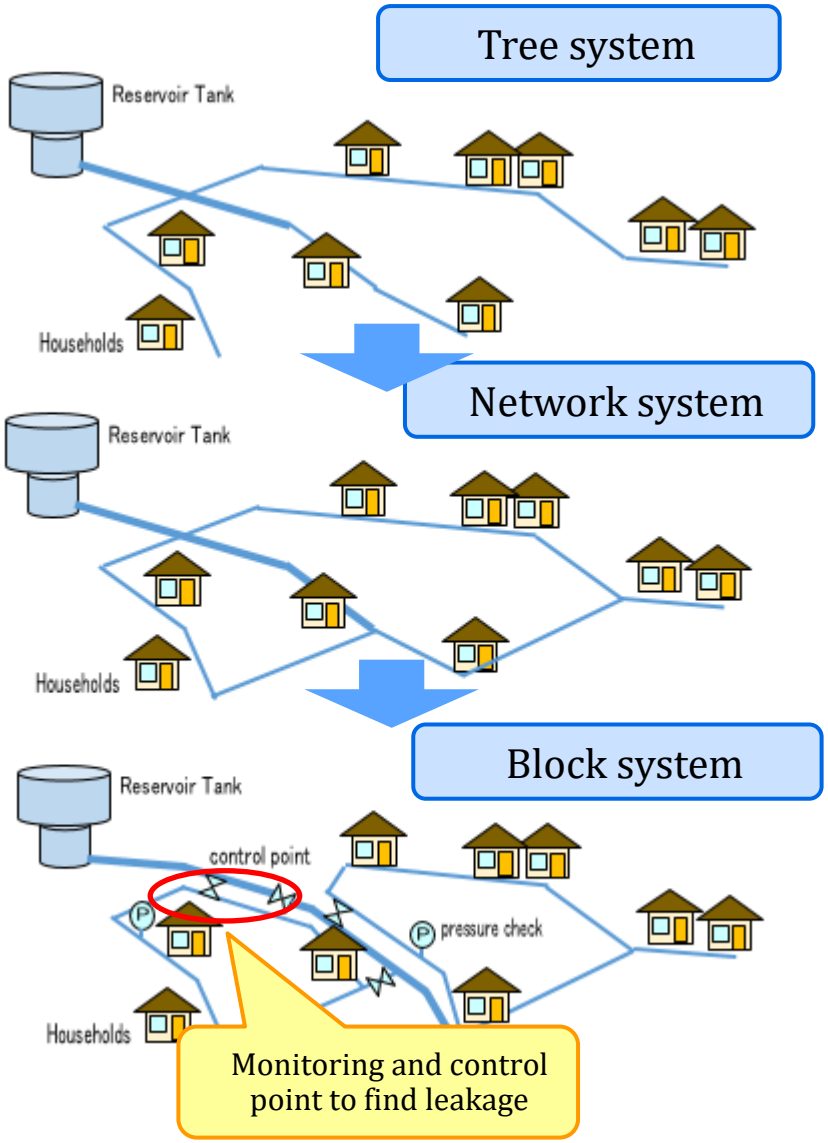
The planning policy for distribution pipelines has been changing gradually in Japan, from simple distribution to more sophisticated control of water distributio

- 1st stage: Tree (dendritic) system for simple distribution
- 2nd stage: Network system to minimize the negative impact of accidents and ensure operational flexibility
- 3rd stage: Block system for

(1) optimizing water pressure

(2) clear picture of water supply operation

(3) identification of accidental damage and provision of backup water supply



7. Engineering Design and Master Plans

(1) Importance of Facility Standards

The most important concept for water supply is to secure the safe supply of water through well-designed water facilities. The design standards to define the function and capacity of water facilities are specified in *the Water Supply Act*.

Need to acquire design methods and accumulate technical knowledge

↓

Share know-how among senior engineers of major water utilities

Coordinated by Japan Water Works Association

↓

Build up the *Design Criteria for Water Supply Facilities*

↓

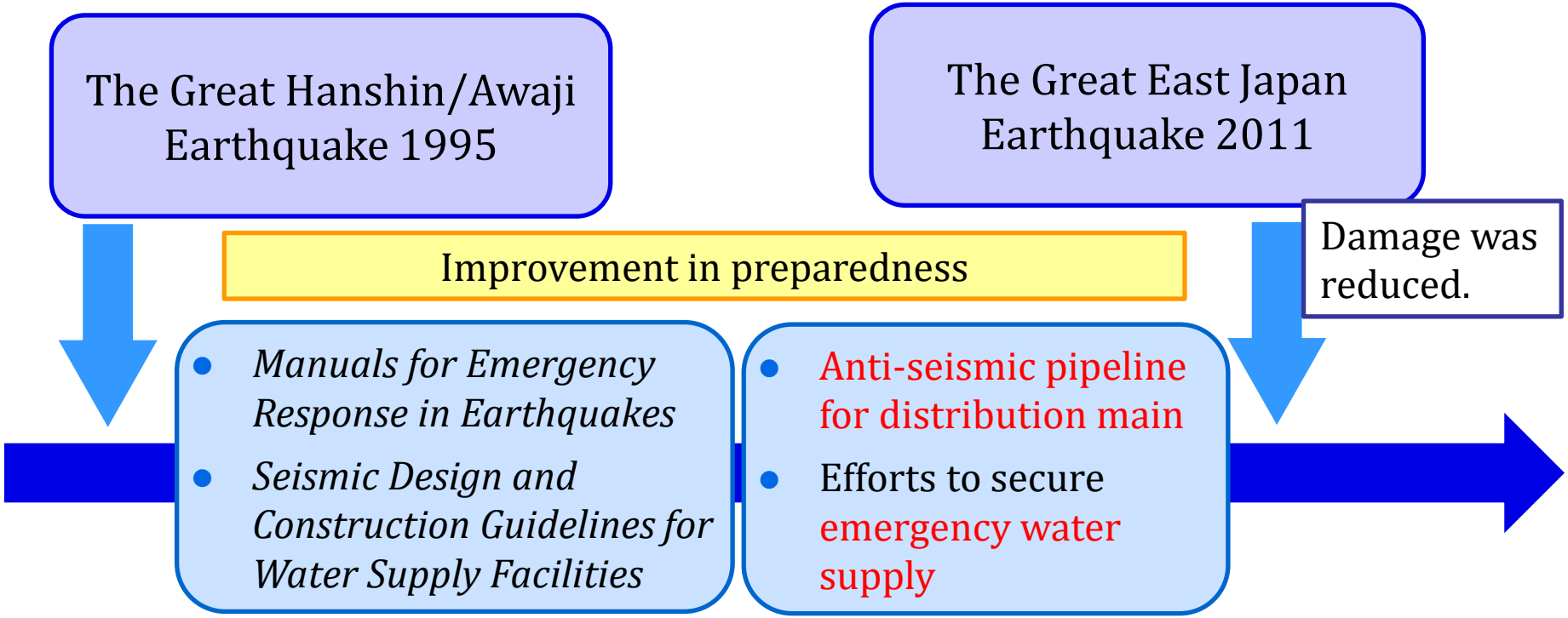
Update the *Design Criteria* on a regular basis

It has been complementing the design standards of *the* Water Supply Act.

7. Engineering Design and Master Plans

(2)Updating the Design Concepts

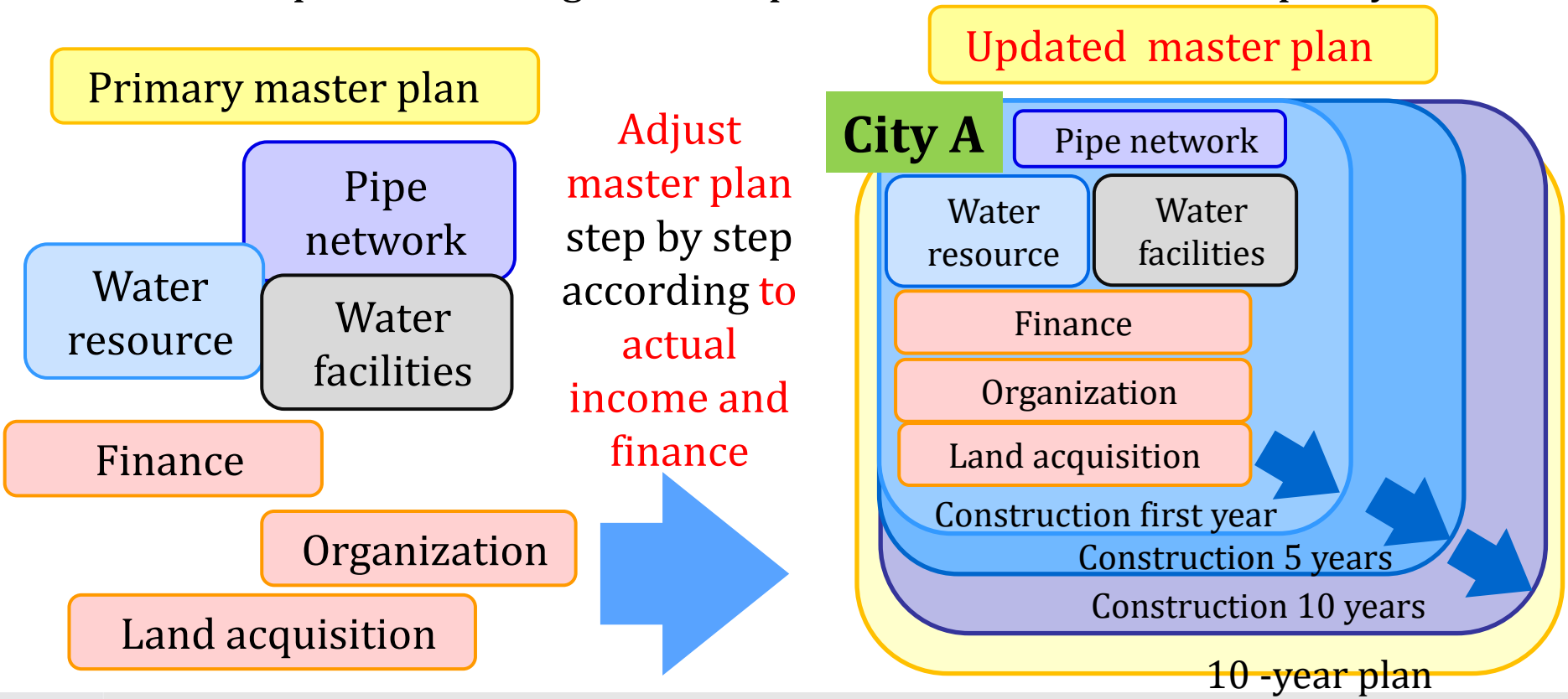
The design concepts for water supply facilities need to be improved, reflecting the situations of each country. For example, since Japan is an earthquake prone country, the design of water supply facilities has been improved gradually based on lessons learned from the damage of past earthquakes.



7. Engineering Design and Master Plans

(3) Step by Step Expansion

Water supply systems require large amounts of funding for construction, and therefore, must be expanded step by step, based on medium to long-term master plans including business plans with sound financial policy.



7. Engineering Design and Master Plans

(4) System to Validate Proper Operation and Management

Approval (License), stipulated in the Water Supply Act, requires a master plan. It was effective in the early stage of expansion when water utilities were not yet technically sophisticated.

- A master plan

  Prepared with technical assistance by prefectural governments and health centers.

As Japan has shifted from the expansion stage to the maintenance stage, Approval(License) is now supplemented by the following plans and systems:

- Waterworks Vision
- Water Safety Plan
- Asset Management

Annual business plan and budget to be approved by local councils

Application for License

- Demand prediction
- Facility plan
- Financial plan (Tariff setting)

Used for screening to obtain subsidy

8. Lessons Learned (1)

- **(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 were 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 tap 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 quality of the raw water and water demand. Many utilities use this method to treat large volume of polluted water especially in urban area, which usually located at downstream.

8. Lessons Learned (2)

- **(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 larger investment, it can produce high quality waters to win the 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 levels 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 for easy control of water distribution.

8. Lessons Learned (3)

- **(Block Distribution Systems)** 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 Plan)** 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 expanding water supply coverage.
- **(Approval(License) System)** The Water Supply Act stipulates the requirements for Approval(License), facility standards and qualification of technical administrators. These set the high standard for water supply quality and sound business management. The national government is encouraging the preparation of Water Vision and Water Safety Plan to ensure technical stability of utilities. Preparation of annual business plan, which includes budget plan based on the Local Public Enterprise Act, and the approval by the local assembly ensures sound business management.