THEME 7 GROUNDWATER MANAGEMENT:
SECURING ALTERNATIVE WATER SOURCES ALONG WITH REGULATIONS

ABSTRACT

Excessive groundwater extraction causes problems such as land subsidence, lowering of groundwater levels, and salinization. This results in additional issues such as damage to buildings, worsening flood inundation levels, and increased water intake. In Japan, land subsidence caused by excessive groundwater extraction worsened because of the increase in groundwater use for industrial purposes during the post-World War II reconstruction period and resulting high economic growth. Problems with groundwater pollution caused by factory wastewater infiltration have also emerged.

These difficulties can be solved by establishing a legal system to regulate groundwater extraction and secure alternative water sources. A monitoring system for land subsidence and groundwater contamination should also be established. A council of groundwater comprising stakeholders of the public and private sectors should be established to build a consensus on groundwater management policy, formulate a groundwater management plan, implement said plan, and monitor progress in groundwater conservation.

CHAPTER 1 INTRODUCTION

Excessive groundwater extraction causes problems such as land subsidence, abnormal lowering of groundwater levels and salinization. Once land subsidence and groundwater quality deterioration occur, it is difficult to reverse them. To ensure sustainable groundwater use, it is important to conserve groundwater by regulating its extraction and securing alternative water sources.

Continuous and excessive extraction of groundwater induces land subsidence, resulting in lower groundwater levels and salinization (Figure 1.1). Land subsidence is an irreversible phenomenon resulting from the consolidation of underground clay layers, which is caused by the drainage of the water contained within the layers. Underground infiltration of wastewater from factories pollutes the groundwater. Once these problems occur, the recovery process is long.

In Japan, land subsidence caused by excessive groundwater extraction has occurred for over a century. During post-World War II (WWII) reconstruction and the resulting period of high economic growth, the amount of groundwater extracted for industrial use increased, resulting in social issues. To mitigate groundwater problems, a legal system was established to conserve groundwater, and subsidence issues have slowed. This theme explains the various approaches to tackling land subsidence and groundwater pollution issues in Japan.

Source: Tokyo Metropolitan Government, Bureau of Environmental Website

Area below sea tide level near river mouth of Arakawa River (1981)

Source: JICA

Area below sea tide level surrounding Pluit pump station (Jakarta Indonesia)

Figure 1.1 Impact of Excessive Groundwater Extraction (Land Subsidence)

Water resources management is closely related to the Sustainable Development Goals (SDGs), and the relationships between groundwater management and the SDGs are shown in the following box.

Relationships between Groundwater Management and the SDGs:

(1) Supply safe water by managing the quantity and quality of groundwater.

SDG 3 "Healthy lives and well-being for all":

3.3 "End the epidemics of water-borne diseases," 3.9 "Substantially reduce the number of deaths and illnesses from water and soil pollution and contamination"

SDG 6 "Availability and sustainable management of water and sanitation for all:"

6.3 "Improve water quality by reducing pollution," 6.4 "Ensure sustainable withdrawals and supply of freshwater," 6.5 "Integrated Water Resources Management"

(2) Groundwater is conserved through public-private partnerships (PPPs)

SDG 17 "Global partnership for Sustainable Development:"

17.17 "Encourage and promote effective public, public-private, and civil society partnerships, building"

CHAPTER 2 GROUNDWATER USE

2.1 Current Status of Groundwater Use in Japan

As groundwater is a vital component of a healthy water cycle system, proper management must be implemented through regulations and monitoring.

(1) Groundwater in the Water Cycle

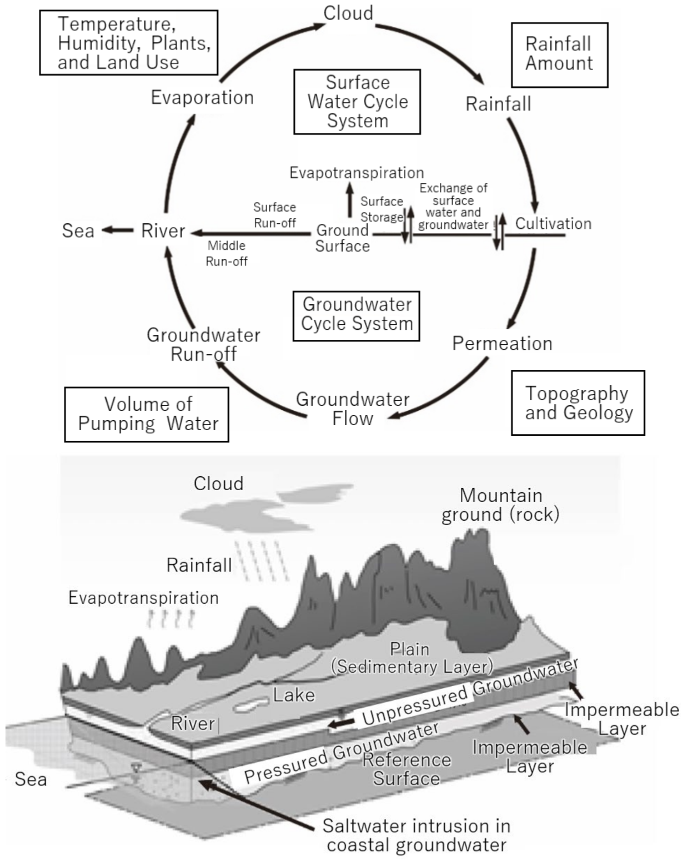
The source of groundwater is precipitation, and groundwater forms a water cycle with surface water. Direct runoff of precipitation into a river is divided into two routes: surface runoff directly flowing into a river and intermediate runoff via the shallow underground. Precipitation that does not flow directly into a river channel infiltrates underground. Groundwater flows extremely slowly compared to surface water. The global average detention time of groundwater is approximately 830 years (Table 2.1). After a long detention time, groundwater flows out to rivers and lakes as surface water.

The water cycle is influenced by atmospheric events and underground structures (Figure 2.1). Groundwater circulation is affected by geological and topographical conditions. The evaporation of surface water is affected by temperature, humidity, and vegetation. Human activities, such as groundwater extraction and land use, affect the water cycle.

Table 2.1 Water Storage and Detention Time on Earth

	Storage Capacity (km3)	Average Dwell Time
Seashore	134,929,000	3,200 years
Ice and Snow	24,230,000	9,600 years
Groundwater	10,100,000	830 years
Soil Moisture	25,000	0.3 years
Lake Water	219,000	a few to hundreds years
River Water	1,200	13 days
Water Vapor	13,000	10 days

Source: Toward the Conservation and Sound Use of Groundwater, Advisory Group on Future Groundwater Use, March 2007, MLIT

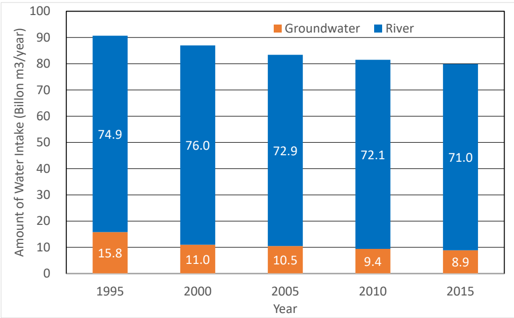


Source: Toward the Conservation and Sound Use of Groundwater, Advisory Group on Future Groundwater Use, March 2007, MLIT

Figure 2.1 Conceptual Diagram of the Water Cycle and Influential Factors

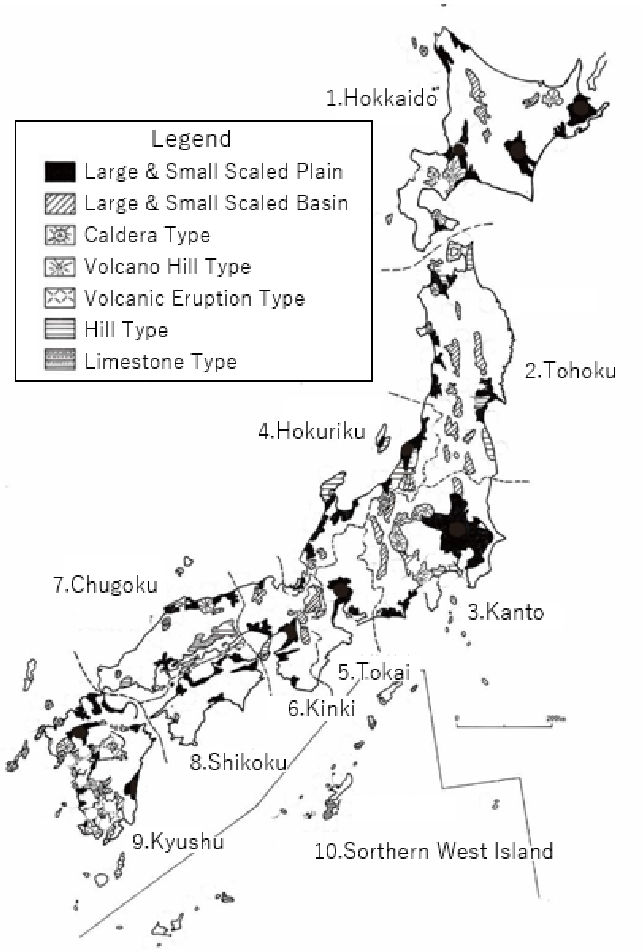
(2) Groundwater in Japan

Figure 2.2 shows the distribution of the groundwater basin formed by topography and geology in Japan. The basin can be classified into several types, including plains, basins, calderas, hills, and others. The annual amount of water used, including river water and groundwater, is shown in Figure 2.3. The total amount of water used has decreased annually. Specifically, the annual amount of groundwater use has decreased by 60% over the past 20 years.



Note: Agricultural Water–2005 data using 1995/10–1996/09 survey results, 2015 data using 2008 data.
Source: Japan's Water Resources, data from MLIT

Figure 2.3 Annual Water Use by Water Source in Japan



Source: Groundwater in Japan, Agricultural Groundwater Research Group (1986)

Figure 2.2 Groundwater Basin Types in Japan

2.2 Regulation and Measures of Groundwater Use by Legislation

Government organizations should establish legal systems to regulate groundwater extraction, secure alternative water sources and monitor groundwater extraction.

(1) Land Subsidence Problem

Groundwater was used as a common property of village communities in Japan until the Edo period (-1968). During the Meiji period (1868-1912), river water was mostly used for agricultural purposes and could not be used to meet new water demands. Urban water supplies increased with the modernization of Japanese society and depended on groundwater. Groundwater use was accelerated by digging deeper and larger wells via drilling mechanization. Governments did not regulate the use of groundwater by landowners. Since 1930, land subsidence

Source: National Ground Environment Information Directory, Ministry of the Environment

Figure 2.4 Subsidence of Bridges in Osaka City

of 15–17 cm per year has been observed locally in urban areas. This subsidence caused the tilting of buildings[1], road damage, settlements of bridge abutments that interrupted navigation in rivers (Figure 2.4), and aggravated flood damage. During the post-WWII reconstruction and resulting high economic growth period, the damages in Tokyo and Osaka caused by land subsidence and groundwater salinization were especially serious . Figure 2.5 shows examples of damage caused by land subsidence in the Tokyo urban area.

(2) Salinization

Salinization of groundwater is caused by seawater intrusion into an aquifer when the groundwater level is lowered below sea level owing to excessive water extraction. Since 1960, salinization issues have occurred in many places in coastal areas; one such example is Fuji City, Shizuoka Prefecture, where a paper industry was developed. The area's salinized groundwater is unsuitable for drinking and industrial water use. Salt damage to crops has also been observed.

The groundwater level must be maintained above the sea water level to prevent salinization through 1) restricting the amount of groundwater extraction, 2) facilitating artificial recharge of groundwater, 3) limiting the groundwater restriction zone to a coastal area and allowing saltwater intrusion in a limited zone, or 4) building impermeable walls to prevent saltwater intrusion.

(3) Legal Regulations against Land Subsidence

The Industrial Water Act of 1956 and the Act on Regulation of Groundwater Extraction for Buildings (the Building Water Act) of 1962 were enacted to restrict groundwater extraction rates. The Industrial Water Act intended to provide a stable supply of industrial water, but did not directly address the problem of groundwater extraction. In addition, it did not restrict groundwater use for purposes other than industrial water. The Building Water Act regulated the extraction of groundwater for water use only in buildings.

Rising of a Building in Urayasu City, Chiba Prefecture | **Rising of a Well Pipe in Katsushika Ward, Tokyo** | **Uneven Ground in Tokorozawa City, Saitama Prefecture**

Source: National Ground Environment Information Directory, Ministry of the Environment

Figure 2.5 Damage by Land Subsidence in Tokyo Urban Area

[1] Phenomena where bases of structures and buildings on the ground rise above the ground level due to lowering of ground level by excessive extraction of ground water, or liquefaction caused by earthquakes.

The ordinances of local governments were more effective in restricting groundwater extraction than national laws. In the 1970s, local governments established ordinances to regulate pollution prevention as well as groundwater extraction in areas that national acts could not cover. The ordinances covered groundwater extraction without limiting the purpose of water use, whereas the Industrial Water Act covered only industrial water use. The ordinances also did not require the alternative development of water sources besides groundwater.

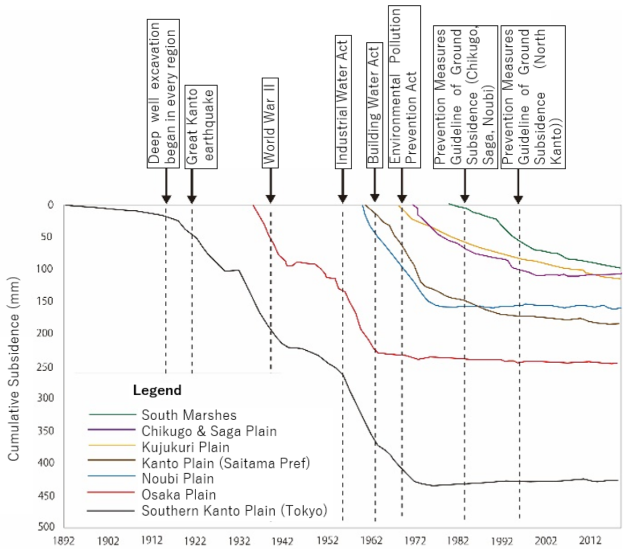
The Basic Environment Act, enacted in 1993, promotes comprehensive conservation measures for both groundwater quality and quantity. The Basic Act on the Water Cycle enacted in 2014 and the Basic Plan on the Water Cycle formulated in 2015 promotes "sustainable groundwater use and conservation " (Theme 1-1: Legislation and Organization, Section 2.6).

(4) Changing Water Sources for Industrial Water

As groundwater extraction for industrial water use was regulated by the Industrial Water Act through restricting the use of existing wells, the conversion of water sources from groundwater to surface water was also promoted. When local governments developed industrial water supply systems, industrial entities were instructed to abolish their wells. Subsidies by the national government were provided to avoid cost increases caused by the conversion of water sources. As the cost of groundwater extraction by industrial entities was 1–3 yen/m^3 , the tariff of industrial water use provided by local governments was set at 3.5 yen/m^3. In 2001, this tariff increased to 24.4 yen/m^3; however, it was still one-eighth of the unit cost of water supply of local governments (Theme 2-1: Management Planning).

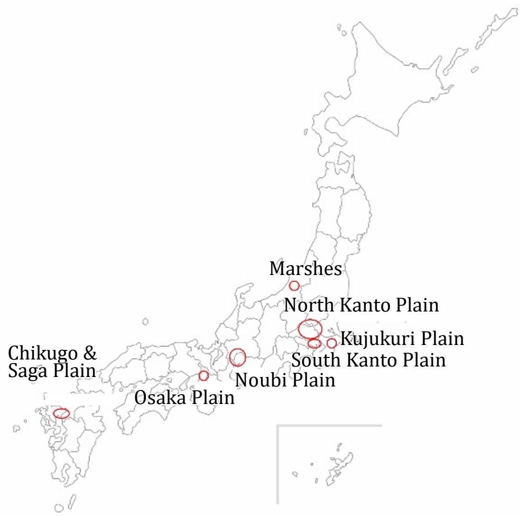
(5) Land Subsidence

As a result of the restriction of groundwater extraction by acts and ordinances, the amount of groundwater extraction decreased nationwide. The groundwater level recovered, and serious land subsidence was mitigated (Figures 2.6, 2.7). In 2019, although five locations showed land subsidence of more than 2 cm per year, the number and area of overall land subsidence incidents decreased.



Source: Overview of Land Subsidence in Japan in 2019, Ministry of the Environment, Water and Air Environment Bureau (2019 March)

Figure 2.6 Land Subsidence at Typical Points



Source: created by Project Team

Figure 2.7 Location Map

(6) Regulation by Tokyo Metropolitan Government

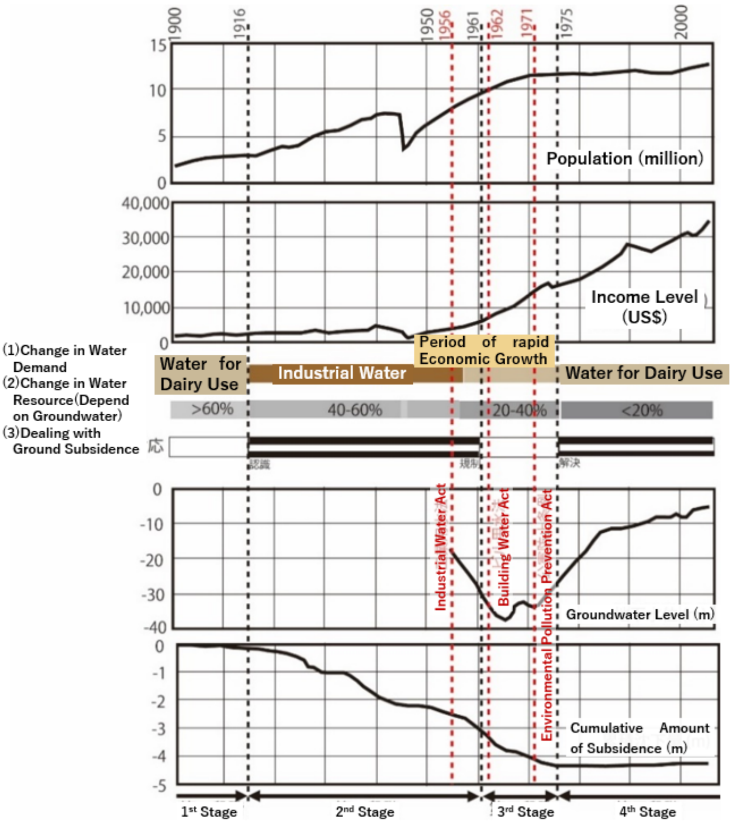
Figure 2.8 presents the relationship between social and economic development, the groundwater level, and land subsidence in the Tokyo metropolitan area. The history of regulations is summarized below.

1) Stage 1 (1900-1916): Water use depended on groundwater by more than 60%, but land subsidence was not substantial.

2) Stage 2 (1916-1960): Land subsidence became substantial. No effective measures were implemented.

3) Stage 3 (1961-1974): Enacted regulations regarding groundwater extraction gradually recovered the groundwater level.

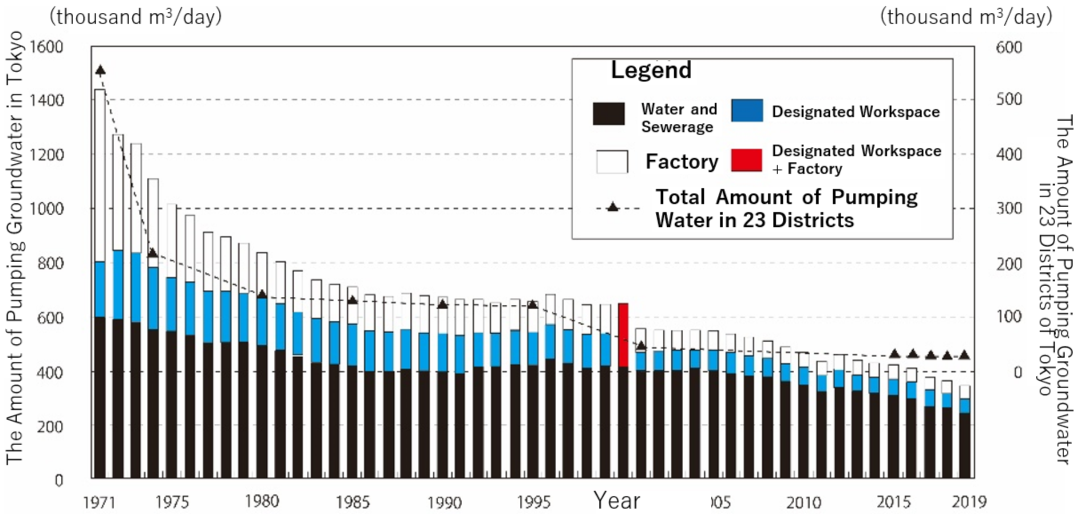
4) Stage 4 (1975–): The groundwater level continued to recover and land subsidence ceased.



Source: Urbanization and Land Subsidence in the Case of Tokyo: A Stage-by-Stage Approach Using Long-term Indicators, Tomoyo Toyoda & Shinji Kaneko, National Institutes for the Humanities, Institute for Global Environmental Studies

Figure 2.8 History of Land Subsidence in Tokyo

Land subsidence in Tokyo slowed because of the regulations of the Metropolitan Government based on the national laws. The regulation based on the Industrial Water Act covered eight wards, and that based on the Building Water Act covered twenty-three wards. The Pollution Prevention Ordinance of 1971, which covered almost the entire area of Tokyo, strictly restricted groundwater extraction rates and converted water sources using surface water. The ordnance requested industrial water users to rationalize their water use, including increasing recycled water usage (Figure 2.9). The amount of groundwater extracted, the groundwater level, and land subsidence were monitored. Recently, uplift pressure on facilities caused by the recovery of the groundwater level has also been highlighted. An uplift pressure acting on the bottom faces of structures that is larger than the pressure assumed by the structure design may cause a structure to float upward.

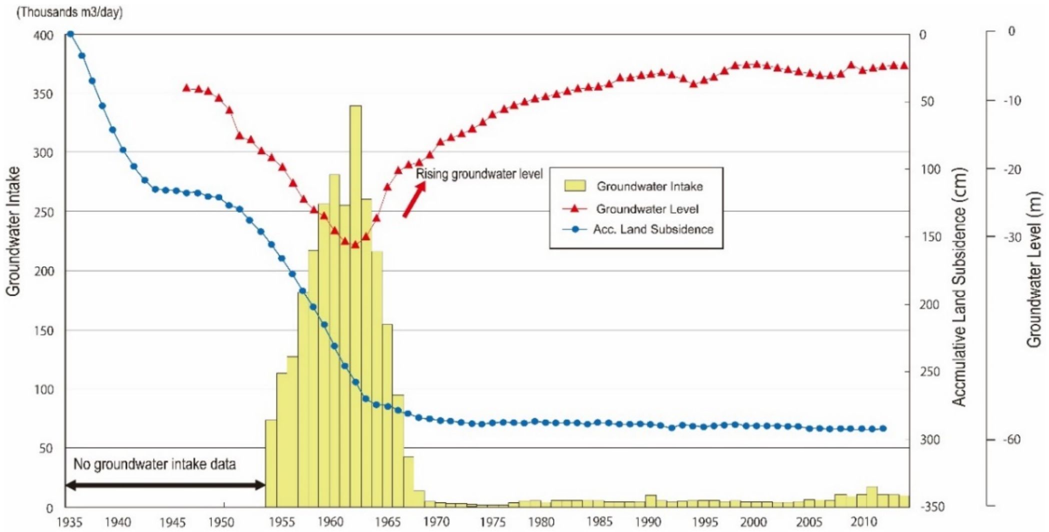


Note: Values from 1972 to 2000 denote the extraction volumes of wells subject to pollution control ordinance regulations (discharge c/a of 21 cm^2 or more) plus the estimated extraction volumes of wells of less than 21 cm^2
Source: Actual Conditions of Groundwater Extraction in Tokyo in 1989, Tokyo Metropolitan Government (March 2021)

Figure 2.9 Trends in Groundwater Extraction of 23 Wards in Tokyo

(7) Regulation in Osaka City

Similar to Tokyo, groundwater extraction rates in Osaka have been regulated and monitored. The Osaka city government allows extractions from layers only below–500-600 m. This makes groundwater use difficult (Figure 2.10).

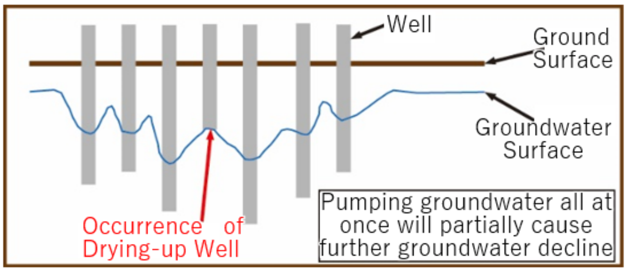


Note: Data on Groundwater Sampling - Port Observatory until 1965, Port Observation II since 1966
Source: "Report on the effective use of groundwater in consideration of the ground environment in the Osaka City area", Study Council on the Effective Use of Groundwater in Consideration of the Ground Environment in Osaka City Area (1991 February)

Figure 2.10 Groundwater Use and Land Subsidence in Osaka City

(8) Measures to counteract Drying of Wells in Snowfall Areas

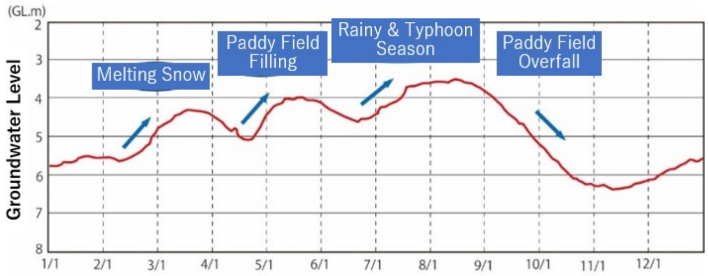
In snowfall areas, groundwater is often used to remove snow from roads to ensure traffic safety. Sometimes, wells dry because of the use of groundwater in the snowy season.



Source: Groundwater and Springs – Revitalization of Spring Water Culture, Ono City, Fukui Prefecture

Figure 2.11 Dried-up Well due in Snow Season

Substantial groundwater consumption for removing snow from December to February causes the drying of wells (Figure 2.11, Figure 2.12). Accordingly, in Ono City, Fukui Prefecture, around a thousand wells dried from 1975 to 1984 during the winter. Some wells were re-bored. Approximately 60% of households and business offices in the city have wells 5 to 10 m deep, and approximately 36% have wells deeper than 10 m. Once a low groundwater level is observed at the monitoring well, a warning is issued to request water saving (Figure 2.13).



Average groundwater level for Ono City from 2002 to 2011.
Source: Groundwater and Spring Water in "Echizen Ono, the Hometown of Yui" ~Revitalization of Spring Water Culture~ Ono City, Fukui Prefecture

Figure 2.12 Seasonal Changes in Groundwater Levels (Kasuga Park Observation Well)

Source: Ono City, Fukui Prefecture

Figure 2.13 Kasuga Park Observation Well

2.3 Groundwater Monitoring

> In groundwater management, long-term monitoring of land subsidence and groundwater extraction by groundwater users is necessary to ensure effective regulation.

Groundwater monitoring includes the amount of water extracted, groundwater level, land subsidence, and water quality. This section explains the monitoring of groundwater extraction, whereas Section 3.2 explains the monitoring of groundwater quality. A registration system was introduced to prevent an abnormal lowering of the groundwater level, a depletion of groundwater, and land subsidence resulting from excessive groundwater extraction. The system requires the registration of pump facility users so that the supervising organization can monitor groundwater extraction and groundwater levels.

(1) Reporting Water Extraction

The ordinances by local governments require groundwater users to record their extraction volume and report it to the governors.

(2) Monitoring Land Subsidence

The guidelines of the Ministry of Environment (MOE) specify monitoring and survey items, which are useful in analyzing the mechanism of land subsidence and assisting in determining preventive measures.

1) Monitoring Items

(a) **Ground Level:** Long-term monitoring of ground levels at the same points is important in obtaining key information for predicting land subsidence. Detailed monitoring of a wide area is required, especially in areas with substantial ongoing land subsidence. The standard frequency of observations is once per year. The observation dates are fixed annually. Seasonal observations are required in areas where seasonal land subsidence has occurred.

(b) **Groundwater Level:** Continuous observations using an automatic water-level recorder are required. If continuous observations are not feasible, a monthly observation is accepted. The observation points must cover the area of ongoing land subsidence, area of future potential land subsidence in the future, and area where land subsidence is not allowed.

(c) **Land Subsidence:** Observation wells must be installed to monitor the settlement of each geological layer. The monitoring area must cover a wide area to fully detail the regional features of the land subsidence. The geological distribution of clay layers must be considered. Automatic monitoring equipment is used to ensure continuous measurements.

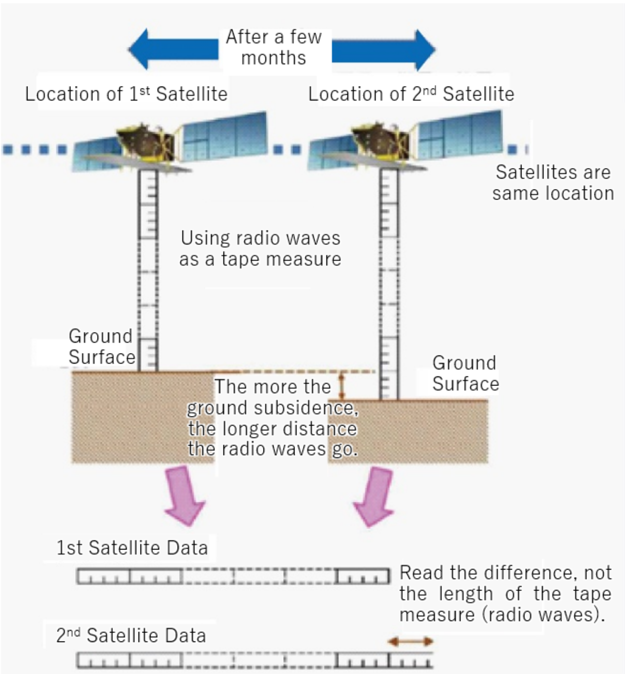
2) Survey Items

(a) **Geology:** Borehole surveys and soil tests are conducted in the land subsidence area to determine the geological strata that cause subsidence.

(b) **Amount of water extraction:** Survey amount of groundwater extraction for each prescribed purpose (industry, domestic use, irrigation, building, hot spring) through records of water users or questionnaires to users. The depth and geological layers of groundwater extraction are surveyed.

(3) Monitoring by Satellite Data

Monitoring land subsidence through leveling surveys requires considerable cost, effort, and time. The utilization of satellite data is expected to enable more efficient observations. The MOE published the "Manual for Utilization of



Source: Manual for the Use of Satellite Observation for Land Subsidence, Ministry of the Environment

Figure 2.14 Land Subsidence Monitoring by SAR Satellite

Satellites in Land Subsidence Observation" (in March 2017) using the satellite data of the Advanced Land Observing Satellite-2 "Daichi-2" (ALOS-2) to provide an easier monitoring system for local governments (Figure 2.14).

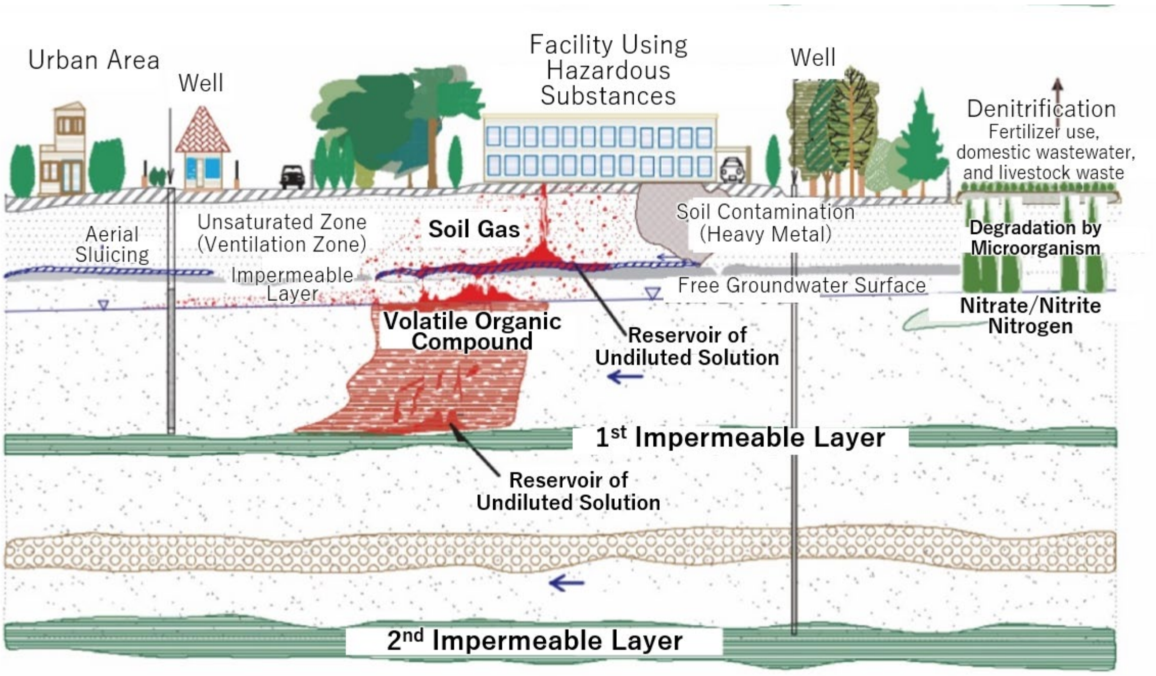
CHAPTER 3 WATER QUALITY MANAGEMENT

> Once groundwater is contaminated, restoring water quality is difficult. Preventive measures against groundwater contamination and for spreading the contamination to decrease pollutant potency are the most important.

In Japan, the standards for environmental conservation include both the surface water as well as the groundwater. Local governments established regulations regarding the monitoring of groundwater quality and the process of remedial measures needed to improve the water quality.

3.1 Groundwater Contamination Mechanism

Monitoring and early warning measures are important in preventing contamination from pollutants infiltrating underground , including volatile organic compounds (VOCs), harmful heavy metals, and nitrate-nitrogen. Measures differ according to the pollutant. Because VOCs as well as nitrate- and nitrite-nitrogen are difficult to decompose and are not easily adsorbed in the soil, contamination is likely to spread into wider areas through the groundwater flow. VOCs may accumulate in soil in undiluted conditions and sometimes infiltrate deeper underground areas according to the geological conditions. Because heavy metals are generally easily adsorbed in soil, contamination is unlikely to spread deeper underground. Figure 3.1 illustrates an image of groundwater contamination, and Table 3.1 explains the nature and cause of the pollutants.



Source: To Clean Up Groundwater, Ministry of the Environment (2004)

Figure 3.1 Depiction of Groundwater Contamination

Table 3.1 Nature, Causes and Characteristics of Pollutants

Pollutant	VOC	Heavy Metals	Nitrate and Nitrite Nitrogen
Nature	High volatility, low viscosity, heavier than water, difficult to decompose underground. Permeates through soil and easily moves into groundwater. (Benzene is lighter than water and more easily decomposes than other VOCs.)	Slightly soluble in water, but not easily conveyed because it is easily adsorbed in soil. (Some heavy metals are soluble in water and are conveyed easily.)	Not easily adsorbed in soil and easily transferred to groundwater. Produced when ammonia nitrogen is oxidized by microorganisms in soil.
Causes	Improper handling or leakage in solvent use or treatment processes. Inappropriate disposal in a landfill or waste solvents.	Leakage from storage or manufacturing processes, underground seepage of wastewater, improper disposal of waste in a landfill, natural origin	Excessive fertilizer, improper disposal of livestock waste, or underground infiltration of domestic wastewater.
Characteristics	Easily infiltrates the ground and spreads to deeper underground areas. Exists in soil in a liquid or gas form.	Not easy to move in soil, exists locally and does not spread to a wide area. Only those from a natural origin may exceed groundwater standards.	Wide source area such as farmland.

Source: To clean up Groundwater, Ministry of the Environment (2004)

3.2 Monitoring of Groundwater Quality

The Water Pollution Prevention Act stipulates continuous monitoring of groundwater. The national and local governments must prepare and implement monitoring plans every year. The results are disclosed on the websites of local governments or in annual reports on the environment (for example, the Environmental White Paper). When the measured values exceed the environmental standards, advice for users who may use contaminated groundwater for drinking must be announced immediately, and an area survey surrounding the contaminated wells is performed. A system and organization for immediate action are established. Three environmental standards have been established.

- Groundwater environmental standards (decided by the Basic Environment Act): standards must be formulated to protect human health (standards for preventing health damage to human beings).
- Groundwater purification standard (the Water Pollution Prevention Act): Targets must be achieved using measures for water purification (the standard of harmful substances for business entities to take measures for groundwater contamination that may impact human health)
- Underground infiltration standard (the Water Pollution Prevention Act): This standard prohibits the infiltration of harmful substances underground by business activities. The standard does not allow water contamination of more than 1/10th of the environmental standard or the lower detection limit of the test methods.

The survey methods comprise (1) a survey for general conditions, (2) an area survey surrounding contaminated wells, and (3) a monitoring survey as follows:

(1) Survey of General Conditions: A survey is conducted to determine the overall groundwater quality in the region. An annual survey plan is established according to the situation of the region. The survey is conducted by a fixed-point survey, a rolling survey, or both. The fixed-point survey intensively observes all observation items to detect groundwater contamination or observes a quality trend of groundwater quality at that point. A rolling survey is conducted sequentially at the mesh grids of a target area to detect local groundwater contamination. In general, a single fixed-point survey may not detect groundwater contamination.

(2) Area Survey surrounding Contaminated Wells: This survey delineates the contaminated area and identifies the cause of the newly detected contamination.

(3) Monitoring: The survey continuously monitors the contaminated area as flollows:

1) The area affected the most by contamination and the area downstream of the contamination source are included in the survey.

2) Installing observation wells is the most effective monitoring method.

3) The monitoring points are flexibly changed according to the contaminated area and the change in the underground flow.

CHAPTER 4 COMPREHENSIVE GROUNDWATER CONSERVATION

> To ensure sustainable conservation and use of groundwater, management according to the regional conditions is required. Establishing a council of stakeholders comprising local government and water users is effective.

The demand for groundwater resources is likely to increase in Japan. People require safe and high-quality water, a stable water supply despite climate change, the sustainable preservation of the lives of residents, and temporary water use after natural disasters until restoration of the water supply system.

Groundwater is a key water resource and component of the water cycle system. To properly use and conserve groundwater, optimal groundwater management based on observed data accumulation and investigations of the actual groundwater use situation are required to understand the diverse groundwater use and availability in the region. The stakeholders who use groundwater and are related to the issue of groundwater conservation are required to participate.

A "groundwater council" comprising various stakeholders, including local governments and interested parties, is effective in facilitating flexible groundwater management according to a population's diverse sense of values. The management policy must be updated in response to regional conditions to maintain a common understanding in the entire region. A groundwater management plan must be formulated based on this policy. Monitoring was conducted in accordance with the plan. The management policy may contain "ordinary groundwater use," "utilization for local revitalization," "preventive measures for risk," and "solutions for groundwater contamination". Efforts to conserve groundwater in the Kumamoto area are described below.

Groundwater Conservation Efforts in the Kumamoto Area

Approximately one million people live in Kumamoto City and the surrounding eleven municipalities, where almost 100% of the water source is groundwater. This is a unique area in Japan. (Figure 4.1). Groundwater management is addressed through a collaboration among local governments, private sector, local residents, universities, and research institutions. The "Kumamoto Groundwater Foundation," established in 2012, seeks to provide efficient, effective, and attractive measures for groundwater management through a scientific approach based on existing research (Figure 4.2).

Source: Kumamoto City Website

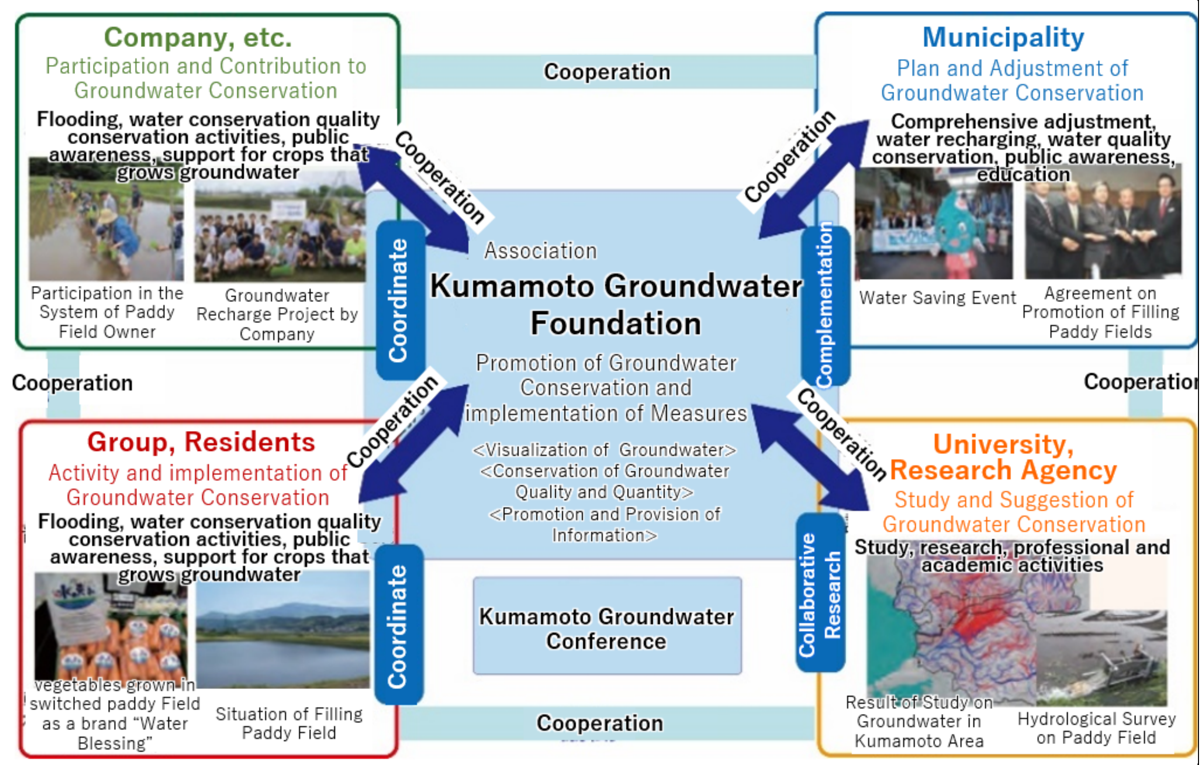
Figure 4.1 Kumamoto Area Sharing a Groundwater

Groundwater pollution by nitrate nitrogen has become an important issue in recent years. Nitrate nitrogen concentrations have increased mainly owing to the inappropriate disposal of fertilizers and livestock waste.

A simulation model was developed to predict nitrate nitrogen concentrations and support to implement projects of reducing nitrate nitrogen concentrations for each municipality. The projects include monitoring polluted soil and guidance to farmers to reduce the use of fertilizer.

The governments address conservation of the paddy fields, which are sources of groundwater, through subsidies. Companies and other local organizations also participate as owners of paddy fields to ensure groundwater conservation. They also maintain watershed protection of the local forest to ensure conservation of a healthy water cycle.

Together with promoting groundwater conservation activities such as disseminating information and education programs, the Kumamoto Groundwater Foundation provides subsidies to install equipment for measuring discharge and valves to water users to control groundwater extraction rates.



Source: Case Studies of Watershed Management, Water Cycle Production Headquarters Cabinet Secretary

Figure 4.2 Activities of the Kumamoto Groundwater Foundation

CHAPTER 5 LESSONS LEARNED

(1) **Excessive extraction of groundwater lowers the groundwater level, which may induce land damage, structural damage, aggravated flood damage, and saltwater intrusion.** Groundwater is a key component of a healthy water cycle. Land subsidence is an irreversible phenomenon resulting from the consolidation of underground clay layers owing to the drainage of water contained in the clay layers.. Excessive extraction of groundwater has caused land subsidence in major cities, including Osaka and Tokyo, at rates of over 20 cm per year and a total subsidence of more than 5 m. Coastal areas have experienced salinization in groundwater, which has precluded its usage for drinking and industrial purposes, and has caused salt damage to crops.

(2) **Regulation of groundwater extraction and the development of alternative water sources are necessary for groundwater conservation.** In Japan, acts and ordinances have been established by the national and local governments to regulate groundwater use. Governments developed industrial water supply systems that use surface water as an alternative source. Their acts and ordinances stipulate the criteria for groundwater use permits. Groundwater users have been registered and are required to record and report the amount of groundwater extracted. Local governments continuously monitor the groundwater situation and land subsidence.

(3) **Proper groundwater quality management is required to prevent the infiltration of hazardous substances into groundwater.** Once groundwater is contaminated and the contamination spreads, restoration of groundwater quality is difficult. Therefore, early monitoring and measures are necessary. Management systems require environmental standards for groundwater quality, annual monitoring plans, and a system that enables prompt responses to emergency situations.

(4) **To ensure sustainable conservation and usage of groundwater, a council of stakeholders should be established according to regional conditions.** Kumamoto City formulated mechanisms of groundwater management in collaboration with local governments, the private sector, residents, universities, and research institutions. Their management is supported by scientific evidence developed with universities and institutions in Kumamoto.