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Special Feature on Groundwater Management and Policy

Land Subsidence and Groundwater Management in Tokyo

Chikafusa Sato,[a] Michiko Haga,[b] and Jiro Nishino[c]

A huge volume of groundwater was being pumped out for factories and to serve a growing population when ground subsidence was first detected in Tokyo in the years after 1910. Over the ensuing decades the water table dropped, falling to as low as 58 meters below sea level in 1965. The volume pumped out continued to grow until 1970, when it peaked at close to 1.5 million cubic meters per day (m^3/d). The depth of subsidence increased over the decades and the area affected continued to expand. At some places the ground surface was dropping over 10 centimeters per year (cm/yr), peaking at about 24 cm/yr in 1968. Meanwhile, the Tokyo Metropolitan Government (TMG) introduced pumping regulations for the thousands of wells in the region in order to slow and reverse the pace of land subsidence. Pumpage declined and the rate of subsidence slowed dramatically. The water table began to rise again in the early 1970s and is now at 6–10 meters (m) below sea level. Even in the areas that were most affected, the rate of subsidence has slowed to about 1 cm/yr in the past five years. Up to 550,000 m^3 of groundwater was still being pumped up daily for public water supply and other uses in 2003. With over 80 percent of the ground surface in the wards of Tokyo covered by buildings and pavement, and farmland area in the Tama region shrinking, however, only a fraction of rainwater percolates into the soil to recharge groundwater. It is therefore important to increase the infiltration of rainwater by conserving green areas and farmland. To this end, the government has issued guidelines and requested that parties who install pumping facilities also include rainwater infiltration facilities. It also requires building owners to submit plans that contain environmental considerations and include the use of reclaimed wastewater or rainwater infiltration, and encourages residents to use water more efficiently. As of the end of March 2003, the TMG's waterworks system in the Tama area was operating up to 290 wells, most of them at a depth of 100–350 m, and treating the groundwater at 50 water purification plants, each using a varying combination of chlorination, iron and manganese removal, aeration, and microfiltration membranes to treat groundwater in some wells that has been contaminated with various pollutants, such as cryptosporidium, nitrate nitrogen, nitrite nitrogen, hexavalent chromium, cis-1,2-dichloroethylene, and 1,4-dioxane, among others.

Keywords: Tokyo, Land subsidence, Groundwater, Pumping regulations, Purification treatment.

1. Groundwater in Tokyo today

Topographically, Tokyo consists of an eastern plain facing Tokyo Bay, along with a more hilly and mountainous area in the western part of the city. The topsoil consists of highly permeable red soil, which has given the area abundant groundwater resources. In the 1960s, however, factories and other facilities began pumping up enormous volumes of groundwater. The water table fell and dramatic

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[a] Director, Training and Technical Development Center, Bureau of Waterworks, Tokyo Metropolitan Government, Tokyo, Japan.

[b] Director, Water Environment Section, Natural Environment Division, Bureau of Environment, Tokyo Metropolitan Government, Tokyo, Japan.

[c] Head, Water Quality Division, Engineering Department, Japan Water Works Association, Japan.

ground subsidence began to occur. In response, new laws and local ordinances were created to regulate pumping. Subsidence is now slowing, and in some places the groundwater level is actually rising. With ongoing urbanization, however, artesian water—which once just bubbled out of the ground as spring water and fed ponds and even small and mid-size rivers—has been exhausted. The waterfront environment has deteriorated as a result. At the same time, groundwater in some places is contaminated with organochlorine compounds, nitrate nitrogen, and nitrite nitrogen.

2. Ground subsidence and regulations on pumping groundwater

2.1. History of ground subsidence

Ground subsidence began in Tokyo after 1910, chiefly in Koto-ku, as factories and other facilities pumped up substantial volumes of groundwater. The phenomenon intensified during the period of economic rehabilitation after the Second World War and the subsequent period of rapid economic growth, and subsidence at sea level or lower—known as the "zero-meter zone"—continued to grow. This increased the risk of flooding and caused structures to float up and destroy underground pipes. In response, the Tokyo Metropolitan Government (TMG) undertook a massive project to raise riverbanks and repair floodgates. For example, the anti-subsidence measures implemented in the Koto delta area—which consists of parts of Koto-ku, Sumida-ku, and Edogawa-ku, between the Sumidagawa and Arakawa rivers—cost the public sector 8.4 billion yen at fiscal 1972 prices. Even today the TMG continues to make massive investments to secure the safety of the region. Starting from the 1950s, pumping regulations were introduced pursuant to the Industrial Water Law, applying to eight wards,[1] and to the Law Concerning the Regulation of Pumping-Up of Groundwater for Use in Buildings, applying in the 23 wards of Tokyo. These regulations encouraged more rational use of groundwater. In addition, the TMG acquired the mining rights in the Koto area and stopped the extraction of natural gas. As a consequence, the significant rate of subsidence in the eastern lowlands area has gradually slowed since the early 1970s and gradually diminished in the Tama region since the late 1970s.

2.2. Reducing subsidence

Subsidence arises mainly from an extensive contraction of soft strata in the ground, such as the clay layer, following a fall in the underwater level that arises from the pumping of groundwater in large quantities. Worse, it is almost impossible to restore the ground level once subsidence has taken place. Figure 1 is a diagram of the cumulative sinking of ground at major benchmarks, illustrating the subsidence trend in Tokyo.

Subsidence began in the Koto area some time after 1910 and in Edogawa-ku and Adachi-ku in the 1920s. This topographical phenomenon gradually intensified. Later, in the 1940s, it showed a temporary slowdown at the final stage of the Second World War, but the subsidence resumed as production activities recovered. The depth of subsidence increased and the area affected continued to grow each year. At some places it reached and even exceeded 10 centimeters per year (cm/yr). In 1968, a

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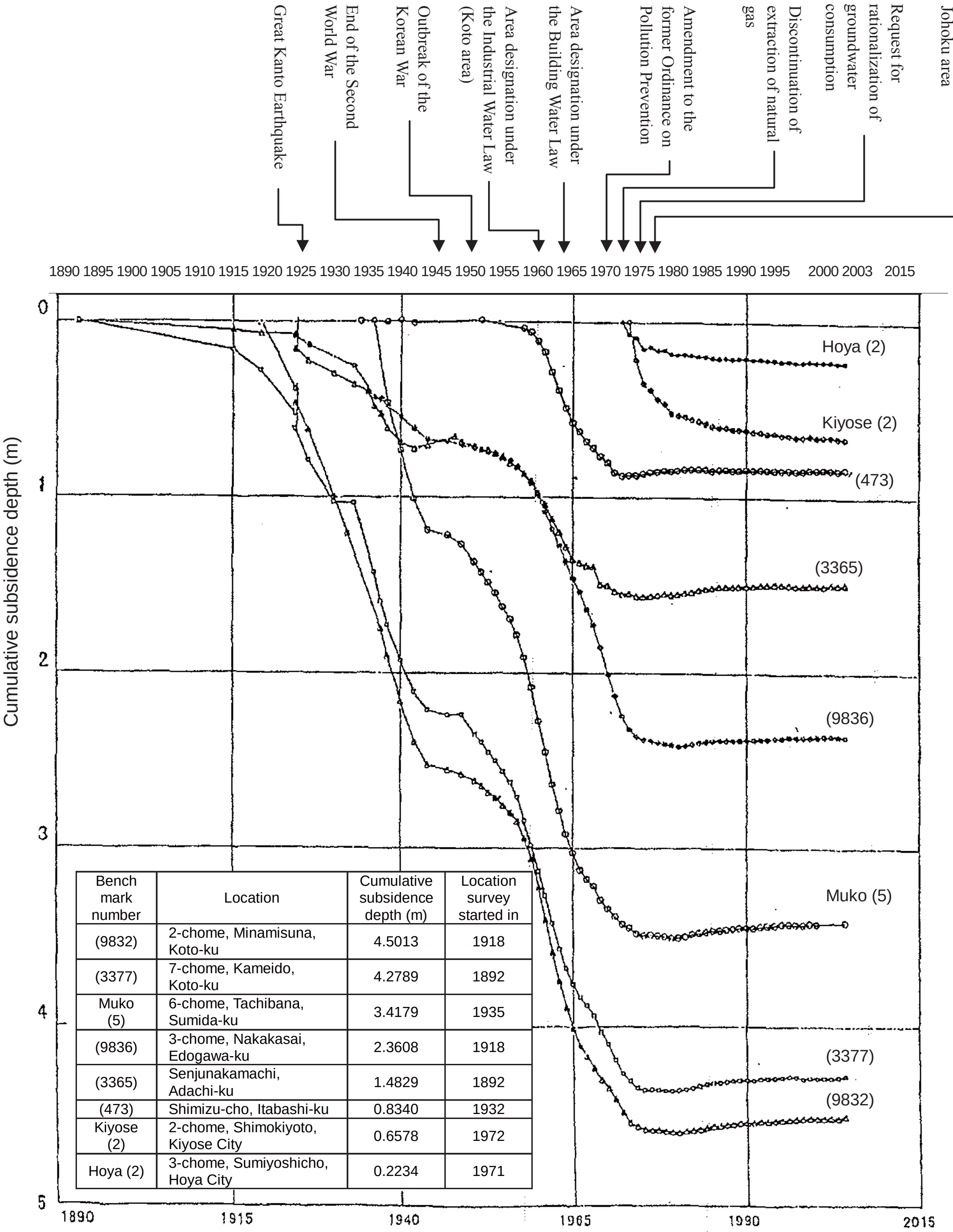
[1] A *ku* (ward) is a district in a large Japanese city.

maximum annual subsidence depth of 23.89 cm/yr was measured in Edogawa-ku in the lowlands district. In the high plains district, the city of Kiyose saw a peak annual subsidence depth of 21.65 cm/yr.



Bench mark number	Location	Cumulative subsidence depth (m)	Location survey started in
(9832)	2-chome, Minamisuna, Koto-ku	4.5013	1918
(3377)	7-chome, Kameido, Koto-ku	4.2789	1892
Muko (5)	6-chome, Tachibana, Sumida-ku	3.4179	1935
(9836)	3-chome, Nakakasai, Edogawa-ku	2.3608	1918
(3365)	Senjunakamachi, Adachi-ku	1.4829	1892
(473)	Shimizu-cho, Itabashi-ku	0.8340	1932
Kiyose (2)	2-chome, Shimokiyoto, Kiyose City	0.6578	1972
Hoya (2)	3-chome, Sumiyoshicho, Hoya City	0.2234	1971

Figure 1. Cumulative subsidence depths at major benchmarks, 1890–2003

Source: Tokyo Metropolitan Research Institute for Civil Engineering Technology 2004.

Following this, the TMG introduced measures to control further land subsidence. Groundwater pumpage was reduced from peak levels of 967,000 cubic meters a day (m^3/d) in 1964 in the 23 wards and 882,000 m^3/d in 1973 in the Tama area, dramatically slowing the rate of land subsidence. It has gradually eased, to the extent that no site in the Tama area has experienced a rate of subsidence greater than 5 cm/yr since 1976 in lowland areas and 1979 in highland areas.

In the last five-year period, there was subsidence of 6 cm or more per year in an area in southern Edogawa-ku and subsidence of 2 cm/yr or more in only four places, namely, the boundary between Nerima-ku and Itabashi-ku, Ota-ku, and the two cities of Kiyose and Higashi Murayama. Excluding these locations, there is no place with a subsidence of 2 cm/yr or more. In some places, elevation of the ground surface continues to be monitored, but it appears that subsidence has stabilized. Even in the area that has seen the most subsidence, the extent has only been about 1 cm/yr in the past five years.

Ground subsidence is closely linked with the confined underground water level. As an example, figure 2 shows the annual trend in the groundwater level in Koto-ku and Sumida-ku where there is a significant rate of subsidence. The level fell from 20–30 meters (m) below ground in 1954 to 37–58 m in 1965. After the introduction of pumping regulations, the level began to rise in the early 1970s and it is now at 6–10 meters below ground level, resulting in the recent slowdown in land subsidence.

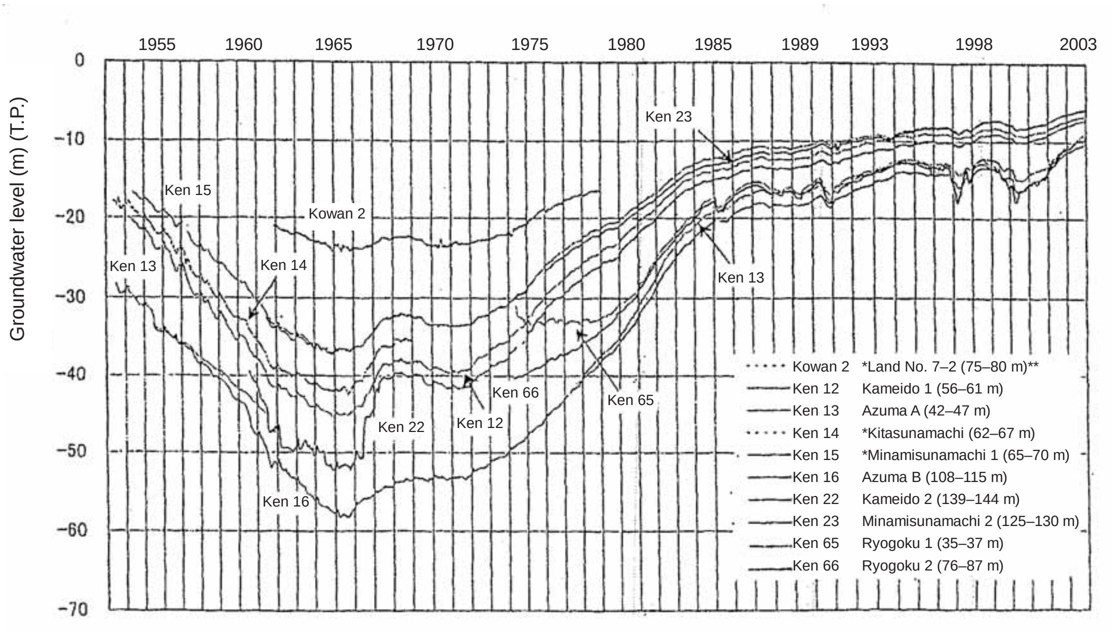


Figure 2. Variation in groundwater level in wells in Koto-ku and Sumida-ku

Source: Tokyo Metropolitan Research Institute for Civil Engineering Technology 2004.

Note: The water level of a well installed in the confined aquifer is higher than the upper surface of the aquifer in the stratum because the well water is pressurized.

*Single asterisk indicates former site of a well.

**Figures in parentheses represent strainer depths.

2.3. Pumping regulations

Introduced as a measure to counter ground subsidence, restrictions on the pumping of groundwater are primarily aimed at the structural design of pumping facilities. These restrictions are implemented in accordance with the Industrial Water Law, the Law Concerning the Regulation of Pumping-Up of Groundwater for Use in Buildings (Building Water Law), and the Tokyo Metropolitan Ordinance Concerning the Environment for Ensuring People's Health and Safety (Environmental Preservation Ordinance). Among other things, the laws ban both new and existing wells that fail to meet certain requirements in the cross-section area of the outlet and in the strainer depth in the zone where the regulations apply, whereas the ordinance only forbids the installation of any such well. Existing wells subject to regulatory controls have all been replaced by industrial water supply service or other facilities.

As pump performance improved in recent years, a growing number of small pumping facilities became exempt from the laws or ordinance on pumping groundwater. To respond to this growing gap, the TMG tightened the regulations under the new Environmental Preservation Ordinance, introduced in April 2004. Specifically, small-scale pumping facilities must now comply with the regulations, and the scope of application was enlarged in terms of the purposes and location. All facilities using a pump with an output of over 300 watts are now obliged to report their pumpage volume once a year. Table 1 outlines the pumping regulations currently in effect.

Table 1. Summary of pumping regulations

Statute	Target facilities	Scale of facility	Controlled items	Target areas
Environmental Preservation Ordinance	Pumping facilities excluding those designated by the Tokyo Metropolitan Governor pursuant to the Industrial Water Law, the Building Water Law, the Hot Spring Law, and the Waterworks Law, or in view of public benefit in case of emergency	Pumping facilities equipped with a pump exceeding the output of 300 watts	Pump output, pumpage, and strainer position varying depending on the cross-section area of the outlet	23 wards, 26 cities, Mizuho-machi, and Hinode-machi
Industrial Water Law	Pumping facilities for manufacturing, electric power supply, gas supply, and heat supply services	Pumping facilities equipped with a pump with the outlet with a cross-section area of 6 square centimeters (cm^2) or more	Strainer position	8 wards, namely, Katsushika-ku, Adachi-ku, Edogawa-ku, Sumida-ku, Koto-ku, Kita-ku, Arakawa-ku, and Itabashi-ku
Building Water Law	Pumping facilities for air conditioning facilities, toilets, car wash facilities, and public baths with a bathroom floor area exceeding 150 square meters	Pumping facilities equipped with a pump with the outlet with a cross-section area of 6 cm^2 or more	Strainer position	23 wards

3. Groundwater quality and pollution

3.1. History of groundwater pollution

Shallow groundwater has long been widely used in Tokyo, a practice that subsequently resulted in groundwater contamination with bacteria and coliform bacteria because of inappropriate equipment maintenance and control of human waste and septic tanks. Ammonium-nitrogen contained in effluent or resulting from excessive fertilization of farmland is transformed into nitrous acid and nitric acid by microorganisms in the soil, which then infiltrates deeper into the ground. Some groundwater has consequently been found to be polluted with nitrate nitrogen and nitrite nitrogen.

In the wake of discovering trichloroethylene contamination in a well used as a source of tap water in the Tama region in 1982, a groundwater survey confirmed that the groundwater was polluted with organochlorine compounds.

3.2. Current state of groundwater pollution

To monitor groundwater, the TMG prepares a water quality measurement plan each year, pursuant to the Water Pollution Prevention Law, and conducts water quality surveys. Table 2 indicates the degree to which environmental standards were met in different surveys conducted in fiscal years 2002 and 2003.

An investigation in fiscal 2003 revealed that among the 26 items environmental standards for the protection of human health were not being met for lead, hexavalent chromium, cis-1,2-dichloroethylene, nitrate nitrogen, and nitrite nitrogen at eight sites out of the 71 surveyed.

Regular monitoring has shown that 69 of 139 survey sites failed to comply with environmental standards in seven items, including lead. A comparison between the regular monitoring survey results in fiscal 2002 and those in fiscal 2003 shows that the number of sites failing in trichloroethylene and in tetrachloroethylene fell from 19 to 15 and from 43 to 33, respectively, while the number of sites failing in nitrate nitrogen and nitrite nitrogen grew from 16 to 18.

The survey results shown in tables 3 and 4 suggest that the environmental standards are still not being met for organochlorine compounds, nitrate nitrogen, and nitrite nitrogen.

Table 2. Surveys of water quality compared to environmental standards (%)

Survey	Items	Achievement of environmental standards	
		Fiscal 2002	Fiscal 2003
Status investigation: for understanding the status of groundwater quality for the entire metropolis. Survey sites vary year by year.	26 items, including cadmium, total cyanide, and lead	87% (62/71)* Substances exceeding standards: - lead (2)** - tetrachloroethylene (1) - nitrate nitrogen and nitrite nitrogen (6)	89% (63/71) Substances exceeding standards: - lead (2) - hexavalent chromium (1) - cis-1,2-dichloroethylene (1) - nitrate nitrogen and nitrite nitrogen (4)

Table 2. —*continued*

Survey	Items	Achievement of environmental standards	
		Fiscal 2002	Fiscal 2003
Investigation of the area surrounding a polluted well: for identifying the area of pollution where pollution was found by the status investigation	Items in which standards were not met in the overall investigation	80% (51/64) Substances exceeding standards: - lead (4) - nitrate nitrogen and nitrite nitrogen (10)	81% (39/48) Substances exceeding standards: - hexavalent chromium (1) - cis-1,2-dichloroethylene (1) - nitrate nitrogen and nitrite nitrogen (7)
Regular monitoring: regularly conducted to continuously monitor the contamination confirmed in the investigation of the surrounding area of polluted wells	Items in which the standards were not met in the past	38% (48/126) Substances exceeding standards: - arsenic (1) - carbon tetrachloride (2) - 1,1-dichloroethylene (2) - cis-1,2-dichloroethylene (5) - trichloroethylene (19) - tetrachloroethylene (43) - nitrate nitrogen and nitrite nitrogen (16)	50% (70/139) Substances exceeding standards: - lead (2) - arsenic (1) - carbon tetrachloride (2) - cis-1,2-dichloroethylene (3) - trichloroethylene (15) - tetrachloroethylene (33) - nitrate nitrogen and nitrite nitrogen (18)

Source: TMG press materials on the results of measurement of public waters and groundwater in fiscal 2003 (August 27, 2004).

* Numerators in parentheses are the number of sites that meet the standards for all measurement items; denominators are the number of sites surveyed. Note that some sites failed to meet multiple standards.

**Figures in parentheses after substance names indicate the number of sites where the standard was exceeded.

Table 3. Results of a study of groundwater quality

Fiscal year	Number of sites surveyed	Number of failed sites	Failure items
1998	87	3 (3%)*	Tetrachloroethylene
1999	88	10 (11%)	Lead, arsenic, tetrachloroethylene, nitrate nitrogen, and nitrite nitrogen**
2000	86	9 (10%)	Arsenic, tetrachloroethylene, nitrate nitrogen, and nitrite nitrogen
2001	87	11 (13%)	Lead, tetrachloroethylene, nitrate nitrogen, and nitrite nitrogen
2002	71	9 (13%)	Lead, tetrachloroethylene, nitrate nitrogen, and nitrite nitrogen
2003	71	8 (11%)	Lead, hexavalent chromium, cis-1,2-dichloroethylene, nitrate nitrogen, and nitrite nitrogen
Total	490	50	

Source: TMG Bureau of Environment 2004a.

* Values in parentheses represent the ratio of the failed sites to the total number of sites surveyed.

**Nitrate nitrogen and nitrite nitrogen were added to the environmental standard in fiscal 1999.

Groundwater flows in the soil so slowly that it is sometimes difficult to identify the source of pollution or to achieve purification. Once it is polluted, it takes a very long time to be restored in many cases. As groundwater is used for potable water in some parts of Tokyo, it is important to purify polluted groundwater in order to prevent any new contamination.

Table 4. Annual trend in the number of failed sites for monitored contaminants, 1994–2003

Fiscal year	Number of sites surveyed	Number of failed sites	Number of failed sites by measurement item								
			Lead	Arsenic	Carbon tetrachloride	1,1-dichloroethylene	Cis-1,2-dichloroethylene	1,1,1-trichloroethane	Trichloroethylene	Tetrachloroethylene	Nitrate nitrogen and nitrite nitrogen
1994	110	39	—	—	—	—	—	0	15	25	—
1995	126	59	—	—	1	1	8	1	26	36	—
1996	126	54	—	1	1	3	7	1	18	36	—
1997	126	71	2	0	2	2	8	0	25	47	—
1998	119	56	2	2	2	2	5	0	18	36	—
1999	118	65	0	2	2	4	7	0	23	37	—
2000	119	71	3	1	2	1	7	0	24	41	4
2001	124	71	0	0	1	1	4	0	19	43	9
2002	126	78	0	1	2	2	5	0	19	43	16
2003	139	69	1	1	2	0	3	0	15	33	18

Source: TMG Bureau of Environment 2004a.

Note: Based on regular monitoring survey results.

4. Groundwater use and balance by recharge

4.1. Uses of groundwater

Although restrictions on the use of groundwater in Tokyo have been tightened to inhibit ground subsidence, a volume of up to 550,000 m^3 of groundwater is still pumped up daily to support the population. Surprisingly, few people are aware of this fact.

a. Trends in groundwater pumpage

Groundwater has limited temperature fluctuations and is generally of good quality. It can be used as is, and the pumping cost, including the cost of digging a well, is low. For these reasons, it is used for both municipal and industrial water supply. In the 23 wards, pumpage was 870,000 m^3/d in 1961. It peaked at 967,000 m^3/d in 1964 and has been declining since. This trend is mirrored in the Tama area, where pumpage in 1961 was 201,000 m^3/d and increased annually to 882,000 m^3/d in 1973 until a similar decline occurred.

Figure 3 shows the pumpage trend in Tokyo since 1970, when approximately 1.5 Mm^3 of groundwater was pumped up, a figure that has since fallen to around 550,000 m^3, although the rate of decline has been slowing in recent years.

The decline in pumpage in the wards is mainly a reflection of the effect of pumping regulations, whereas the decline in the Tama area is due to a combination of pumping regulations pursuant to ordinances, guidance on the more rational use of groundwater, and a shift of the source of waterworks from groundwater to surface water.

A breakdown of pumpage reduction by type of establishment reveals that the drop has been remarkable in “factories and designated workshops” yet limited in “waterworks,” a sector that is not subject to regulations, and therefore the volume of groundwater withdrawals has not gone down.

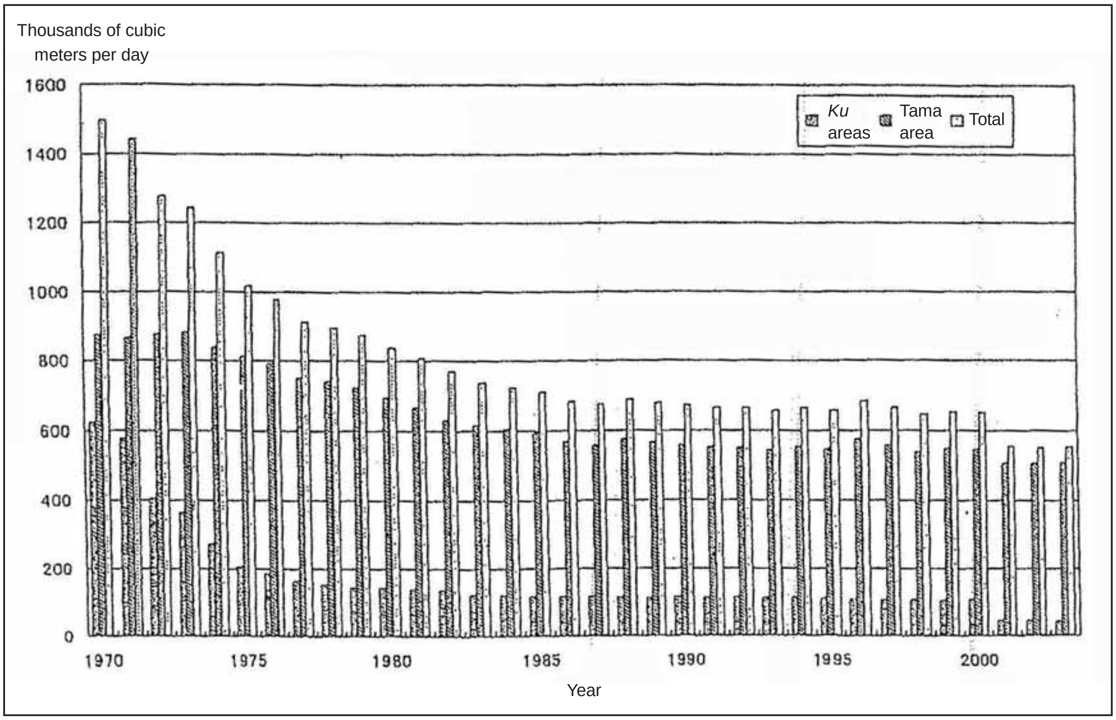


Figure 3. Trends in the volume of groundwater pumpage in Tokyo, 1970–2003

Source: TMG Bureau for Environment 2004b.

b. Use of groundwater

In 2003, there were 1,763 wells in the wards and 1,794 in the Tama area. Daily groundwater pumpage reached 45,000 m^3/d in the wards and 508,000 m^3/d in the Tama area, making a total of 553,000 m^3/d of groundwater pumped up for all of Tokyo.

Figure 4 illustrates the distribution of pumpage by type of establishment, which shows that 70 percent of groundwater pumped up is used for waterworks. Most of the districts using groundwater for tap water are in the Tama area.

As a comparison of groundwater consumption by type of establishment, waterworks pump 403,000 m^3/d, while factories, etc., pump 76,000 m^3/d, and designated workshops pump 74,000 m^3/d.

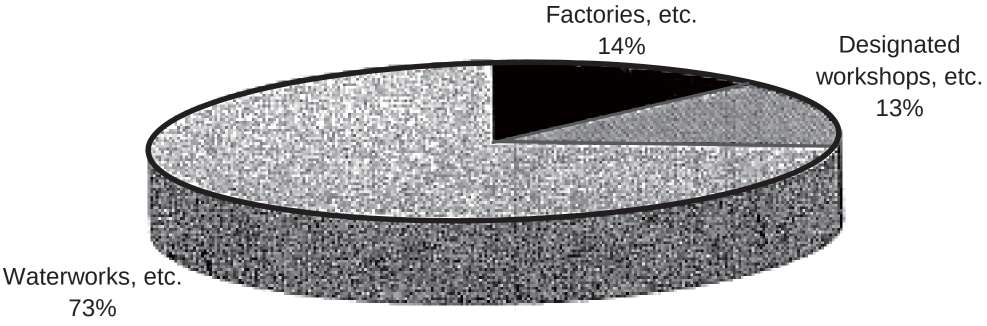


Figure 4. Share of groundwater pumpage by sector, fiscal 2003

Source: TMG Bureau for Environment 2004b.

4.2. Balancing groundwater use and recharge

When the land surface is undeveloped and in a natural state, a considerable portion of rainwater penetrates the soil. Part of it gushes out as spring water while the rest percolates down further.

Figure 5 shows the results of groundwater balance surveys conducted in Tokyo from 1994 to 1996. The amount of rainfall and other factors that help recharge groundwater were estimated and compared with pumpage and other factors that reduce the volume of groundwater. The surveys confirmed that there has been some surplus recharge in recent years, and that pumping and recharge are now nearly in equilibrium.

The municipality-by-municipality comparison in figure 6 shows that some municipalities in the midstream area of the Tamagawa River lose more groundwater from pumping than the volume recharged by rainwater.

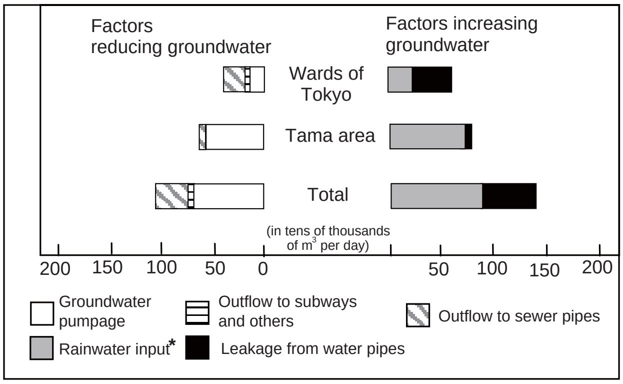


Figure 5. Groundwater pumpage and recharge in Tokyo, 1994–1996

Source: TMG 1998.

Note: The Tama area does not include Hinode-machi, ex-Itsukaichi-machi, Okutama-machi, or Hinohara-mura.

*Precipitation: 1,405 millimeters per year.

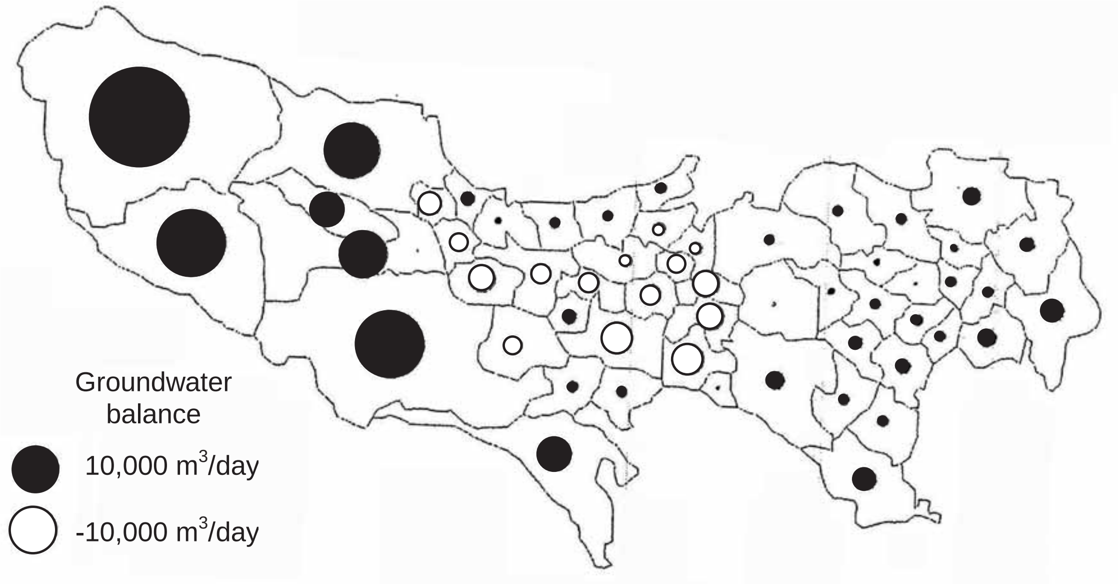


Figure 6. Groundwater recharge and pumpage in Tokyo, by municipality

Source: TMG 1998.

4.3. Boosting groundwater recharge

The groundwater level depends not only on pumpage but also on the permeation of rainwater into the soil. Figure 7 shows that over 80 percent of the ground surface in the wards of Tokyo is covered by buildings and paved roads and that the area of farmland in the Tama region is shrinking, which makes it almost impossible for rainwater to percolate into the soil. As a result, a growing percentage simply flows through rivers and sewerage systems when it rains and less rain infiltrates into the soil. To promote groundwater recharge, it is therefore important to increase the infiltration of rainwater into the ground by conserving green areas and farmland.

For this purpose, the TMG established guidelines on rainwater permeation, in accordance with Article 141 of the Environmental Preservation Ordinance, and requested installers of groundwater pumping facilities to install rainwater infiltration facilities at the same time, including an infiltration pit, to ensure the same amount of water as the volume pumped is permeated back through the soil. The TMG also encourages residents in Tokyo to take measures to promote rainwater infiltration into the ground.

In addition, the TMG set up a system that requires building owners to submit plans on environmental considerations and plans on the use of reclaimed wastewater or rainwater infiltration. Moreover, guidelines have been prepared to encourage more efficient water use. The metropolitan government also plans to expand the use of water-permeable pavement, encourage public facilities to introduce rainwater infiltration, and proceed with rainwater infiltration measures within the frameworks of the general flood control program and urban development project.

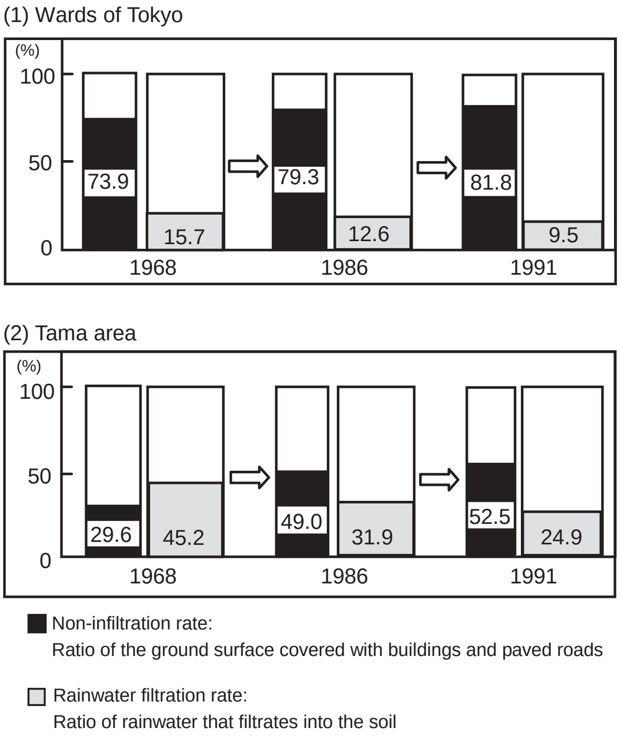


Figure 7. Ratios of ground cover preventing or enabling rainwater infiltration in Tokyo wards and the Tama area

Source: TMG 1998.

Note: The Tama area does not include Hinode-machi, ex-Itsukaichi-machi, Okutama-machi, or Hinohara-mura.

Infiltration of rainwater into the soil to recharge groundwater in urban areas not only leads to an increase in available groundwater, it also serves to restore the natural water cycle in the city, increases the dry-weather flow volume in rivers that originate from springs, reduces the amount of rainwater and wastewater that flows into rivers and the sewer system in rainy weather, and prevents flooding and the overflow of urban sewage.

In order to create a more sustainable urban environment, it is vital to step up efforts to encourage rainwater infiltration during urban development and to raise public awareness of groundwater in order to build support for conservation.

5. Use of groundwater for tap water

5.1. Overview of groundwater use by the TMG Bureau of Waterworks

The Bureau of Waterworks of the Tokyo Metropolitan Government (TMG Bureau of Waterworks) runs the waterworks service in the 23 wards and in the Tama area, which consists of 25 municipalities. It covers 55.9 percent of the total area of Tokyo and serves 96.7 percent of its population. In fiscal 2003, it supplied an average of 4.41 Mm^3/d of water to approximately 12 million people—a huge scale of operation. Tokyo's tap water mainly comes from surface water from the Tonegawa, Arakawa, and Tamagawa river systems, but the TMG Bureau of Waterworks also pumped 280,000 m^3/d of groundwater on average in fiscal 2003 to meet demand.

The TMG's water supply service started with the inauguration of the Yodobashi Water Purification Plant in 1898. At first, its service coverage area was limited to today's 23 wards. In 1970, the bureau started to integrate the water supply services in the Tama area, then run by local municipalities. Many had been launched with groundwater as their water source. Most of the underground water sources used by the TMG Bureau of Waterworks are deep wells (confined groundwater) and shallow wells (unconfined groundwater) in the Tama region (figures 8 and 9).

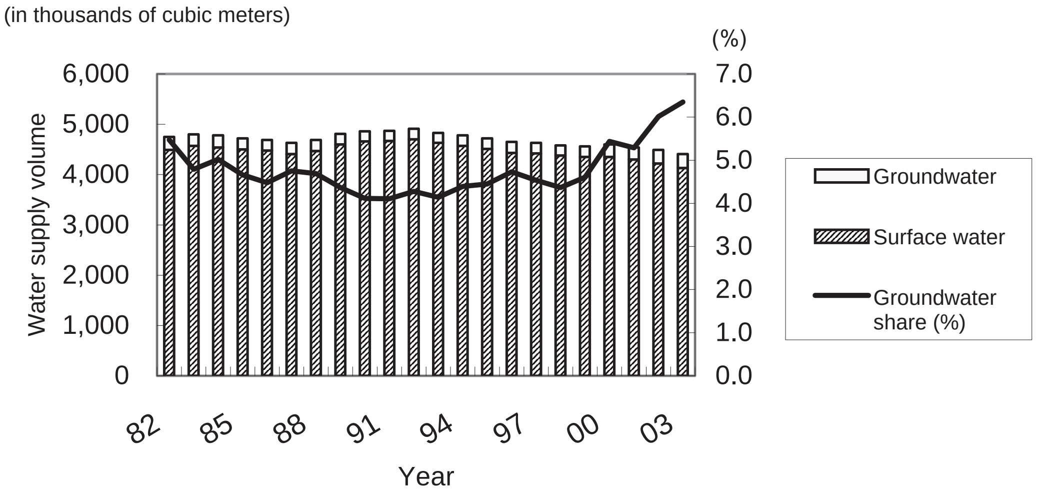


Figure 8. Groundwater share of total water stocks of TMG Bureau of Waterworks, 1982–2003

Note: Daily average supply volume.

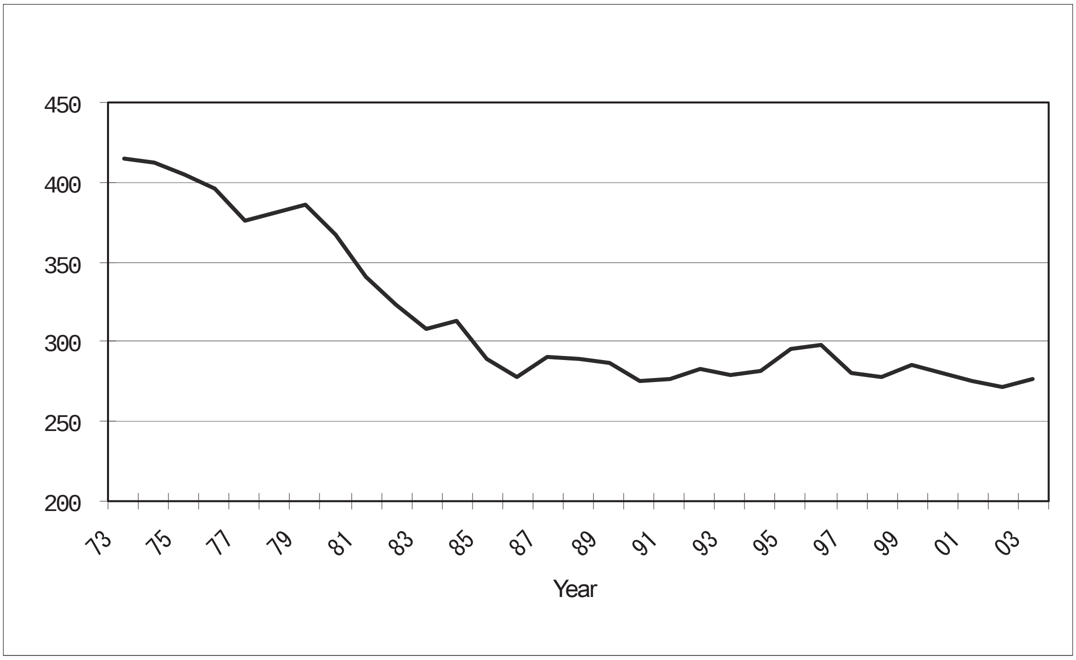


Figure 9. Trend in groundwater pumpage by the TMG Bureau of Waterworks, 1973–2003

As of the end of March 2003, the TMG's waterworks system in the Tama area was operating 290 wells for water supply (table 5). Their combined capacity is approximately 380,000 m^3/d, but 30 wells are out of service (nine due to poor water quality, 15 due to falling water levels, five for the prevention of subsidence, and one on account of renovations). The remaining 260 wells in operation supply some 350,000 m^3/d of groundwater.

Table 5. Overview of facilities using groundwater in the Tama area, 2003

	Total number of wells	Facility capacity (in thousands of cubic meters)	Number of wells in operation	Number of wells out of operation
Deep wells	280	341,600	253	27
Shallow wells	10	40,600	7	3
Total	290	382,200	260	30

In order to conserve groundwater for use in the future, it is necessary to take into account the aspects of groundwater pollution and the decline in groundwater level from a long-term perspective. Given that groundwater is a precious water source easily accessible in the event of drought, earthquakes, and other disasters, the primary goal should be to maintain, conserve, and protect the resource, using it only at a sustainable rate.

5.2. Management of wells used as water sources

Most of the wells for the TMG-run water supply services in the Tama district are deep. The well casing thickness is 30 cm and the depth is within the range of 100–350 m. A typical well facility has a submersible pump and a lifting pipe in a casing (which has three to six strainers) for taking in groundwater. It is equipped with an electric unit for powering the submersible pump, a control unit, and a flow meter.

For the purpose of water quality control, every well is subject to testing every three years in rotation. Raw water in individual water purification plants where well water is stored undergoes a monthly water quality test. Water is tested more frequently in wells not in operation, for better groundwater monitoring.

5.3. Overview of groundwater quality

Groundwater is not overly susceptible to climate or weather conditions. It has limited year-round seasonal fluctuations in temperature, for example. The groundwater in the Tama area is cloudy, low in organic concentration, and the quality is consistently good.

In some wells, however, the water contains a relatively high concentration of iron and manganese, and equipment has been installed to remove these substances, while the operation of any wells contaminated with trichloroethylene, tetrachloroethylene, or other organic solvent has been suspended, although some have resumed operations after aerators were installed. Table 6 details the quality of water measured in various wells.

Table 6. Groundwater quality of typical wells used as water sources (2003 average)

	Bacteria	Coliform bacteria	Nitrogen in ammonia state	Nitrate nitrogen and nitrite nitrogen	Tetrachloroethylene	Trichloroethylene	Iron	Manganese	Potassium permanganate consumption	pH	Turbidity	Electric conductivity
Unit*	Count per ml		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		NTU	µS/cm
Normal deep wells	0.1	0/12	0.00	0.82	0.0000	0.0000	0.00	0.000	0.6	7.9	0.0	169
Normal shallow wells	4.9	10/12	0.00	1.7	0.0000	0.0000	0.00	0.000	0.7	7.3	0.0	140
Wells with high concentration of nitrogen in ammonia state	0.0	(-)	0.26	0.00	n/a	n/a	0.20	0.14	0.3	7.7	0.0	228
Wells with high concentration of nitrate nitrogen	0.0	(-)	0.00	7.3	n/a	n/a	0.00	0.002	0.3	8.2	0.0	398
Wells with high concentration of iron	0.0	(-)	0.12	0.05	n/a	n/a	1.4	0.12	1.4	7.3	0.0	178
Well with high concentration of manganese	3.0	(-)	0.04	0.00	n/a	n/a	0.26	0.18	0.9	7.8	0.0	153
Well with high concentration of tri-chloroethylene	0.0	(-)	0.00	2.3	0.0002	0.066	0.00	0.001	0.9	7.4	0.0	227

*mL = milliliter; mg/L = milligram per liter; NTU = nephelometric unit; µS/cm = microSeimens per centimeter.

5.4. Past cases of water quality problems

The TMG treats groundwater at 50 water purification plants distributed around the region, each using a varying combination of chlorination, iron and manganese removal, aeration, and microfiltration (MF) membranes (table 7). Then it is distributed directly as tap water or mixed with water from other purification plants that treat surface water from rivers.

Table 7. Water purification plants by method

Water purification treatment method	Number of plants
Chlorination only	23
Iron and manganese removal	18
Aeration	7
MF membranes	1
High speed filtration	1
Total	50

The following sections explain purification treatment methods and specific cases of contamination.

a. The fight against cryptosporidium parvum (from chlorination to MF membranes)

As discussed above, the overall quality of groundwater is good, and in the past well water was only treated by chlorination. Membrane treatment was started in the wake of an outbreak of diarrhea caused by cryptosporidium parvum in the tap water in Ogose-machi in 1996. With the guidance of the national government, water purification plants at risk of contamination of raw water introduced MF membrane treatment, a purification method that can remove cryptosporidium parvum. Other factors considered included the quality of water after treatment, economic efficiency, and operational requirements.

In 2003, the fecal coliform group was detected in seven shallow wells (indicating contamination with cryptosporidium parvum). Three of them were taken out of operation, while two now use MF membrane treatment (figure 10 and table 8) and two use high-speed infiltration.

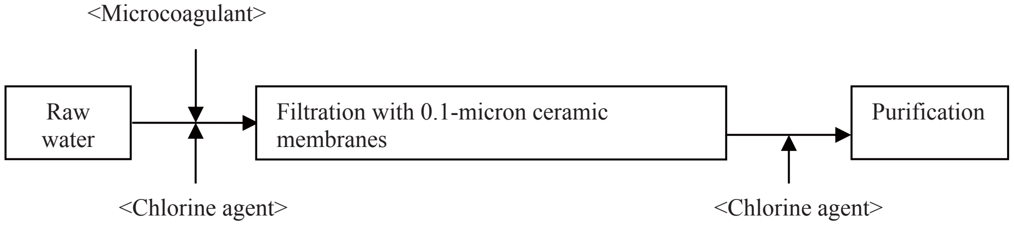


Figure 10. Process flow in the water purification plant using MF membrane infiltration

Table 8. Water quality before and after MF membrane filtration (2003 average)

	Bacteria	Coliform bacteria	Arsenic	Nitrogen in ammonia state	Nitrate nitrogen and nitrite nitrogen	Tetrachloroethylene	Tri-chloroethylene	Iron	Manganese	Potassium permanganate consumption	pH	Turbidity	Electric conductivity
Unit	Counts per ml		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		NTU	μS/cm
Raw water	10	5/12	0.000	0.00	1.8	0.0001	0.0000	0.00	0.000	0.7	7.3	0.0	240
Purified water	0	0/12	0.000	—	1.8	0.0000	0.0000	0.00	0.000	0.6	7.4	0.0	243

b. Removal of iron and manganese

Wells with a high concentration of iron and manganese are equipped with iron and manganese removal units to ensure that these contaminants are removed and the treated water fully meets the drinking water quality standards. It is necessary to take special care with water from deep wells, because iron and manganese are both dissolved. In particular, manganese is oxidized by chlorination into manganese dioxide. A minute amount of this substance would result in colored water from faucets and deposits in water supply and distribution pipes, and so manganese is thoroughly removed.

Currently, there are 18 water purification facilities equipped with iron and manganese removal units, which employ the sand filtration method using chlorine, manganese sand, and then re-chlorination. Soluble silica, a coagulant, is also added to well water with high concentration, at least 50 mg/L, to increase the effect (figure 11 and table 9).

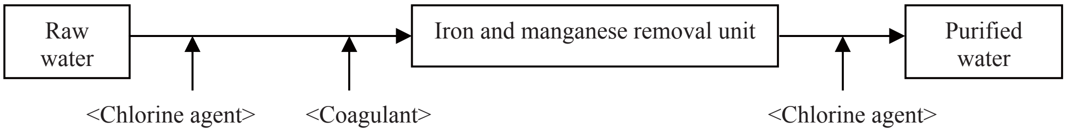


Figure 11. Iron and manganese removal process flow for removal of soluble silica

Table 9. Water quality before and after iron and manganese removal for removal of soluble silica (2003 average)

	Bacteria	Coliform bacteria	Arsenic	Nitrogen in ammonia state	Nitrate nitrogen and nitrite nitrogen	Tetrachloroethylene	Tri-chloroethylene	Iron	Manganese	Potassium permanganate consumption	pH	Turbidity	Electric conductivity
Unit	Count per mL		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		NTU	µS/cm
Raw water	0.2	0/12	0.003	0.02	0.00	0.0000	0.0000	0.97	0.120	1.1	7.4	0.3	176
Purified water	0.2	0/12	0.000	—	0.00	0.0000	0.0000	0.00	0.000	0.8	7.3	0.0	180

For some deep wells, the amount of chlorine is increased to treat nitrogen in the ammonia state reduced from nitrate nitrogen (figure 12 and table 10). In other deep wells, chlorine is directly applied to combat iron bacteria.

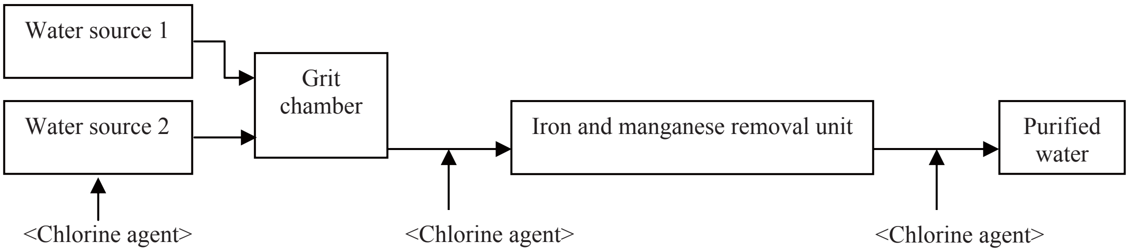


Figure 12. Iron and manganese removal process flow to address ammonia-nitrogen

Table 10. Water quality before and after iron and manganese removal to address ammonia-nitrogen

	Bacteria	Coliform bacteria	Arsenic	Nitrogen in ammonia state	Nitrate nitrogen and nitrite nitrogen	Tetrachloroethylene	Tri-chloroethylene	Iron	Manganese	Potassium permanganate consumption	pH	Turbidity	Electric conductivity
Unit	Counts per mL		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L		NTU	µS/cm
Raw water	0.8	0/12	0.000	0.28	0.03	0.0000	0.0000	0.24	0.110	0.7	7.8	0.1	206
Purified water	0.1	0/12	0.000	—	0.03	0.0000	0.0000	0.01	0.004	0.7	7.8	0.0	212

c. Contamination with trichloroethylene and tetrachloroethylene

When trichloroethylene pollution of wells was detected in 1982, ten wells were taken out of operation because of contamination with organic solvents. One was later scrapped. Aeration systems for removing trichloroethylene and other substances were then introduced and seven wells were put back into operation (three in 1991, one in 1995, and another three in 1999). One of the wells that resumed operation in 1991 was again suspended because of contamination with 1,4-dioxane (discussed below).

The aeration system sprinkles the filling material with raw water from above like a shower and blows air from the lower part to disperse trichloroethylene and other substances into the air (figure 13). This approach is effective for removing carbon tetrachloride as well as trichloroethylene and tetrachloroethylene. These systems are also installed in wells that already meet the drinking water quality standards to ensure safe water.

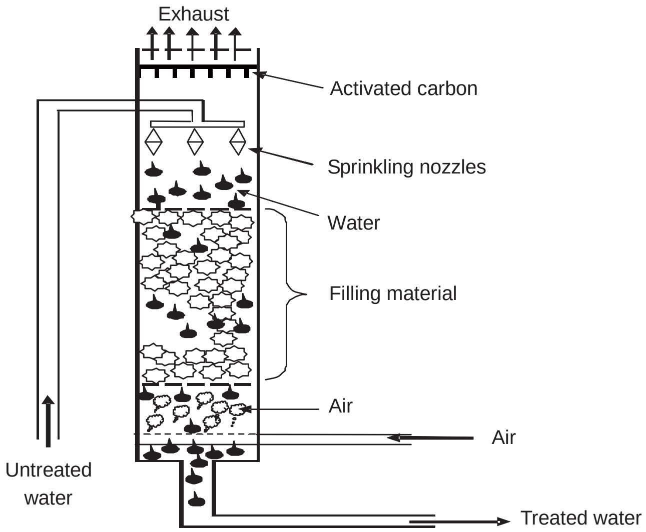


Figure 13. Mechanism of the aeration system

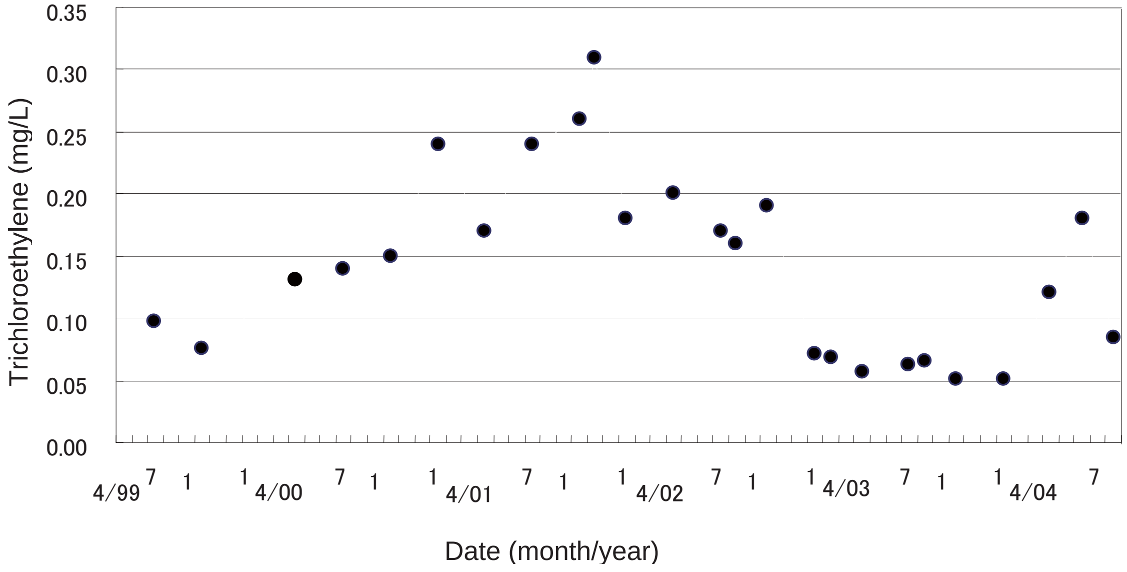


Figure 14. Trend in trichloroethylene concentration in non-operating wells after contamination with organic solvents

d. Contamination with 1,4-dioxane

In 2002, there was still no provision on 1,4-dioxane in Japan's drinking water quality standards, but three wells with a 1,4-dioxane concentration exceeding 0.03 mg/L were closed to prevent any possible hazard (table 11). Earlier, the U.S. Environmental Protection Agency (EPA) confirmed that this substance was carcinogenic and set the potable water concentration associated with a cancer risk of 1/100,000 at 0.03 mg/L.

Table 11. Trend in 1,4-dioxane concentration in non-operating polluted wells (mg/L)

Date	Well A	Well B	Well C
Jun. 2002	0.043	0.048	0.034
Aug. 2002	—	—	0.037
Mar. 2003	0.048	0.044	0.057
Nov. 2003	0.048	0.045	0.062
Aug. 2004	0.050	0.047	0.065

As 1,4-dioxane is so soluble in water that it is difficult to separate out, and activated carbon adsorption and aeration are not useful in removing it, some theorize that it can be removed with the use of ozone or nanofiltration (NF) membranes (table 12), but they have yet to be developed into an established water purification method. There is no prospect of the resumption of operation at non-operating wells. The contaminant, 1,4-dioxane, was added to the list of controlled items in the drinking water quality standards amended in 2003. The allowable limit has been set at 0.05 mg/L.

Table 12. Water quality before and after removal of 1,4-dioxane by NF membrane

	Unit	Source water	Treated water	
			Molecular weight fraction of 150	Molecular weight fraction of 65
1,4-dioxane	mg/L	0.128	0.115	0.016
Turbidity	NTU	0.023	0.015	0.016
Nitrate nitrogen	mg/L	5.0	5.3	0.5
Potassium permanganate consumption	mg/L	6.8	1.2	0.9
Evaporation residues	mg/L	150	130	12
Electric conductivity	μS/cm	312	229	37

e. Other issues

To control the quality of groundwater it is important to pay attention to nitrate nitrogen levels. Because of the broad application of fertilizers in Japan, chiefly on farmland, nitrate nitrogen concentrations in groundwater are generally higher than in surface water. The same trait can be seen in the Tama region, but to date no well appears likely to fail to comply with the drinking water quality standards, in which the total allowable limit of nitrate nitrogen and nitrite nitrogen is set at 10 mg/L. No differences have been identified between shallow wells and deep wells, and no local particularities have been noticed.

In a recent case, however, some negative effects were discovered in connection with a public works project that involved the construction of building foundations. Shallow wells are susceptible to this kind of contamination. Judging from the variation in chlorine input and the state of residual chlorine, chemical contamination was suspected. An investigation revealed that it was the result of amidosulfuric acid used at a worksite upstream. Non-toxic as it is, amidosulfuric acid still affects chlorine sterilization. The party responsible and the substance were successfully identified, and the substance was then replaced with a non-hazardous alternative that does not affect chlorination. The problem was thus resolved quickly.

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