Case History No. 9.4. Tokyo, Japan, by Soki Yamamoto, Rissho University, Tokyo, Japan

9.4.1 TOPOGRAPHY AND GEOLOGY OF TOKYO

Tokyo is situated at the bottom of the Kwanto structural basin, the biggest plain in Japan. Kwanto Plain is surrounded by mountains and hills on the north, west, and south where basement rocks of Tertiary and Pre-Tertiary age are exposed. The overlying new strata dip to the center of the basin.

All the rivers, such as the R. Tone, the R. Ara, and the R. Tama, start from this divide, transporting their sediments into Old Tokyo Bay. They developed fans at the foot of the mountain and a deltaic plan at their mouths in Tokyo Bay.

After the intermittent uplift, broad terraces were formed on this basin (Figure 9.4.1); on the surface of the terraces, thin volcanic ashes (Tephra) of different origins and deposited at different times are found. The maximum thickness of sedimentary rocks above the basement complex is about 300 m at the center of the basin.

The metropolis of Tokyo is located on the upland and lowland. The stratigraphic succession and schematic cross section in the Tokyo area are shown in Table 9.4.1 and Figure 9.4.2. There are many buried valleys in the lowland where an alternation of fairly thick sand and gravel layers are deposited, underlain by the Tokyo Group (Figure 9.4.3).

9.4.2 HYDROLOGY

The areas in Tokyo where land subsidence has taken place are tile Musashino upland and the alluvial lowland. There are two groups of aquifers, shallow and deep ones. The main shallow aquifer on the lowland (Koto) is Holocene sand and gravels and that on the upland area is Musashino gravel which is extensively distributed. In addition, deep artesian water is obtained from the Tokyo Group in the lowland and the Tokyo and Kazusa Groups in the upland. The Kazusa Group in the lowland contains natural methane gas which was produced for municipal supply in the Koto district. The large scale ground water development started in 1914 in Tokyo. After that time, the number of deep wells with large diameters increased rapidly. In an area extending from the northern part of the alluvial lowland to the southern part of Saitama Prefecture, there was artesian flow of ground water until the latter half of the 1920’s. At that time the ground-water level in the Koto district had fallen to about 10 m below the ground surface. The ground-water level continued to fall year after year, but toward the end of World War II it rose again temporarily. After the War, as the quantity of ground-water withdrawals increased, the ground-water level again went down until August, 1971, when it reached a low of minus 63-94 m from the mean sea level of Tokyo Bay (Tokyo Peil) in the northern part of the alluvial lowland.

Figure 9.4.4 shows the annual change of the ground-water level in selected observation wells.

The annual amounts of ground-water withdrawal in Tokyo from 1964 to 1975 are shown in Table 9.4.2. In the 23 wards, 1,160,000 m^3/day of ground water was withdrawn in 1964, but the quantity began to decrease by 1966, and it fell to 128,000 m^3/day, or about a tenth, in 1975. This decline is attributed to the withdrawal restrictions imposed to control land subsidence. Figure 9.4.5A shows the distribution of withdrawals by ward in 1967, and Figure 9.4.5B shows the annual total, 1950-1967.

In the northern part of Tokyo, the drilling of wells to a depth of up to 160 m had been banned by December, 1971; by May, 1974 drilling of wells with a depth exceeding 160 m was also banned. As a result, the quantity of ground-water withdrawals, which amounted to 80,000-90,000 M^3/day in the period from May, 1972 to 1973, decreased to 7,000-8,000 m^3/day after May 1974. Furthermore, the ground-water level, which was lowest (T.P.* minus 48.9 m) in July, 1971, rose again gradually, as the quantity of ground-water withdrawals decreased.

* T. P. = Tokyo Bay datum

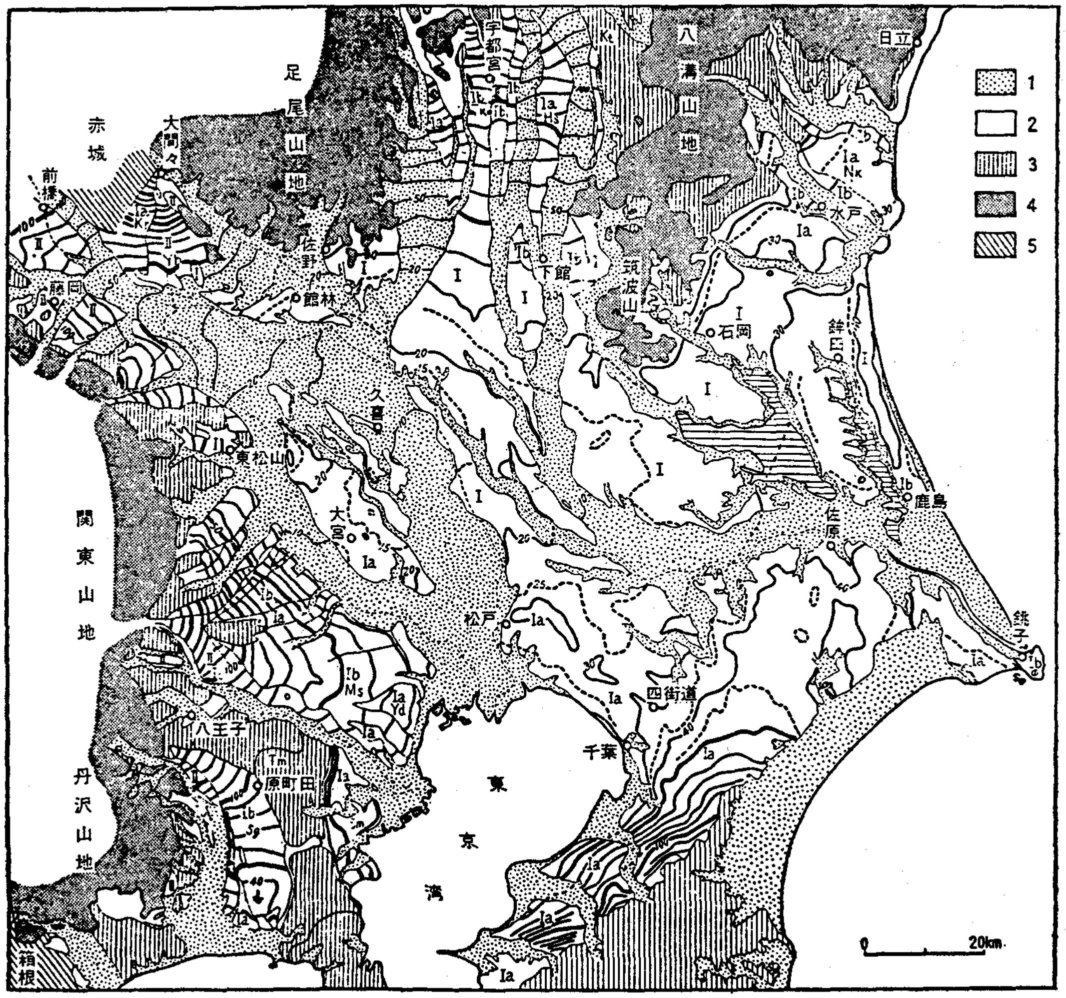


Figure 9.4.1 Geomorphological map of Kwanto District (after Kaizuka). 1, Alluvial lowland; 2, Diluvial upland; 3, Tertiary hill; 4, mountain; 5, volcano.

9.4.3 LAND SUBSIDENCE

In 1923, a severe earthquake occurred near Tokyo, causing widespread damage in the Koto region, east of the city of Tokyo. In order to study the crustal disturbance which might have accompanied this severe earthquake, a precise leveling was rerun in this region. As a result, it was found that the land subsidence was as a whole increasing gradually year by year. It was also found that the extent of the region where the land subsidence was then advancing occupied an area of about 100 km^2, situated between the Sumida and the Arakawa rivers, which flow through the region from north to south.

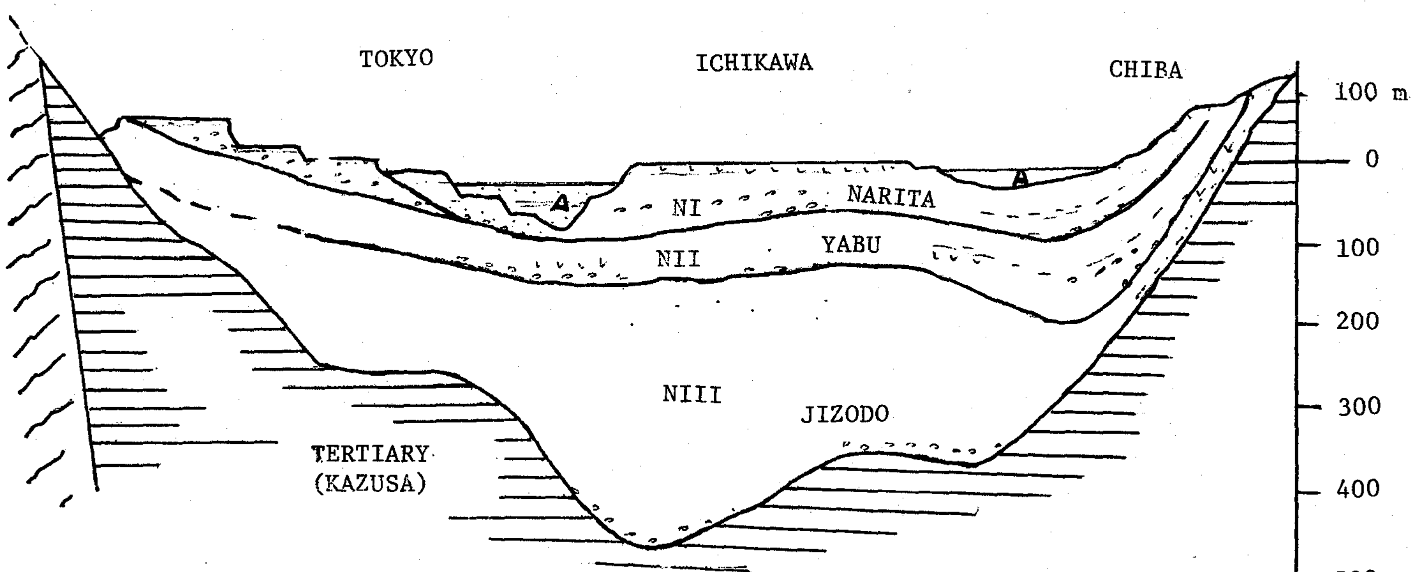
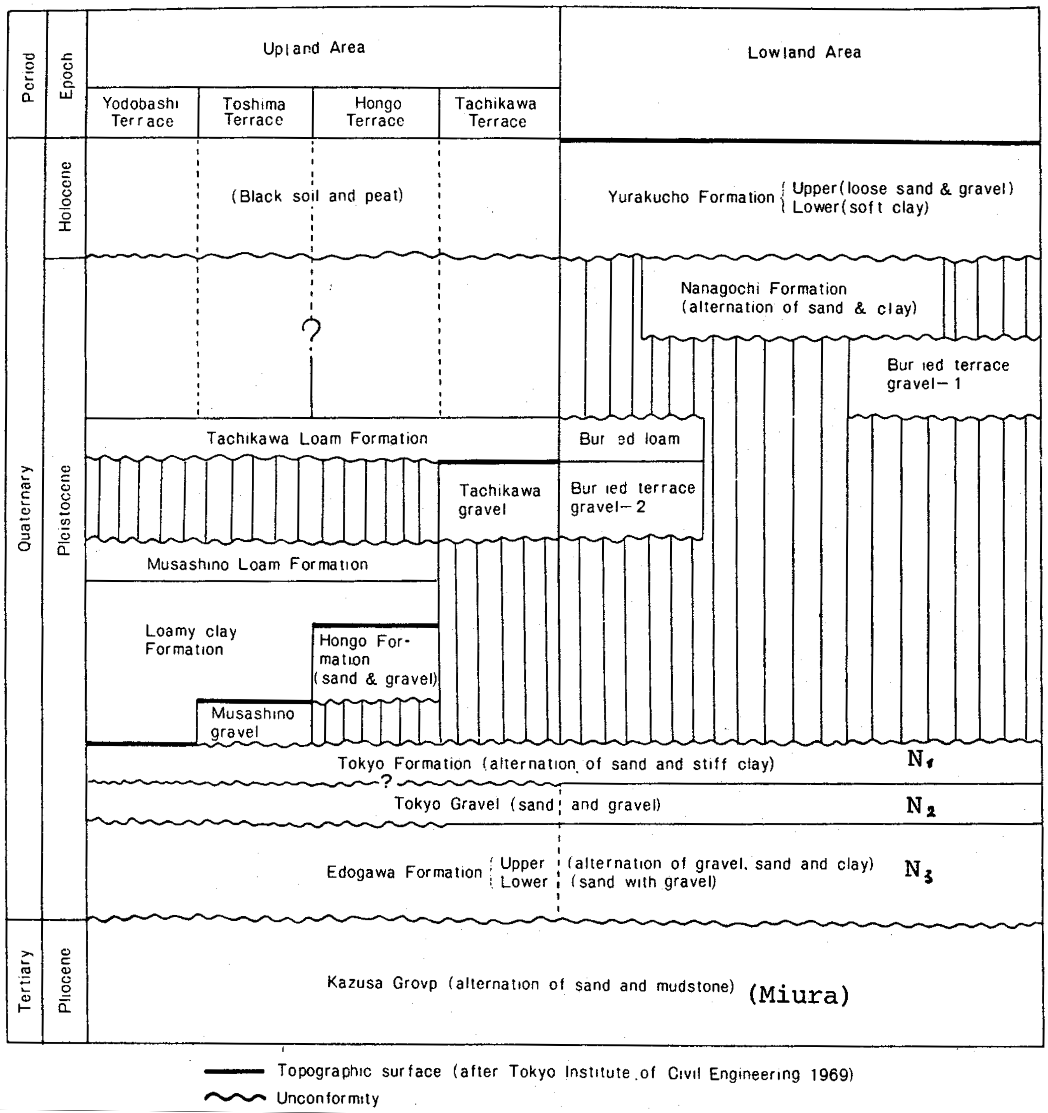


Figure 9.4.2 Schematic geologic cross section of Kwanto Basin.

Table 9.4.1 Stratigraphic succession in Tokyo



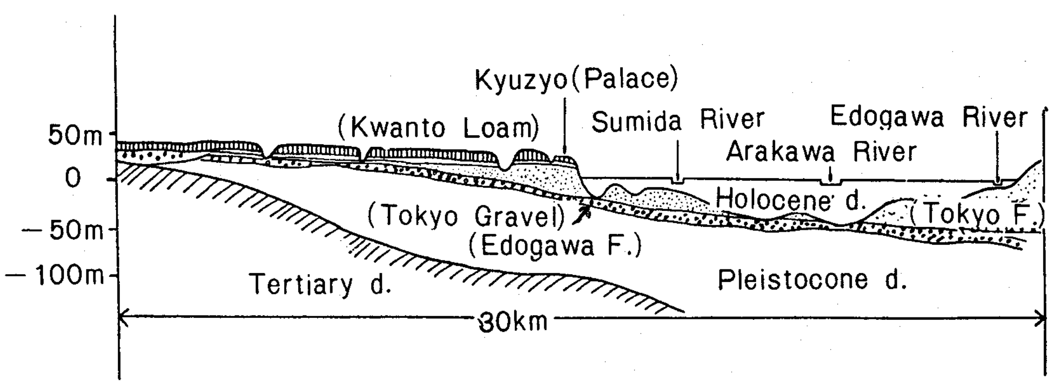


Figure 9.4.3 Geologic cross section.

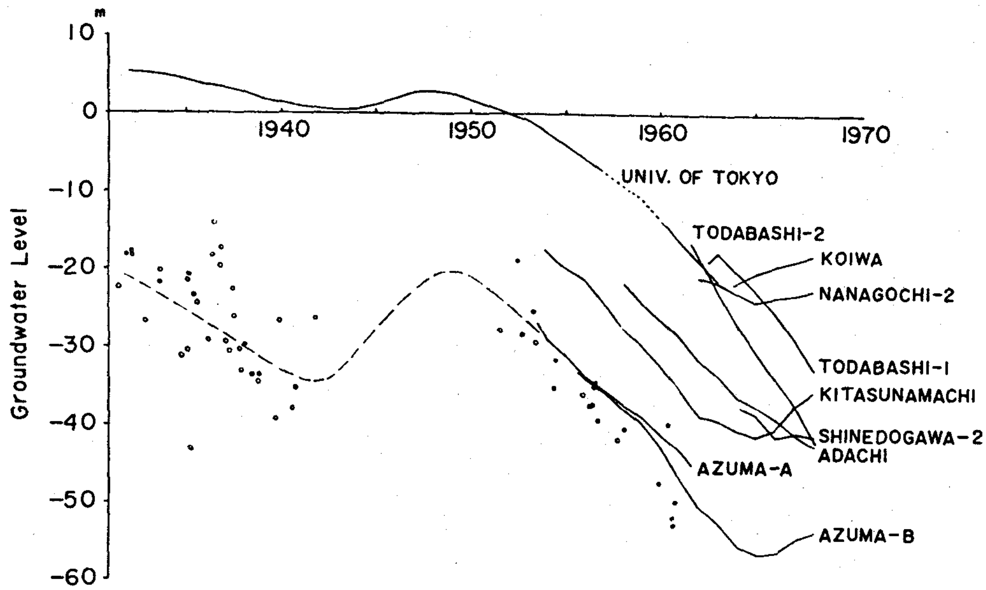


Figure 9.4.4 Secular trend of ground-water levels. Small circles indicate ground-water levels at the time of bore drilling near AZUMA-A and B (node 4)

Table 9.4.2 Amounts of ground-water withdrawal in Tokyo.

Unit: 1000m^3/day

Year / Area	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
23 wards	1162	1017	805	732	679	674	747	550	324	283	195	128
Tama	353	480	536	594	626	765	953	891	853	861	818	790
Total	1515	1497	1341	1326	1305	1439	1700	1441	1177	1144	1013	918

Data from Bureau of Environmental Protection, Tokyo Metropolitan Government

In association with the advancement of such a local subsidence, several remarkable phenomena occurred, such as "lift up" of masonry buildings and well pumps and inundation by rivers and sea tide.

In order to make clear the general features of the subsidence, precise leveling along the network of the leveling routes in Tokyo was started. It takes, however, considerable time to carry out the leveling survey on the network, including all bench-marks in Tokyo. Therefore, the leveling survey has been repeated frequently on the network of bench-marks in the region where the land subsidence is greatest.

In the first stage of study of the subsidence, the leveling was repeated at irregular intervals. Afterwards, it was thought to be inconvenient to work out vertical displacements based on the data of precise levels repeated at irregular intervals, since the amounts of the subsidence became larger and the rates of the subsidence were different from place to place. Therefore, in the Koto region, i.e., the region east of the Sumida river, where the subsidence was greatest, the leveling was repeated every two years, during the period from 1938 to 1946. Since then, leveling has been repeated every year in this region.

First order leveling and observations of the compaction of soil layers and the ground-water levels by means of observation wells were also carried out. As of January, 1976, the area Surveyed by leveling extended to 900 km^2, using 632 bench-marks where the levelings are made

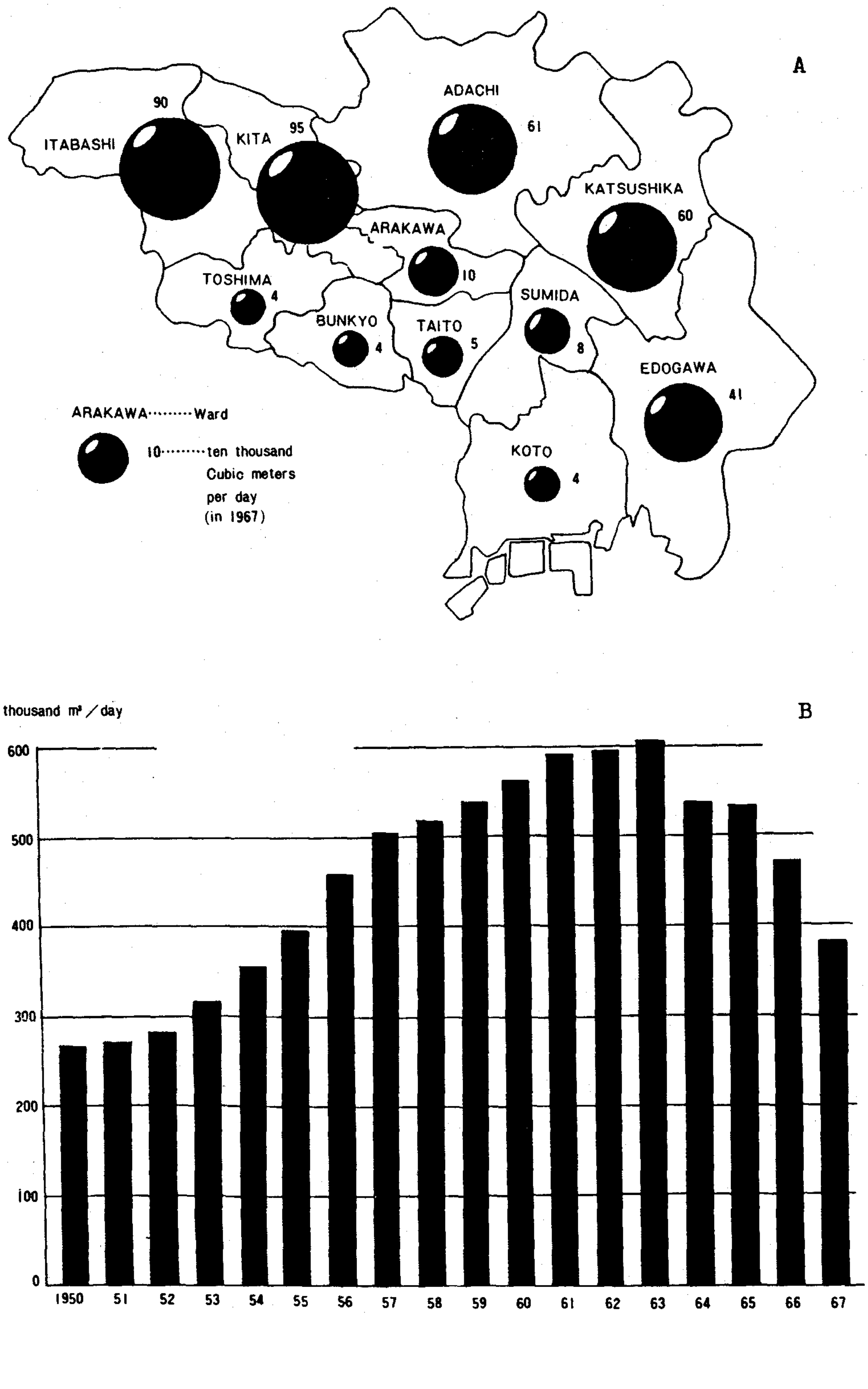


Figure 9.4.5 Amounts of ground-water withdrawal; A, by ward; B, by year.

every year. The compaction of soil layers and the changes of ground-water levels are observed at 68 observation wells located at 34 sites (Figure 9.4.6). The water-level plots are dashed.

Land subsidence has occurred in the Koto district since around 1900 and in the eastern part of the alluvial lowland (Edogawa Ward) since 1920. On the other hand, in the Musashino upland, land subsidence began to occur in the latter half of the 1950’s.

The maximum subsidence in Tokyo is about 4.6 m and the maximum rate is 27 cm/yr (Figure 9.4.7). The total subsiding area in Kwanto (Tokyo, Chaiba, Kanagawa, and Saitama) amounts to 2420 km^2 and the area where the subsidence amounts to more than 10 cm/yr is still about 100 km^2.

In order to prevent or abate such a rate of subsidence, the pumping of ground water was restricted as stated above, and thus the rate has dropped year after year since 1972.

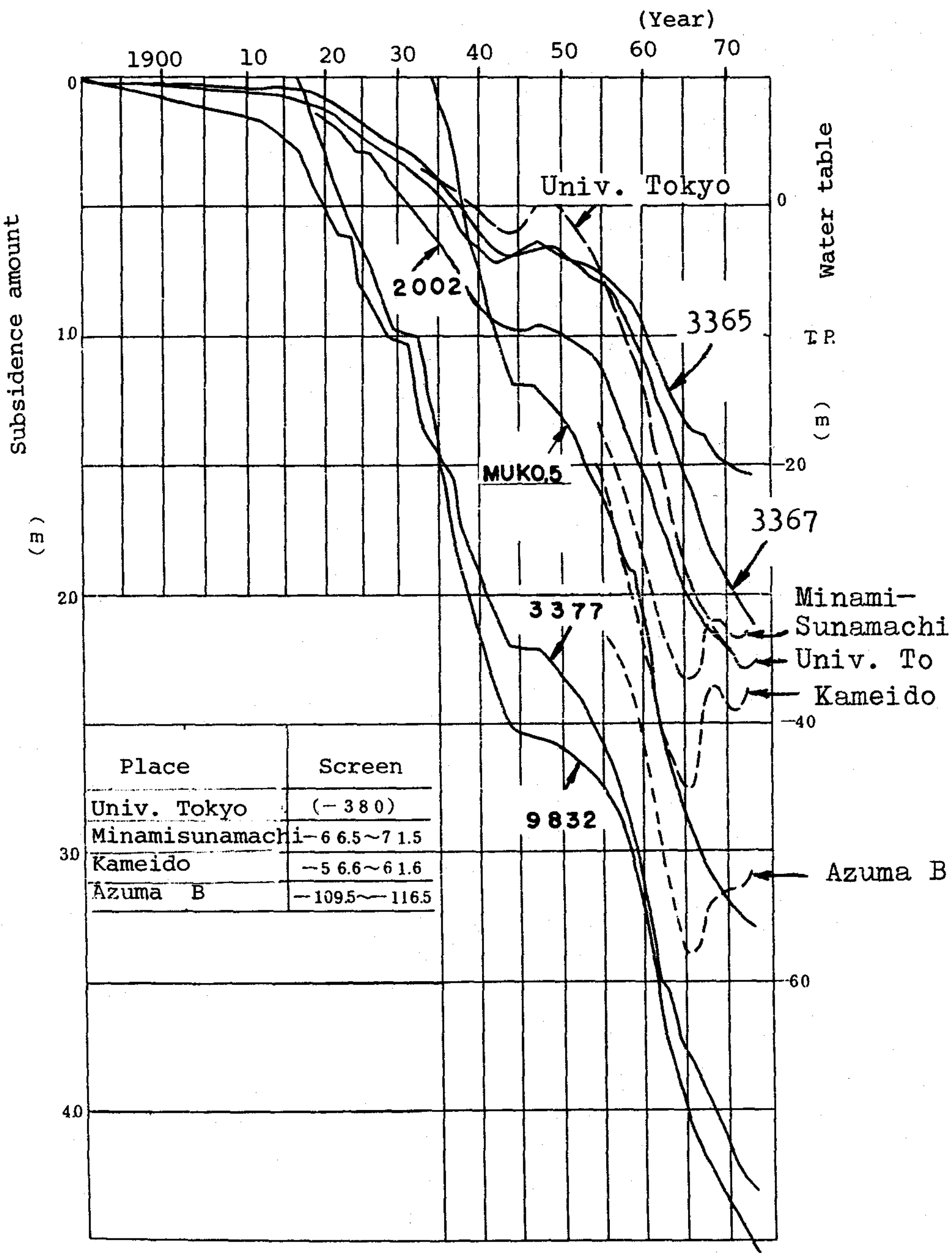


Figure 9.4.6 Secular changes of land subsidence and ground-water levels in Tokyo.

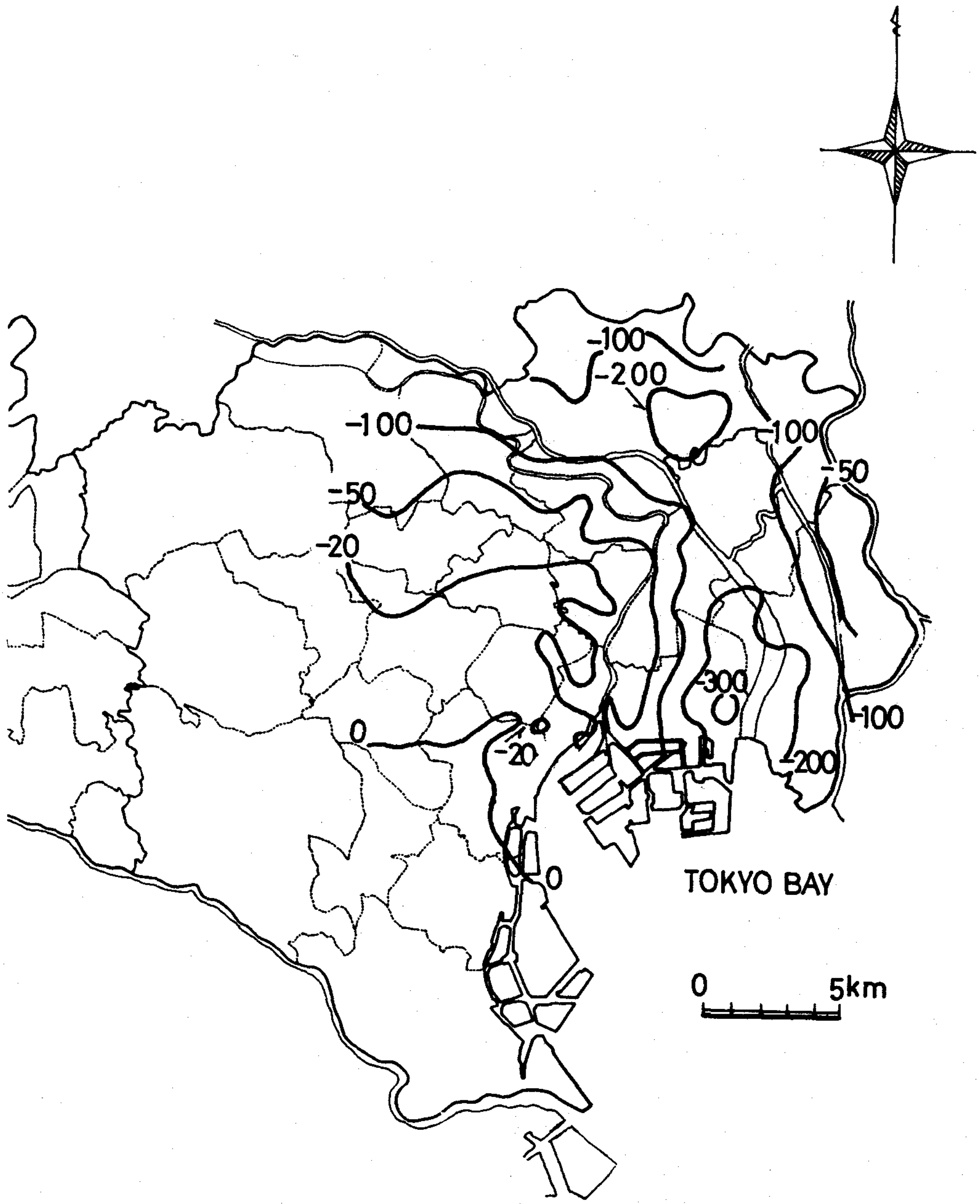


Figure 9.4.7 Total subsidence in Tokyo from 1938 to 1975.

9.4.4 PARAMETERS

Soil tests were carried out on undisturbed core samples. Consolidation tests were made by applying one-directional pressure. C_c value ranged from 0.2 to 1.2 and has the tendency of increasing with increasing water content. The M_v value varies as follows:

Alluvial clay	$2 - 3 \times 10^{-2}$ cm^2/kg
Diluvial clay	$2 - 6 \times 10^{-3}$
Tertiary clay	$1 \times 10^{-3} - 4 \times 10^{-4}$.

K: hydraulic conductivity

Tokyo Group	2.1×10^{-2} cm/sec
Kazusa Group	1.3×10^{-2}

9.4.5 COUNTERMEASURES

In Tokyo, the local government legislated a Metropolitan Ground-Water Law, superposed on the "Industrial Ground-Water Law" and "Building Ground-Water Law." Moreover, they constructed dikes for floods and high tides, pumping installations for drainage, water-supply works for industry, and polder systems. The estimated cost for the countermeasures for the period 1957 through 1970 is about 225 million U.S. dollars.

The regulations for ground-water withdrawal are as follows:

1. Restrictions under the Industrial Water Law.
   The restrictions are designed to reduce the ground-water withdrawals by supplying substitute waters. The main restrictions are described chronologically in the following:

   January 1961: A ban on drilling a new well in the southern part of the alluvial lowland (the Koto district).
   July 1963: A ban on drilling a new well in the northern part of the alluvial lowland (the Johoku district).
   June 1966: Pumping of ground water in the southern part of the alluvial lowland (the Koto district) was restricted.
   December 1971: Pumping of ground water in the northern part of the alluvial lowland (the Johoku district) was restricted.
   April 1975: Pumping of ground water in the eastern part of the alluvial lowland (the Edogawa district) was restricted.

2. Restrictions under the Law Controlling Pumping of Ground Water for Use in Buildings
   The law aims at holding in check the pumping of ground water for air conditioning and other non-drinking purposes in medium- and highrise buildings. The progress of restrictions under the law is described chronologically in the following:

   July 1963: A ban on the drilling of new wells in the alluvial lowland.
   July 1965 and July 1966: Restrictions on the pumping of ground water in the alluvial lowland.
   May 1973: The restriction was extended to the whole area of the 23 wards, and the control of ground-water withdrawals was strengthened.

3. Restrictions under the Tokyo Metropolitan Environmental Pollution Control Ordinance.
   The ordinance restricted the drilling of new wells in areas not covered by the two laws mentioned above.

4. Suspension of drawing ground water containing natural gas
   The Tokyo Metropolitan Government in December 1972 bought the mining rights for water-soluble natural gas extracted in the neighborhood of the Ara River estuary, and thereby suspended the pumping of gas-water (3,000 M^3/day) from the Kazusa Group.

   On the other hand, in the Tama district, the drilling of new wells for industrial water and water for non-drinking purposes (for example, the supply of bath water) is restricted under the Metropolitan Ordinance mentioned in (3) above, but with an increase in population in the district, the demand for ground water climbed from 350,000 m^3/day in 1964 to some 900,000 M^3 /day in 1971.

The replacement drinking water and building water are supplied from the River Tone through the Musashi aqueduct and the industrial water is supplied from the Metropolitan industrial water works on the Tone which is provided by the construction of high dams on the upper part of this river.

9.4.6 SELECTED REFERENCES

MIYABE, N. 1962. Studies in the ground sinking in Tokyo, Rept. Tokyo Institute of Civil Engineering, p. 1-38.

INABA, Y., AOKI, S., ENDO, T., and R. KAIDO. 1969. Reviews of land subsidence researches in Tokyo, IAHS Pub. No. 88, p. 87-98.

ISHI, M., KURAMOCHI, F., and T. ENDO. 1977. Recent tendencies of the land subsidence in Tokyo, IAHS Pub. No. 121, p. 25-34.