SUBSIDENCE OF THE NŌBI PLAIN*

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Abstract

The Nōbi plain underlain by younger sediments is situated in the central part of Japan and is about 1300 km^2 in area. The yearly rates of subsidence in this area were 1.4 - 1.8 mm before 1925, 2 - 5 mm during the period from 1925 to 1950, 10 - 20 mm during the period from 1950 to 1960, 20 - 40 mm during the period from 1960 to 1965 and more than 100 mm at places having severe subsidence recently. The major cause of this increasing subsidence is the increasing withdrawal of ground water for industrial, agricultural and other purposes. As a result of such subsidence, an area of 250 km^2 subsided below the mean sea level. The drainage during and after heavy rainfalls has been becoming difficult day by day, and the potential danger of tidal flood under a typhoon has been increasing year by year. Against such subsidence of the Nōbi plain, investigations are being done by officials of central and prefectural governments and professors of universities in this area. Based on the investigations, withdrawal of ground water in this plain is now being controlled by regulations of the authorities concerned.

The Nōbi plain underlain by younger sediments is situated in the central part of Japan as shown in Fig. 1 and is about 1300 km^2 in area. The land surface subsided 237 cm in 87 years from 1888 to 1975 at Yatomi (a place in this plain).

This area faces the Ise bay, where Ibi, Nagara, Kiso and Shōnai rivers find their ways, and is composed of alluvial fans, flood plains, deltaic plains, terraces, reclaimed lands and filled-up grounds as shown in Fig. 2.

The west-east profile of the southern part of this area is illustrated in Fig. 3. The basement block in the Nōbi plain area bounded by Yōrō fault has tilted and is covered with sediments dipping westwards. The strata from a depth of about 2000 m to the ground surface in

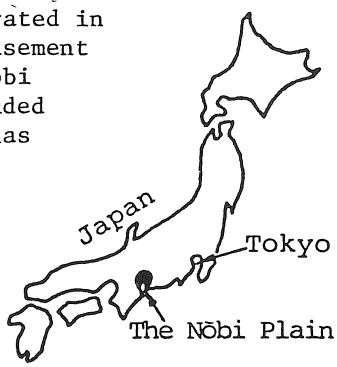
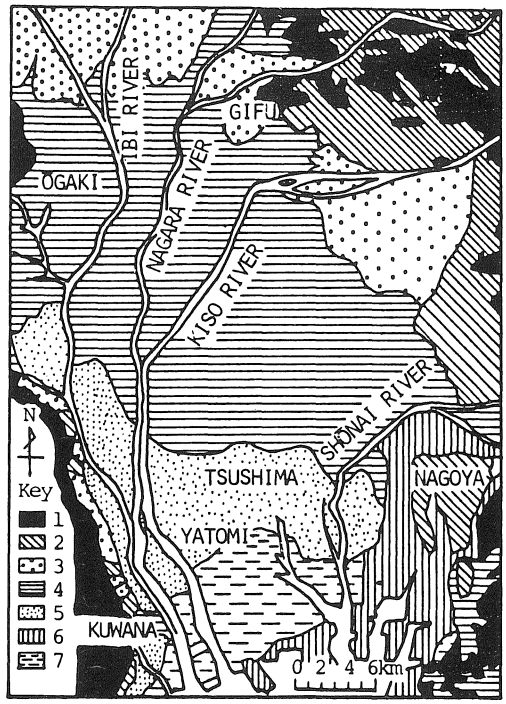


Fig. 1 The Nōbi Plain



1. Mountain and Hill 2. Terrace
3. Alluvial Fan and Cone
4. Flood Plain 5. Deltaic Plain
6. Filled-up Ground
7. Reclaimed Land

Fig. 2 Topographic Features of the Nōbi Plain

*Paper presented to the Second International Symposium on Land Subsidence, Anaheim, California, U.S.A., December 13-17, 1976

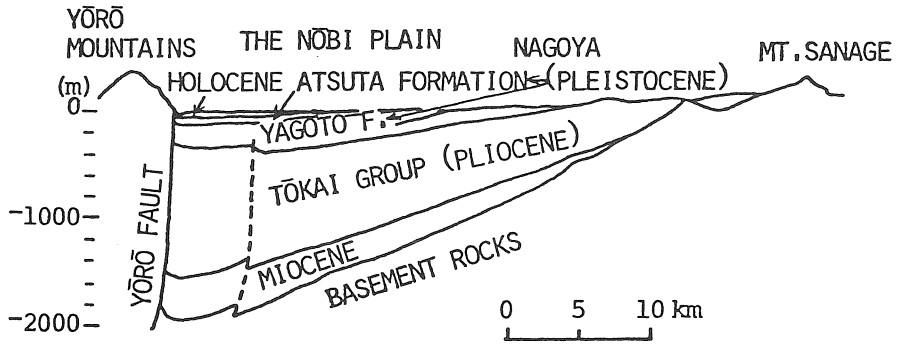


Fig. 3 West-East Profile of the Nōbi Plain

the western margin of the tilting block are sediments since the Pliocene. The average rate of displacement of the basement, based on the geological profile, was estimated only about 1 mm/year at Yatomi as shown in Table 1 (Kuwahara, 1968). Therefore, the recent subsidence of more than a few cm per year in this area is caused by consolidation of younger sediments, in which the pore water pressure has been decreasing by increasing withdrawal of ground water.

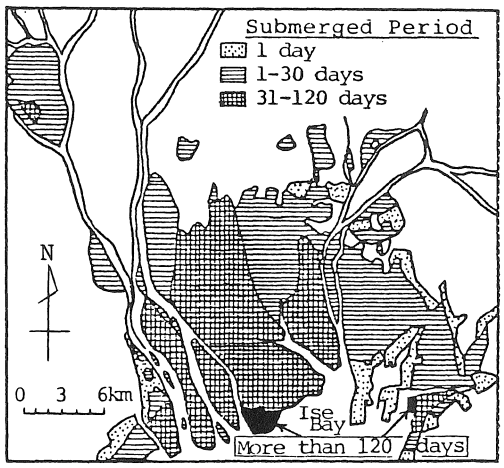


Fig. 4 Submerged Area of the Nōbi Plain after a Typhoon on 26 Sept.1959

Formerly, this plain was mainly farming lands. But recently, a large number of textile mills and many kinds of factories using great quantities of ground water have been located and many residential quarters have also been developed. Since 1963, there have been developed several hot-spring resorts pumping up hot water from depths of more than 1000 m.

Since old times, people of this plain often suffered damages from floods. Especially, they suffered severely from the flood caused by a typhoon which passed this plain in the northeast direction from Ise bay on the 26th of September, 1959. By this typhoon, 5,122 persons were put to death, 15,384 persons were wounded, 127,625 houses were destroyed completely or partly, and 3,846 houses were washed away in the whole of Japan. But the Nōbi plain suffered most of the damages. After this typhoon, considerably wider area of this plain was submerged for a long time as shown in Fig. 4. It was known by this submersion that there was an area of 186 km^2 below the

Table 1 Geological Displacement of the Nōbi Plain

Item / Target	Age $\times 10^4$ years B.P.	Inclination	Displacement at Yatomi	Ave. Rate of Displacement
Atsuta Surface	3.5	2.5×10^{-3}	60m	1.7mm/year
Yagoto Surface	30 ~ 70	4×10^{-3}	300m	1~0.4mm/year
Base of Tōkai Group	400± (200±)		2000m	0.5± (1.0±) mm/year

mean sea level at that time.

The history of ground subsidence in this area is shown in Fig. 5 by the use of three bench marks, the locations of which are given in Figs. 6 and 7. During the period from 1950 to 1973, the subsidence increased exponentially and some places subsided more than 20 cm/year in 1973.

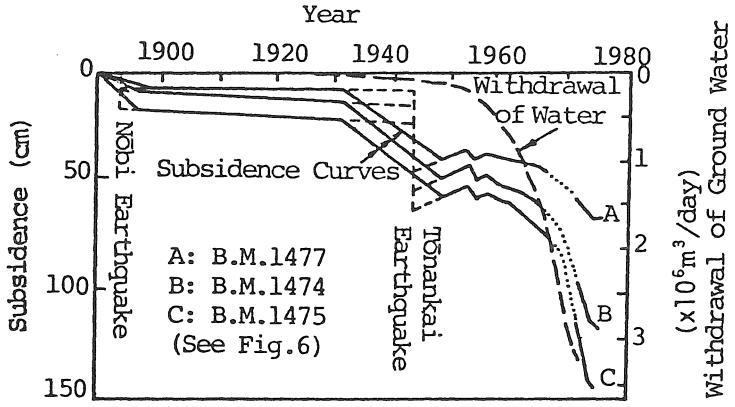


Fig. 5 Subsidence of Bench Marks and Withdrawal of Ground Water in the Nōbi Plain

Fig. 6 shows the comparison between the area subsided more than 2 cm/year from Feb.1961 to Feb.1962 and the one from Nov.1972 to Nov.1973. This figure explains how the subsiding area in this plain enlarged from 1961 to 1973.

The subsidence of this plain for about 15 years from Feb.1961 to Nov. 1975 is shown in Fig. 7. The southern part of Nagashima facing the Ise bay settled 147 cm during these 15 years. The total subsiding area is 1140 km^2 (Environment Agency, Japan, 1976). By 1973, 363 km^2 has become lower than the mean high-sea level (1.1 m higher than the mean sea level), 248 km^2 lower than the mean sea level and 37 km^2 lower than the mean low-sea level (1.4 m lower than the mean sea level) as shown in Fig. 8. The area below the mean sea level enlarged from 186 km^2 in 1961

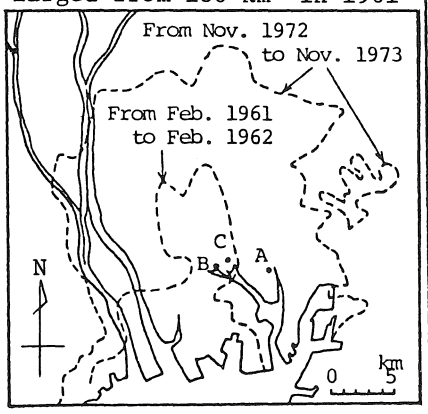


Fig. 6 Enlargement of the Area subsided more than 2 cm/year

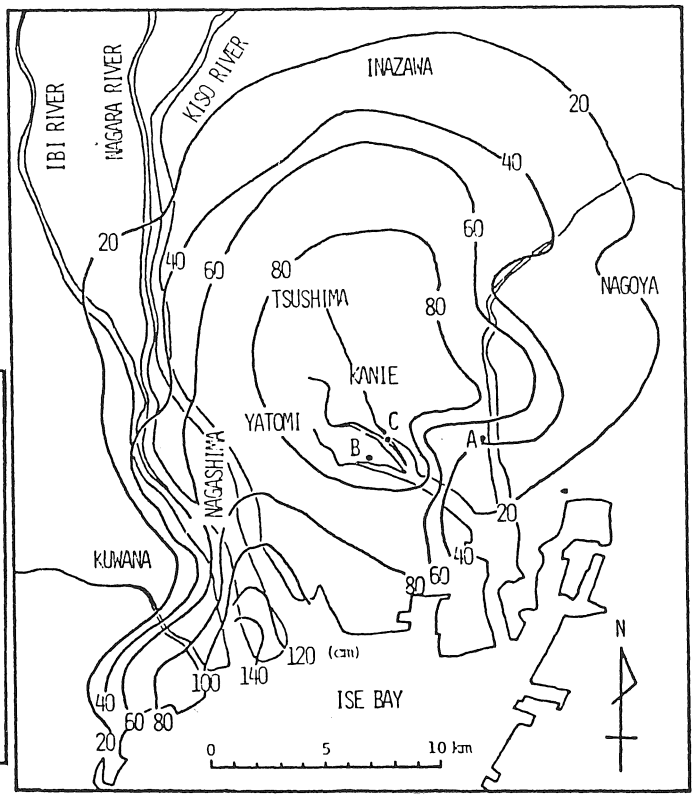


Fig. 7 Subsidence for 15 Years from Feb.1961 to Nov.1975 in the Nōbi Plain (cm)

to 248 km^2 in 1973.

The increasing withdrawal of ground water in the Nōbi plain is shown in Table 2 and Fig. 5. The use of ground water is shown in Table 3. The use for industry amounts to 60 per cent of the total.

The recent yearly withdrawal of ground water in the Nōbi plain is equal to the volume of 32 per cent of the yearly rainfall on this plain. This volume is much larger than the natural recharge of ground water. Therefore, the withdrawal of ground water must be reduced to arrest the subsidence of this plain (Ueshita, 1976).

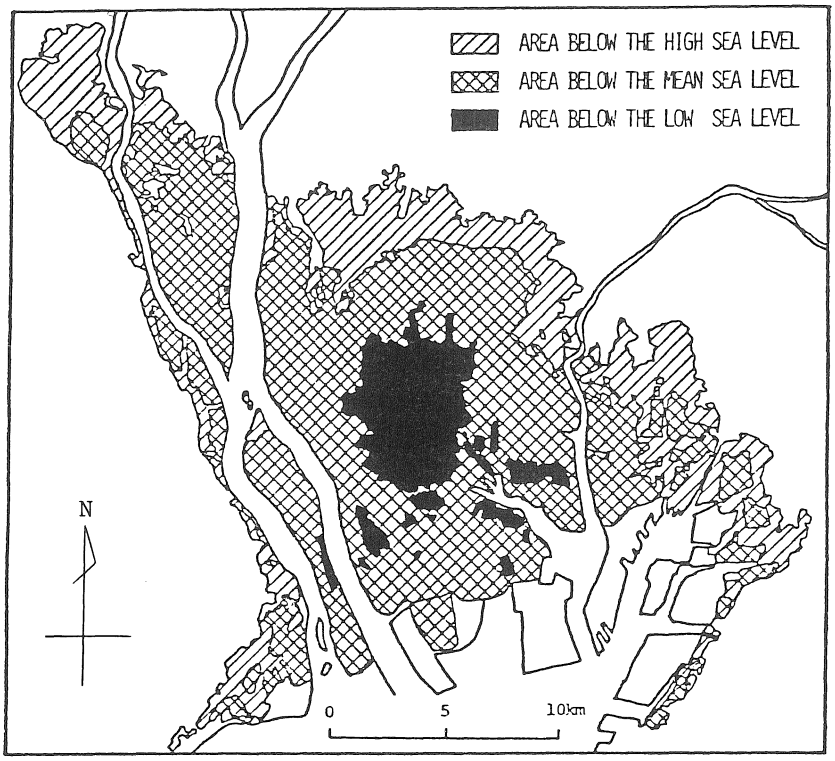


Fig. 8 Area below the Sea Levels in the Nōbi Plain

In the 1920's, the piezometric levels of confined aquifers were higher than the ground surface in the most part of this plain. In the 1940's, flowing wells were still observed in Ōgaki, Kanie and Kasugai districts as shown in Fig. 9. But the piezometric levels fell down corresponding to the increase in number of artesian wells. The piezometric level of the 2nd confined aquifer (G_2) was already lowered as shown in Fig. 10 (see Kuwahara et al, 1976).

In order to arrest the subsidence of the Nōbi plain, the Tōkai Three-Prefecture Investigation Committee on Land Subsidence was organized in 1971 and reorganized to strengthen in 1975, and many investigations have been done by officials of central and prefectural governments and professors of universities in this area. Based on the investigations, the withdrawal of ground water in this plain is now controlled by regulations of the authorities

Table 2 Withdrawal of Ground Water in the Nōbi Plain

Year	m^3/day
1925	1 638
1945	129 088
1950	154 040
1955	360 301
1960	849 338
1965	1 552 764
1970	3 002 128
1973	3 514 195

Table 3 Use of Ground Water for Each Purpose in the Nōbi Plain (1973)

Item	Total	Industry	Buildings	Water Supply	Agriculture
Withdrawal of Ground Water (m^3/day)	3 802 293	2 290 015	343 025	477 028	692 225
Percentage	100	60	9	13	18

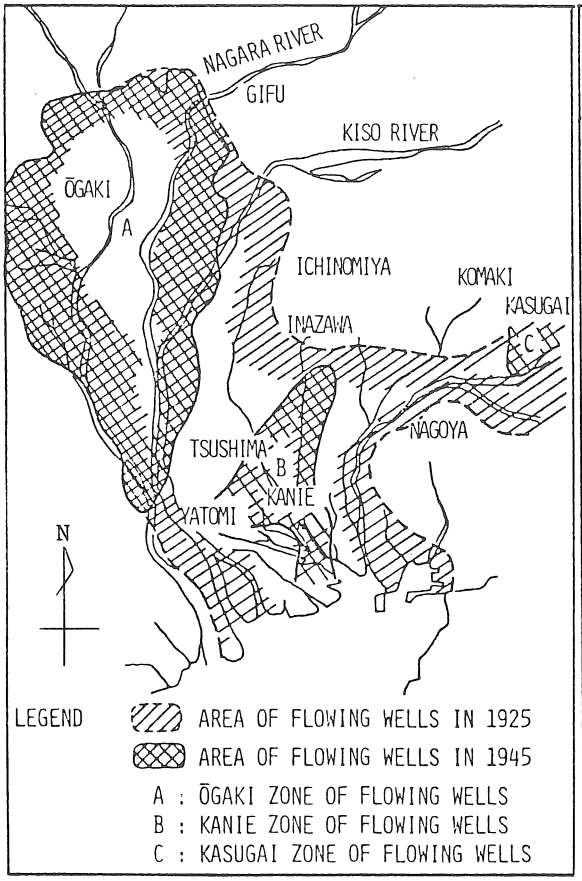


Fig. 9 Area where Flowing Wells existed in the Past

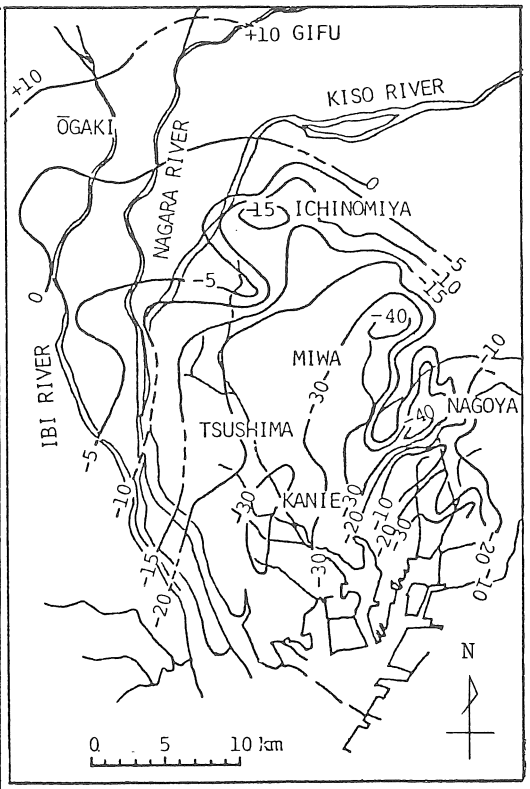


Fig. 10 Piezometric Level of the 2nd Confined Aquifer (G_2) in 1973 (measured in Meter based on the Mean Sea Level)

concerned as shown in Fig. 11.

Regulations of withdrawal of ground water in the Nōbi plain are as follows:

The Industrial Water Law (established in 1956)

The areas designated by the Industrial Water Law are supplied with

Table 4 Regulations for the Areas designated by the Industrial Water Law

Area	Zone (See Fig.11)	Allowed Depth of Strainer	Inside Area of Discharge Pipe
Southern Industrial Area of Nagoya designated in 1960	N_1	deeper than 80 m	less than 46 cm^2
		deeper than 300 m	greater than 46 cm^2
	N_2	deeper than 90 m	less than 46 cm^2
		deeper than 180 m	greater than 46 cm^2
Industrial Area of Yokkaichi designated in 1957 and 1963	Y_1	deeper than 100 m	less than 21 cm^2
		deeper than 230 m	from 21 cm^2 to 46 cm^2
	Y_2	deeper than 50 m	less than 21 cm^2
		deeper than 150 m	from 21 cm^2 to 46 cm^2

industrial water from surface sources instead of restriction on pumping up of ground water. The regulations for these areas are shown in Table 4.

Regulations by Ordinance of Aichi Prefecture

(1) Aichi Regulation Zone I (enforced on 30 Sept. 1974)

This regulation zone was decided considering the rate of subsidence greater than 5 cm/year in 1972 and/or 1973. In this zone, a newly bored well must have the following conditions;

a) The depth of strainer should not be greater than 10 m.
b) The inside area of discharge pipe should be less than 19 cm^2.
c) The power of motor should be less than 2.2 kW.
d) Total discharge should be less than 350 m^3/day.

Concerning the wells that existed before the regulation, flow meters were installed to them and the discharge records are reported to the Prefectural office every year. Since the 1st of January, 1976, the withdrawal of ground water from existing wells was restricted within 80 percent of the discharge in the past.

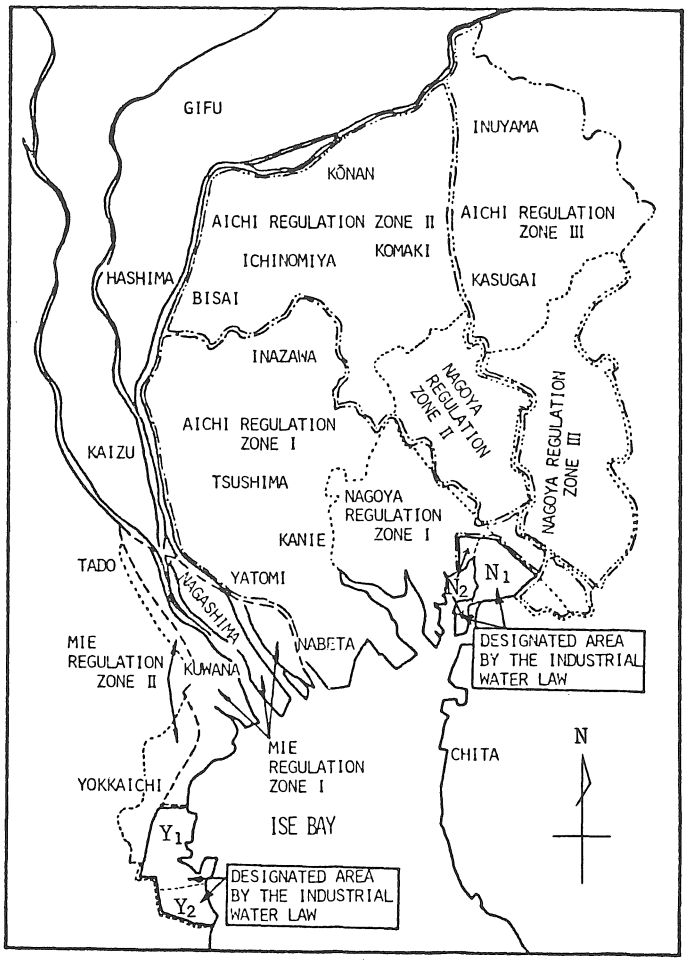


Fig. 11 Restriction of Withdrawal of Ground Water in the Nōbi Plain

(2) Aichi Regulation Zones II and III (enforced on 1 April 1976)

The regulations for newly bored wells and existing wells are the same as those for Zone I, excepting that for the existing wells in Zone II, the withdrawal from the 1st of April, 1977 is going to be restricted within 80 percent of the discharge in the past, and for the existing wells in Zone III, the withdrawal in future is going to be restricted within the discharge in the past.

Regulations by Ordinance of Mie Prefecture (enforced on 1 April 1975)

The regulations for newly bored wells and existing wells are the same as

Table 5 Dealing with Existing Wells in the Case where the strainers are deeper than 10 m in Nagoya

Zone	Wells for Buildings	Wells for Industry
I	Changed to use city water since 16 Nov. 1975	Change to the industrial water supply as soon as possible
II	Changed to use city water since 16 Nov. 1976	
III	Increasing of withdrawal is forbidden.	

those explained for Aichi Regulation Zones II and III, where Mie Regulation Zones I and II correspond to Aichi Regulation Zones II and III, respectively.

Regulation by Ordinance of Nagoya City (enforced on 16 November 1974)

According to the ordinance of Nagoya City, a new well can be allowed only in the case where the strainer is not deeper than 10 m and the inside area of discharge pipe is less than 19 cm^2. Existing deep wells are being treated as shown in Table 5. The regulation zones of Nagoya City are overlapped by the regulation zones of Aichi Prefecture. Therefore, the withdrawal of ground water in Nagoya is controlled by ordinances of Nagoya City and Aichi Prefecture.

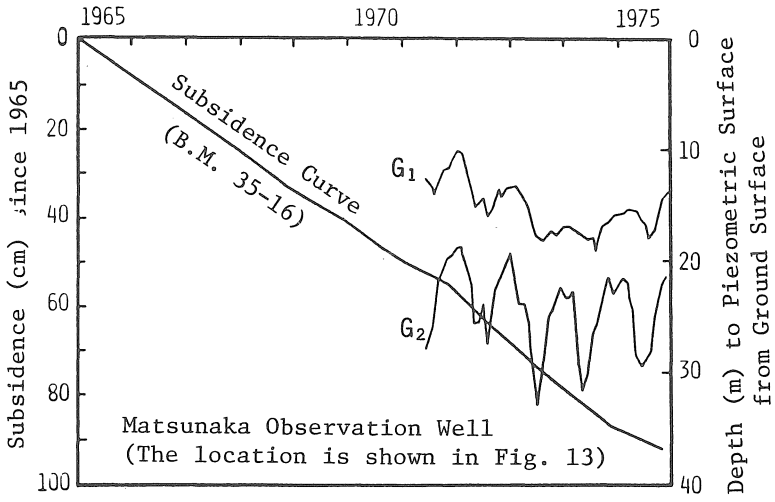


Fig. 12 Subsidence and Ground Water Condition at Nagashima during Recent Years

Fig. 12 shows the subsidence of Nagashima during the recent ten years and the piezometric levels of the 1st confined aquifer (G_1) and the 2nd confined aquifer (G_2) measured by Matsunaka observation well during the recent five years. The confined aquifers G_1 and G_2 are located at depths between 40 m to 60 m and 100 m to 115 m respectively at the observation site. Concerning the piezometric levels, seasonal changes are superposed on total trends of ground water levels. The seasonal drops of piezometric levels are caused by the increase of pumpage for cooling and irrigation in summer. The piezometric level of the deeper confined aquifer is lower than the one of the shallower confined aquifer, because ground water of better quality is pumped up in plenty from the deeper aquifer.

The piezometric levels of aquifers are having recovering trends since 1974. Corresponding to this phenomenon, the rate of subsidence reduced in 1975. Reflecting this favorable turn in ground water

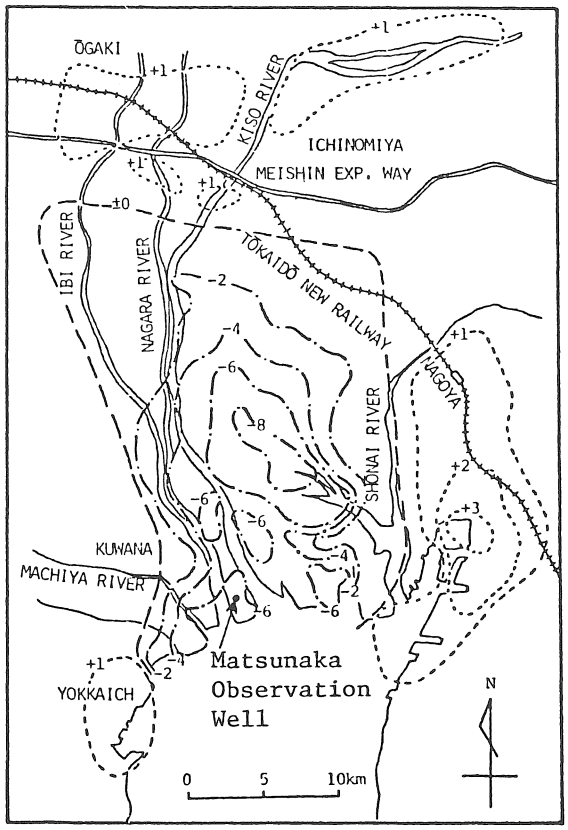


Fig. 13 Subsidence and Rebound of the Nōbi Plain from Nov.1974 to Nov.1975 (Unit: cm/year)

situation, the subsiding area became smaller and the rate of subsidence decreased for the period from Nov.1974 to Nov.1975 as shown in Fig. 13. Moreover, there appeared several rebounding areas around the area having reduced subsidence.

The organs and persons concerned are still directing their efforts to stop the subsidence of this plain completely.

In conclusion, the authors would like to express their hearty gratitude to the members of the Tōkai Three-Prefecture Investigation Committee on Land Subsidence and to the organs and persons concerned, especially the Ministry of Construction, Aichi and Mie Prefectures for their cooperation and their agreement in presenting this paper at the Second International Symposium on Land Subsidence. The research grants from the Ministry of Education are also acknowledged.

The authors are thankful to Professor M.S.I.Khan for his helpful advice on English expression of this paper.

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