Role of The Tokai Three-Prefecture Investigation Committee on Land Subsidence in The Nobi Plain

T. Sato[1], K. Daito[2] and G. Takigawa[3]

1 Chairman of The Committee, Gifu University, 1-1 Yanagido, Gifu, Japan
2 Chairman of The Analysis Part of The Committee, Daido University, 10-3 Takiharu-cho, Minami-ku, Nagoya, Japan
3 Secretariat of The Committee, River Planning Division, Chubu Regional Development Bureau, Ministry of Land , Infrastructure , Transport and Tourism, 2-5-1 Naka-ku, Sannomaru, Building No.2, Nagoya, Japan
Contact: tsat@gifu-u.ac.jp

Background

The Nobi Plain (136.5-137.0 East Longitude, 35.0-35.5 North Latitude) of almost 1,300 km2 carries the main rivers, the Kiso, the Nagara and the Ibi those which originate from the northern part of the mountainous area in the central of the Honshu island and pour into the Ise bay opening to the Pacific Ocean. Average precipitation has been recorded as 1,543 mm per year since 1961. Groundwater withdrawal reached 1,251 million m3 per year in 1976 which breakdown is 743 million m3 for industry, 228 million m3 for drinking and 156 million m3 for agricultural use1). The groundwater regulation was started in 1974 and expanded to the area in 1976. The Owari water works for industry use started in 1985 and has been continued to enlarge the supply area to distribute surface water. The amount of groundwater withdrawal1) was consequently decreased to more than 50% of 1976.

The area below the mean sea-water level reached to 284 km2 in 2020 which was the largest area in Japan (see Figure 1). This area is originally correspondent with reclamation and delta which is featured as young deposits. The soil structure is not enough to resist the failure and deformation. This causes high risk to natural disaster, such as earthquake, tsunami and/or high tide. More than 3 meters height of tsunami are predicted at the seaside residence when the Tokai, the Tonankai and the Nankai earthquake are simultaneously generated in the Pacific ocean.

The excess withdrawal in the aquifers(G1, G2 and G3 of Figure 2) has caused sudden change of piezometric head of groundwater within adjoining marshy clay and sand. This causes leakage and/or consolidation in the adjacent mud and sand layers. In 1960s, more than 10 centimeters land subsidence was recorded per year due to groundwater head decrease in the aquifers.

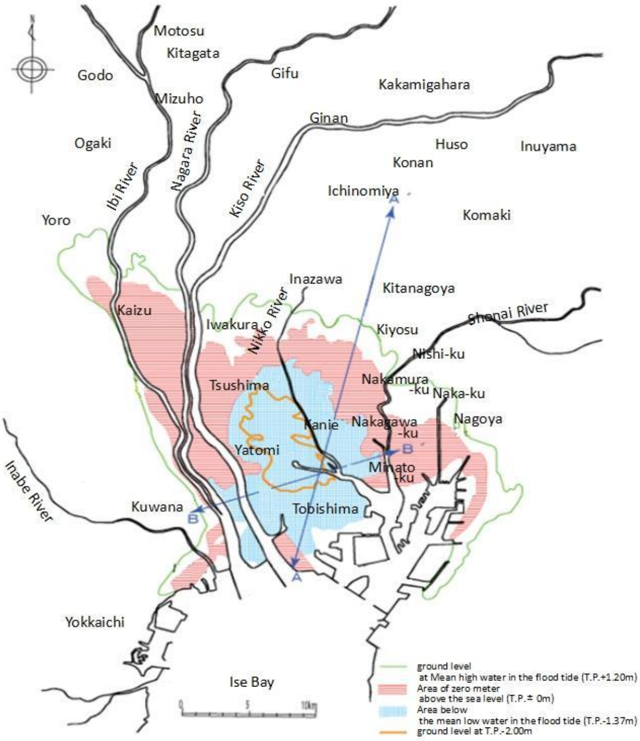

Figure 1 Area below the mean sea water level (T.P. is Tokyo Peil).

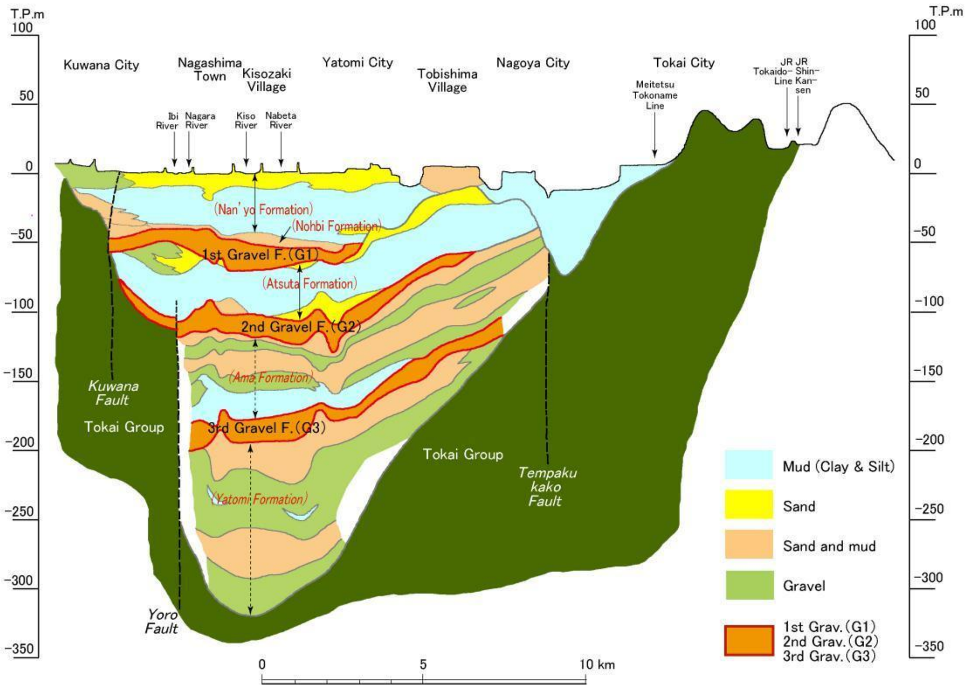

Figure 2 Geological profile at B-B' section in Figure 1.

Methods

More than nine hundred bench marks and one-hundred observation wells were used in the calculation of subsided volume due to land subsidence. Each observation well provides settlement gauge to measure vertical displacement of the top of the inner pipe which is fixed on a specified stratum. The Tokai Three-Prefecture Investigation Committee on Land Subsidence in the Nobi Plain established in 1961, which is organized by three national institutions, three prefectures, one city and two port authorities, collects and summarizes the observed values in order to proclaim the present condition of land subsidence on September 1 every year(Disaster Prevention Day in Japan).

Several methods1, 2) have been used in calculations of the safety groundwater level and/or the allowable yield of groundwater needed to stop the land subsidence. The observation wells were used in the estimation of the allowable yield. The mutual relationship between yearly averaged value of groundwater head and yearly deformation of ground was studied by Ministry of Land, Infrastructure, Transport and Tourism, Water Management and Land Conservation Bureau1). This procedure requires another relationship between average value of groundwater head and yearly groundwater withdrawal. The authors have been tackling a three dimensional finite element simulation of regional groundwater flow in the whole area of the Nobi plain3). Land subsidence was computed by the one dimensional finite element model at the observation wells. The model was coupled with the three dimensional groundwater flow model through the boundary conditions of piezometric head of confined aquifer. The combination of the three dimensional groundwater flow and the one dimensional land subsidence model showed excellent results of which fifty percent decrease of groundwater withdrawal in 1971 can stop the progress of land subsidence due to the drawdown of piezometric head of groundwater induced by excess withdrawal.

Numerical methods such as finite elements are one of supreme tools for estimating the allowable yield of groundwater and/or the safety groundwater level within the aquifers. Geological features in regional hydrology background were easy to reflect in the models. However numerical modeling asks for a lot of information about the parameters reflecting local geological and hydrologic features within the flow region. Lots of trial calculations were sometimes needed for precise results under several scenarios. Especially special attention was important to get the most suitable estimates of the parameter values, such as hydraulic conductivity, specific storage, compressibility, etc.

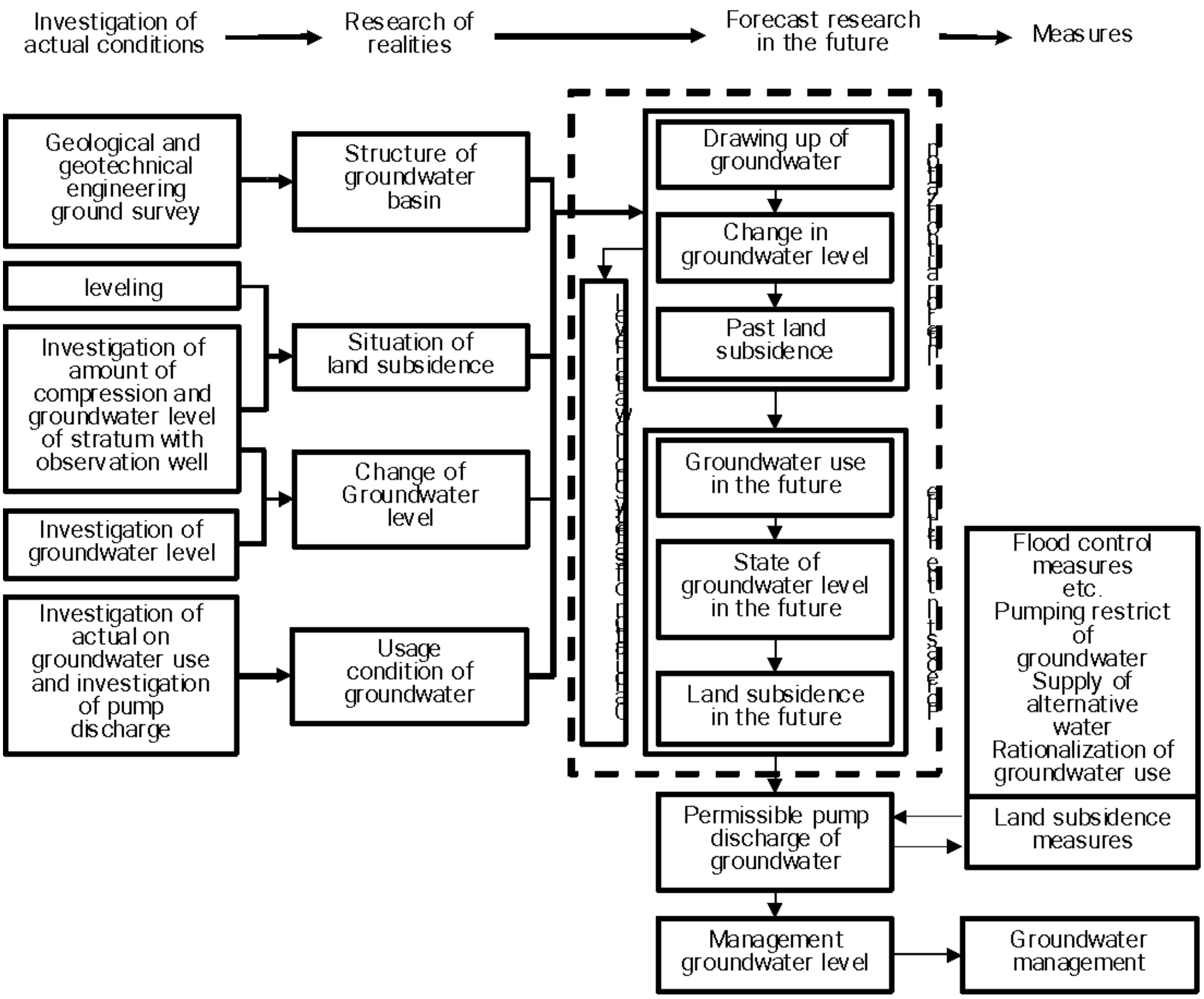

Figure 3 Subjects of The Tokai Three-Prefecture Investigation Committee on Land Subsidence Organized by Ministry of Land Infrastrubture, Transport and Tourism, Ministry of Economy, Trade and Industry, and Ministry of Agriculture, Forestry and Fisheries, Aichi Prefecture, Gifu Prefecture, Mie Prefecture, Nagoya City, Nagoya Port Authority and Yokkaichi Port Authority.

Results

The committee has been investigating the mutual relationship between land subsidence volume and groundwater withdrawal since 1975. A good linear relationship was confirmed as shown in Fig.4. A regression analysis was applied with correlation coefficient of 0.944 to the estimation of the allowable yield in the Nobi plain. Figure 4 shows a graphical method to check the relationship between land subsidence volume (V) and groundwater withdrawal (Q). The graph expresses not only the value of the allowable yield in the Nobi groundwater basin but also the justice of the countermeasures in the plain except the value in 1994.

An unique straight line of falling to the right can be drawn on the graph with reference to subsided volume and groundwater withdrawal during one year. The falling to the right straight line expresses a comprehensive correlation between groundwater withdrawal and subsided volume under the excess withdrawal condition in the Nobi groundwater basin. This line will be different to each groundwater basin reflecting with geological features, weather conditions, human activities, etc.

The graphical method of V-Q relation has been applied to the estimation of allowable yield which stopped land subsidence in the Nobi plain. As for the measured values since 1992, the subsided volume remains zero even when groundwater withdrawal is recorded as almost the same value of the threshold of the allowable yield.

Subsided volume was measured in the draught of 1994 even when groundwater withdrawal was recorded less than the threshold. Such an intense groundwater discharge during short term can not be pursued by the V-Q relation. The V-Q relation assumes that yearly difference of groundwater withdrawal keeps a strong mutual relation to land subsidence which is measured once a year. The quantity of zero in the subsided volume is recognized that piezometric head of groundwater continues rising to satisfy the mass balance of groundwater that keeps equilibrium condition of income and expenditure averaged by one year.

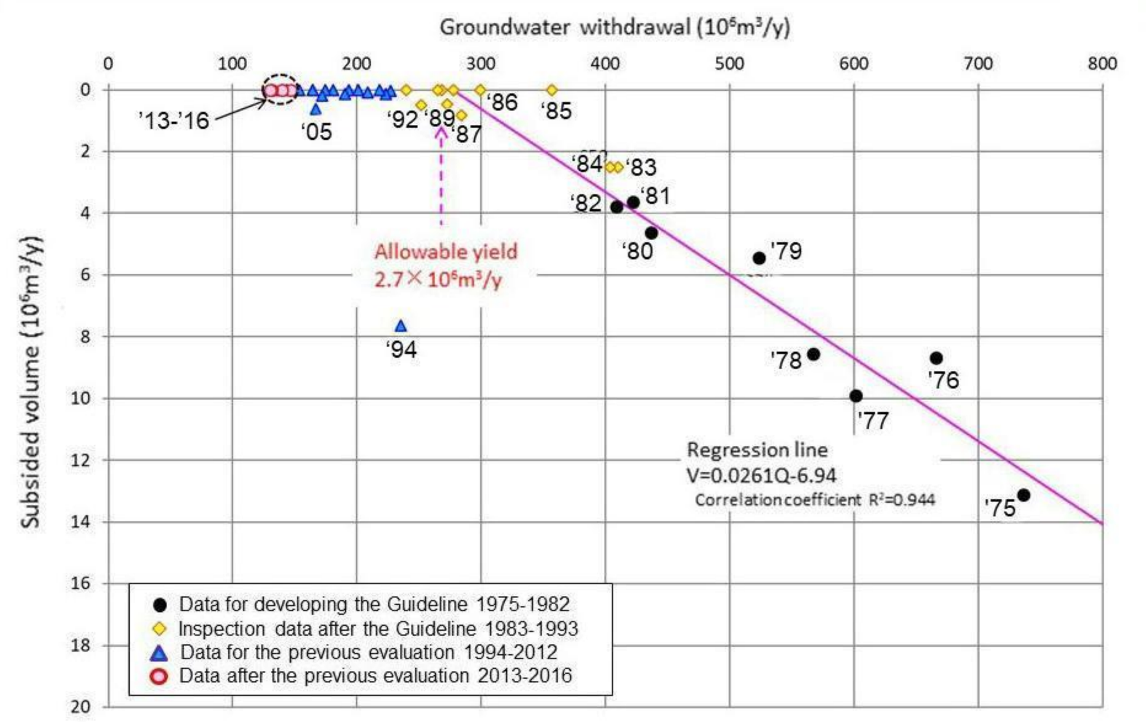

Figure 4 Relation between groundwater withdrawal(Q) and subsided volume(V).

References

Ministry of Land, Infrastructure, Transport and Tourism, Water Management and Land Conservation Bureau (2020). Evaluation and Review Committee for Prevention of Land Subsidence in The Nobi Plain(in Japanese)

The Tokai Three-Prefecture Investigation Committee on Land Subsidence (1985). Land Subsidence and Groundwater in The Nobi Plain(in Japanese), The University of Nagoya Press

T. Sato, K. Daito and K. Ueshita (1986). Analysis of Land Subsidence Due to Withdrawal of Groundwater in the Nobi Plain, Proceedings of 3rd International Symposium on Land Subsidence, pp.89-99