EVALUATION ON HYDRAULIC CHARACTERISTICS OF AQUIFERS WITH THE DEEP WELL DATABASE IN THE OSAKA PLAIN, SOUTHWEST JAPAN

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ABSTRACT

In the urbanized alluvial plain in Japan, ground subsidence was occurred due to over pumping of groundwater after the World War II. Japanese government and local administration have regulated the usage of groundwater in such area since the 1960's. The groundwater regulation brought the ground subsidence to a stop. For the countermeasure, Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has been surveying the deep tube well data in Japan. This result is gathered together into a database which is released into the public domain on the Internet. This database consists of geological data, hydraulic properties of wells and groundwater quality just after drilling at each site since 1952.

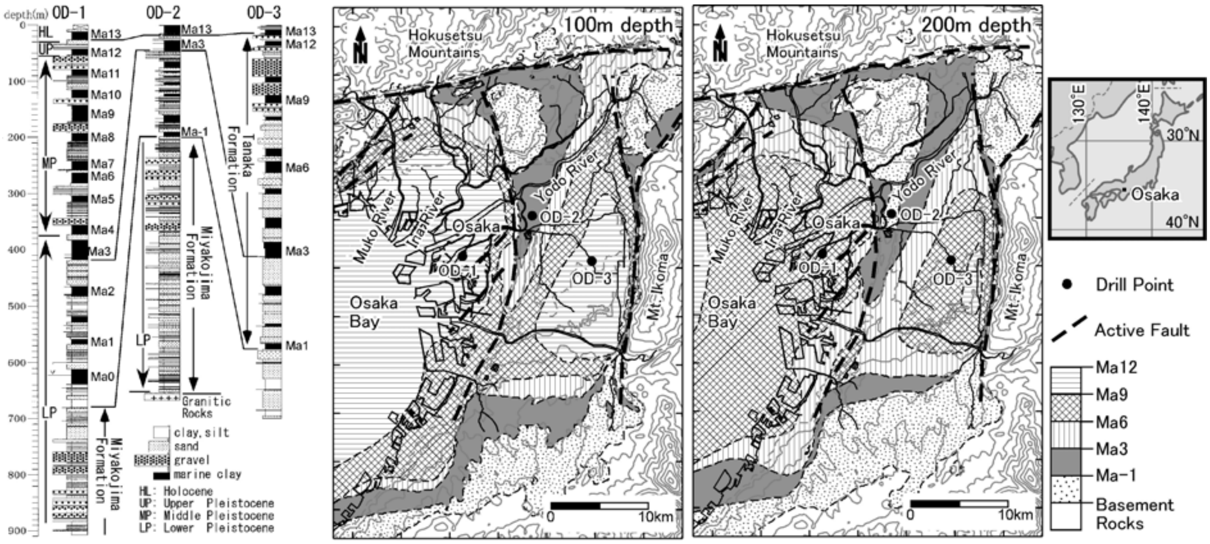
The hydraulic characteristics of aquifers are evaluated from deep well data using with the database. The exploitable well data in the Osaka Plain is 1061 site which drilled from the 1950's to the 1980's. About 70% data is well drilled from the 1960's to the 1970's. Intended purpose of well, well depth, length of the well strainer, natural water table, pumping rate, are specific capacity of well are plotted as distribution maps. Because almost wells are closed due to the groundwater regulation now, these maps present the groundwater feature from about 40 to 50 years ago. But, the distribution map on specific capacity of well indicates hydraulic property of aquifer in the Osaka Plain. 76% of the wells were install strainers from 100 to 300 m depth. This horizon is correlated to upper Middle Pleistocene formation (the horizon from Ma9 to Ma12 marine clay bed; MIS 11 to 5e). On the other hand, the main aquifer in the hilly area is correlated to the lower half part of the Quaternary formation.

The specific capacities of wells in the northeastern part of the Osaka Plain are over 1000 m2 / day, and higher than the other area. On the other hand, specific capacities in the hilly area are less than 100 m2 / day. In the southern part, specific capacities are gradually increase from hilly area to coastal area. This distribution of specific capacities suggests that the lower part of the Quaternary formation is lower permeability than the upper horizons. Because the Yodo River flows in the northeastern part of the Osaka Plain, Quaternary formation in this area deposited mainly coarser sediments such as fluvial sediments and alluvial fan deposits. So, the specific capacity in this area is higher than the other area in same Quaternary horizon.

1. INTRODUCTION

The urbanized lowland areas in Japan caused ground subsidence for the excessive pumping of the groundwater. The Japanese government and the local administration regulated the pumping of groundwater for an anti-subsidence measure. By this regulation, the ground subsidence has been able to calm. For actual situation grasp of the subsurface water use, the administration collected the basic documents of existing deep wells. These well data have been gathered up in several account books (e.g., National Land Agency of Japan, 1975), and computerized as a database on the World Wide Web.

The Osaka Plain also has been one of the subsidence areas in Japan. The groundwater regulation gave an effect for restraint of the ground subsidence (Editorial Committee for Technical Report on Osaka Land Subsidence, 1969). But, the new issue in groundwater, such as pollution, pumping from deeper aquifer, pumping out of regulation is occurring (Togami and Hashimoto, 2002). For the countermeasure on current problems, the aquifer properties



(a) (b) (c)

Figure 1. Subsurface Geology of the Osaka Plain.

(a): geologic logs of deep drilling (Yoshikawa and Mitamura , 1999)

(b): subsurface geologic map at 100 m depth form ground surface

(c): subsurface geologic map at 200 m depth form ground surface

must be clarified with collecting the information of many aspects. This deep well database is available for the evaluation on the aquifer characteristics and groundwater condition in the groundwater usage area. This paper reports the case study of the evaluation on the Quaternary aquifer properties with deep well database and the 3D-model of Quaternary formation in the Osaka basin.

2. QUATERANRY FORMATION AND AQUIFERS

Several active faults run along the margin of the Osaka Basin. This region has been subsided tectonically since Quaternary. The mountain range around the basin distributed as uplifted areas. Total vertical displacement is ranging more than 1000 m. The total thickness of the Quaternary formation is more than 1500 m (Figure1a; Editorial Committee for Technical Report on Osaka Land Subsidence, 1969; Ikebe *et al.*, 1970).

The lower half of the formation (the Miyakojima Formation) mainly consists of sandy alternation deposited in fluvial and lacustrine environment (Yoshikawa and Mitamura, 1999). Muddy layers intercalated in the sands and gravels are weak horizontal continuity. Thickness of this formation is about 1000 m tick under the alluvial plain (Figure 1a). This formation directly exposed in the northern and southern hilly area of the lowland area. These exposed formations named as the Osaka Group (Pleistocene). The upper half part of the Quaternary formation (the Tanaka Formation) is alternation sands and marine clays, and more than 500 m thick (Figure 1a). This formation intercalates more than 10 marine clay beds named as Ma-1, Ma0, Ma1, Ma2, …, Ma12 (Yoshikawa and Mitamura, 1999). These marine clay beds continue well horizontally, and deposited in the inner bay environment at interglacial stages. Main tick marine clay beds, such as Ma1, Ma3, Ma6, Ma9, and Ma12, are correlated with Marine Isotope Stage (MIS) 23, 21, 19, 11, and 5a in each other (Yoshikawa and Mitamura, 1999). This formation is correlated with upper half part of the Osaka Group and terrace deposits in the hilly area. The recent alluvial formation (the Namba Formation) ranging from upper Pleistocene to Holocene covers unconformically the former formations in the alluvial plain. The Namba Formation intercalates a Holocene marine clay bed in the middle part, and is 30 m thick.

Aquifers of the Quaternary formation are mainly divided into lower half and upper half zones correlated with the Miyakojima and Tanaka formations in each other. Groundwater for industrial use was pumped up from the upper half zone (the Tanaka Formation), and caused ground subsidence due to the compaction of marine clay beds. The upper half zone can be divided into several sub aquifer zone with main thick marine clay beds.

The 3 dimensional model of the Quaternary formation in the Osaka Basin has been constructed with geologic map in hilly areas, deep drilling logs, seismic surveys, and gravity surveys (Mitamura, 2004). Figure 1b and 1c shows the subsurface geologic maps on 100, 200 m depths. The Quaternary formation generally dips toward the center of the basin (the center of the Osaka Bay). The lower part of the formation is exposed in the marginal area of the basin. The Uemachi Fault running from north to south in the central part of the Osaka Plain makes basement rocks a vertical displacement ranging about 1000 m. The geologic structure in the Osaka Plain is divided into the western part and the eastern part with this fault. The geologic structure of eastern part between the Uemachi and the Ikoma Faults tilts down toward southeast. Quaternary strata in the western part gently dip to the center of the Osaka Bay.

3. GROUND SUBSIDENCE AND CURRENT GROUNDWATER PROBLEM

The Osaka Plain has been also caused ground subsidence for the excessive use of groundwater from 1950 to 1965(Editorial Committee for Technical Report on Osaka Land Subsidence, 1969). Before the remarkable subsidence, the main horizon for the pumping object of groundwater was the confined aquifer from 30 to 40 m deep. The development of powerful borehole pump enabled the pumping from deeper aquifers. The upper half part of the Quaternary formation consists of the alternation gravel, sand and thick marine clay beds of the Middle-Upper Pleistocene and Holocene. The excessive use of groundwater caused the consolidation of marine clay beds. As a result, the cumulative subsidence for 30 years from 1935 to 1965 reached nearly 3 m in the coastal area of the Osaka Plain (Editorial Committee for Technical Report on Osaka Land Subsidence, 1969). Osaka Prefecture and Osaka City devised the regulations of the groundwater pumping, and the subsidence become calmness in around 1965. The content of the regulation is to make well strainer depth more shallow than 500 or 600 m, and to do the area of the outlet of pump with lower than 21 cm^2.

Because the lower half part of the Quaternary formation mainly consists of sandy alternations, this part also constitutes good aquifers, and includes hot groundwater from 30 to 50 ˚C due to geothermal gradient. Because the deeper horizon than 600 m is out of the pumping regulation, the groundwater of this horizon came to be pumped up by spa resort institutions. On the other hand, by the development of the high-performance pump, enough quantity of water is able to be covered with pumps of the small outlet out of regulation. A large-scale hospital and the commercial institution are pushing forward well developments in the regulated horizon as the exclusive water service. These well developments may cause groundwater disorders and a recurrence of the subsidence.

The Osaka Plain is also the urbanized area, and located industrial areas. The industrial activity generates pollution in the local factory sites and the local shallow aquifer. Most cities do not supply groundwater for water service business in the Osaka Plain. But, it is important to improve the subsurface environment for sustainable development of the city area. The groundwater table becomes shallow in comparison with the time when the subsidence is prosperous due to the pumping regulation of groundwater (Togami and Hashimoto, 2002). The shallow ground water table in the aquifer near the ground surface causes liquefaction at earthquake. It is necessary to lower the water table of shallow aquifers for earthquake disaster reduction. For improvement of groundwater environment and

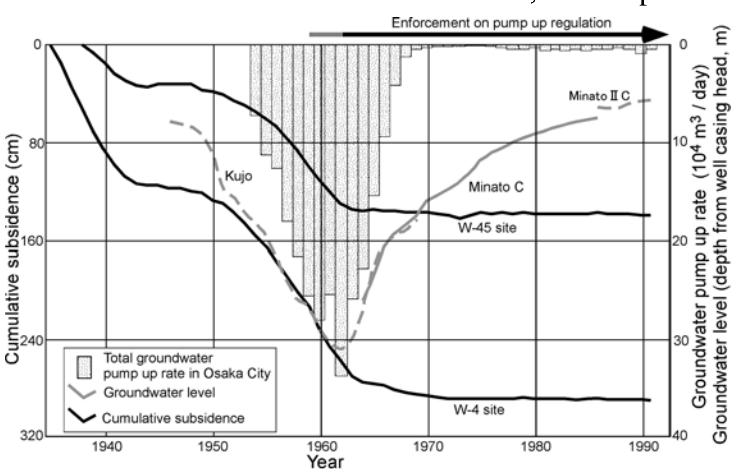


Figure 2. Ground subsidence in Osaka City.

(Committee on the countermeasure of ground subsidence in Osaka, 1997) disaster prevention, the shallow groundwater needs to be performed sustained practical use.

As above mentioned, the current groundwater problems consists of environmental improvement of shallow aquifer, sustainable use of middle and deeper aquifers. For these problem approvals, it is necessary to grasp the characteristic of aquifers in detail and regionally.

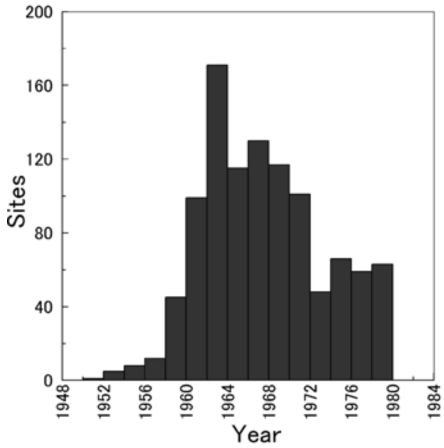


Figure 3. Histogram on installation date of Well in using data.

4. DEEP WELL DATABASE

Land and Water Bureau, National Land Survey Division, Ministry of Land, Infrastructure, Transport and Tourism, Japan has carried out the basic survey on water resources (groundwater survey) which has collected deep tube well document of all over Japan since 1952. These well documents are gathered together into a public domain database on the Internet (http://tochi.mlit.go.jp/tockok/inspect/ landclassification /water / basis / underground /F9_exp.html). These documents consist of geologic features of drilling log data, aquifer properties by pumping test, and groundwater quality. These data are saved in the ASCII text format of a TAB end with a header which is able to read with the spreadsheet software. This data file mainly consists of survey year, region code, geodesic coordinates, groundwater usage, drilling length, length and location of screens, groundwater table in natural and pumping, pumping rate, geological column, water temperature and pH, and main element of groundwater quality. Well data in every prefecture or district is saved a file in each other. The well location data is saved by the Environmental Systems Research Institute (ESRI) Shapefile format.

5. AQUIFER PROPERTY OF QUATERNARY FORMATION

This study used 1061 tube well data which is described drill length, strainer features, pumping rate, and groundwater table in the data file of the Kinki District. These well data ranges 30 years from 1950's to 1980's (Figure 3). The 70% of these data covers 10 years from 1960 to 1970, because the groundwater regulation has started form 1965 for countermeasure to ground subsidence.

Wells for miscellaneous use are the most, and are slightly concentrated around northern and southern hilly areas. The secondly many uses are for industry. These wells are located in the lowland areas in the main part of the Osaka Plain. Wells for agricultural use are located in the hilly areas and around the terrace.

The deepest wells reach to 1000 m depth, and almost wells were drilled less than 400 m depth. 54.4% of the wells were drilled from 100 to 200 m depth (Figure 4). Almost wells have several strainer sections. In general, the total strainer length is about 50 m. The water intake positions extend over the several aquifers. As mentioned above, almost well data are from 1960's to 1970's. In this term, the groundwater table in lowland area was located from 20 to 40 m depth. The water table in the northern hilly area is more than 50 m depth.

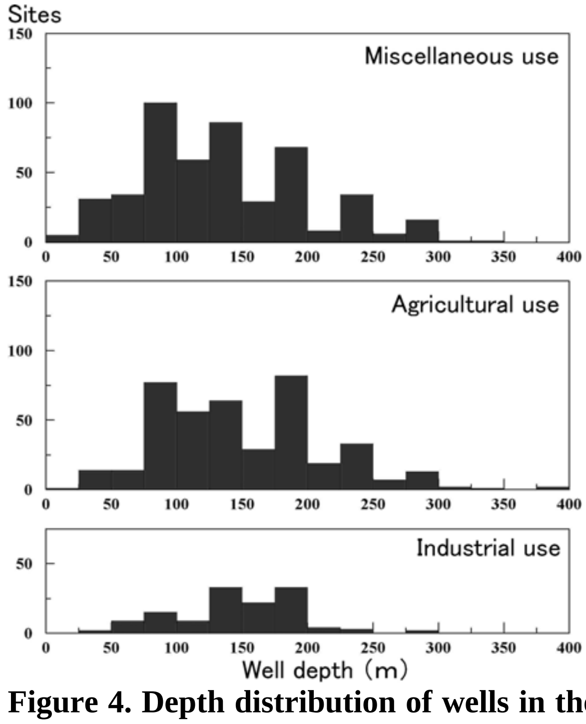


Figure 4. Depth distribution of wells in the Osaka Plain.

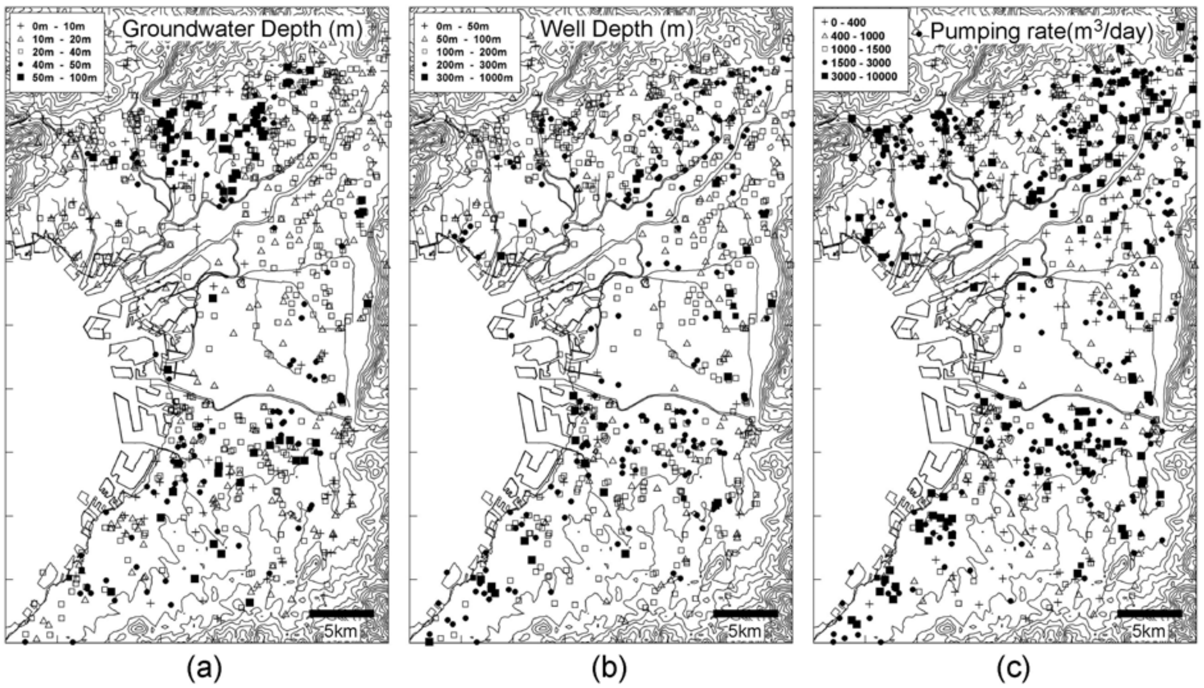


Figure 5. Distribution on common items of deep well data.

(a): Groundwater depth on natural state, (b): Well depth, (c): Pumping rate. Almost data is from 1960 to 1970.

Pumping rate is larger in the terrace area and lowland area along the large rivers, such as the Yodo, Muko, Ina rivers. In these areas, pumping rate at one well is more than 3000 m^3/day. Because almost records of the pumping rate in the lowland area are after the regulation for the ground subsidence, the pumping rate was less than 1000m^3/day.

Specific capacity is the pumping rate at unit drawdown level (1 m), and is an index almost equivalent to transmissivity. Specific capacity in the northern area is larger than the southern area. Particularly, the specific capacity in the northern part along the Yodo River is more than 500m^2/day. The specific capacity in the hilly area is relatively small. In the southern part of the plain, specific capacity gradually decreases from coastal area to hilly area.

Compared with the distribution of Quaternary formation and the well strainer data, the horizon of Quaternary formation of the aquifer for pumping groundwater becomes clear. the Horizon in the lowland area is correlated with the Middle Pleistocene sand and gravels (upper part of the Osaka Group, mainly between Ma6 and Ma12 beds). The horizon in the hilly area corresponds to the Lower Pleistocene (lower to lowermost part

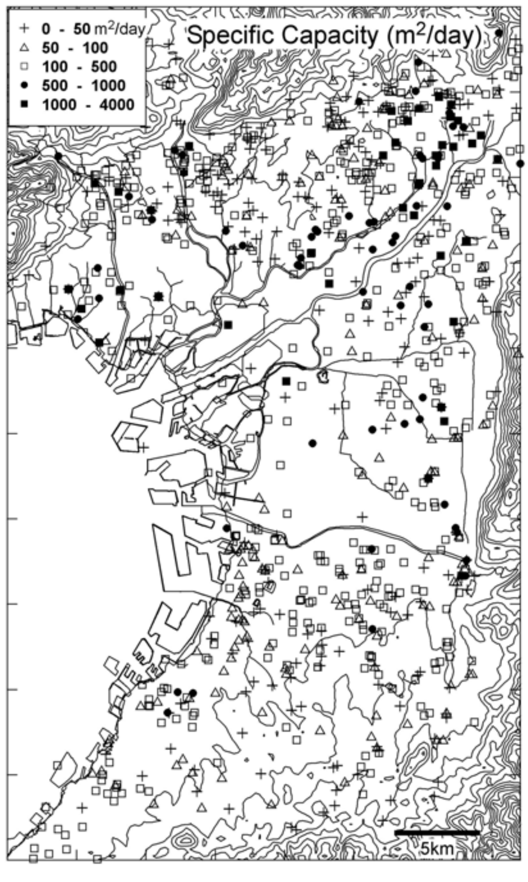


Figure 6. Distribution of calculated specific capacity of wells.

of the Osaka Group, mainly below Ma-1 bed). The distribution of the specific capacity suggested that the Lower Pleistocene formation has smaller permeability (below 5E-5 m/sec) than the upper horizons. The Middle Pleistocene aquifers in the northern area along the Yodo River have large specific capacity. In this area where is located in the northeastern inlet of the Osaka basin, coarser sediments are deposited along the old Yodo River and alluvial fans from the northern mountains. The aquifers in this area consisting of coarser materials have larger permeability (from 1E-4 to 1E-2 m/sec) than in the other areas.

Recently, groundwater table gradually recovers near the sea level in the low land area due to the effect of the regulation for countermeasure to ground subsidence (Togami and Hashimoto, 2002). But, ground water level in the hilly area does not trend to recover until now (Yoden, 2004). It is clear that the decreasing of water recharge from the ground surface in the hilly area is due to paving with asphalt and cement by developing of residential areas.

6. CONCLUSION

As the result of the evaluation on the Quaternary aquifer with deep well database and the 3D geological model in the Osaka Plain, we made clear the Quaternary aquifer properties as follows.

The aquifer for pumping groundwater in the lowland area is correlated with the Middle Pleistocene horizons, such as the upper part of the Osaka Group, and in the hilly area correlated with the Lower Pleistocene horizons, such as the lower and lowermost part of the Osaka Group. The distribution of the estimated specific capacity suggests that the Lower Pleistocene horizons are lower permeability than the upper horizons. In the northern area along the Yodo River, Quaternary aquifers consisting of coarser materials have the largest permeability in the Osaka Plain. Recently, the residential development in the hilly areas has decreased the recharge of groundwater by covering the ground surface with impermeable materials.

The accumulation of these deep well data is available for the evaluation on aquifer systems. However, recent pumping data is not stored to the database in the Osaka Plain, because many wells have been closed for the shift to industrial water works from the Yodo River. On the other hand, deep wells and pumping systems out of regulation is increasing now. So, the pumping up groundwater from these aquifers is not completely regulated in the Osaka Plain, and needs to be managed under the groundwater monitoring. We have to investigate the groundwater flow system with the clarified aquifer property, the 3D model, and additional data on groundwater in the Osaka Basin.

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