Hydrogeology on Echi-gawa Alluvial Fan, Shiga Prefecture, Central Japan

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Abstract

The R. Echi-gawa is one of the major rivers in Shiga Prefecture with the river length of 50 km and the catchment area of approx. 204 km^2. Upstream area of the basin from "Eigenji" is steep mountainous area in the Suzuka Mountain Range while downstream area is flat land. The Echi-gawa alluvial fan is formed by the fluvial terrace deposits, which inclined gently toward northwest direction from the apex-of-fan part near "Eigenji" temple.

The terrace deposits is divided into Terrace I (upper) to Terrace V (lower). At the upstream side, the geology of R. Echi-gawa basin mainly consists of sedimentary rocks of Paleozoic-Mesozoic, Cretaceous welded tuff (Koto rhyolites) and granite. In the downstream side, Late Pliocene-Early Pleistocene Kobiwako Group and Late Pleistocene-Holocene deposits are distributed with the basement of the Koto rhyolite.

Most groundwater used in the Echi-gawa alluvial fan area is groundwater embedded in the Kobiwako Group, and the aquifer is roughly classified into three layers, Shallow Aquifer, Medium Aquifer, and Deep Aquifer.

The Shallow Aquifer consists of the terrace gravel layer, and the sand and gravel beds which are the surface layers of Kobiwako-Group. Thickness of the Shallow Aquifer varies depending on the locations. The thickness of the aquifer is 20m-30m from the apex-of-fan part to the center-of-fan part while it is 50m-60m from the center-of-alluvial-fan part to the toe-of-fan part. Besides, toe-of-fan part corresponds to the eastern edge of distribution of inselberg of the Koto rhyolites, and the Shallow Aquifer extended downstream from this part is overlaid by the alluvium and groundwater is confined.

The Medium Aquifer is composed of sand and gravel layer with thick silt layer, and is distributed in a depth of 30m-80m and the Deep Aquifer is located below the Medium Aquifer. Groundwater in the Medium and Deep Aquifers is confined.

Judging from the coefficient of permeability, which varies from 1.2×10^{-4} to 4.0×10^{-6} m/sec and 1.0×10^{-5} m/sec order in average, the permeability of sand and gravel layer of Kobiwako Group is relatively high and good as groundwater aquifer. On the other hand, the silt layer of the Kobiwako Group is considered as the aquiclude with the coefficient of permeability of 7.4×10^{-7} to 1.6×10^{-8} m/sec. The permeability of the terrace gravel bed is very high with the coefficient of permeability of 3.7×10^{-3} to 1.0×10^{-4} m/sec.

KEYWORDS : Groundwater, Kobiwako Group, Echi-gawa alluvial fan, Hydrogeology

1. Introduction

In the Echi-gawa alluvial fan, the groundwater is used as a source of agriculture and industrial water as well as domestic water. The proportion of groundwater to the water resources in the area is the highest in Shiga

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Prefecture. The irrigation and industrial waters are taken from the several hundreds shallow wells along the former river course of R. Echi-gawa and also many discharge wells from the aquifer in the Kobiwako Group on terrace (Fig.1).

However, study on hydrogeology of the basin has been merely conducted. In this paper, hydrogeology of the Echi-gawa alluvial fan is studied based on the surface-geology exploration, the boring-survey, the hydrogeological data from the existing wells and other geological-survey data.

It is noted that alluvial fan is defined as "half-conic geographical feature made by moving a river channel by making into an apex of fan the place where the river comes out from mountain to the flat ground (Saito, 1988, 2006)", and "distribution area of alluvial fan deposit" is not considered.

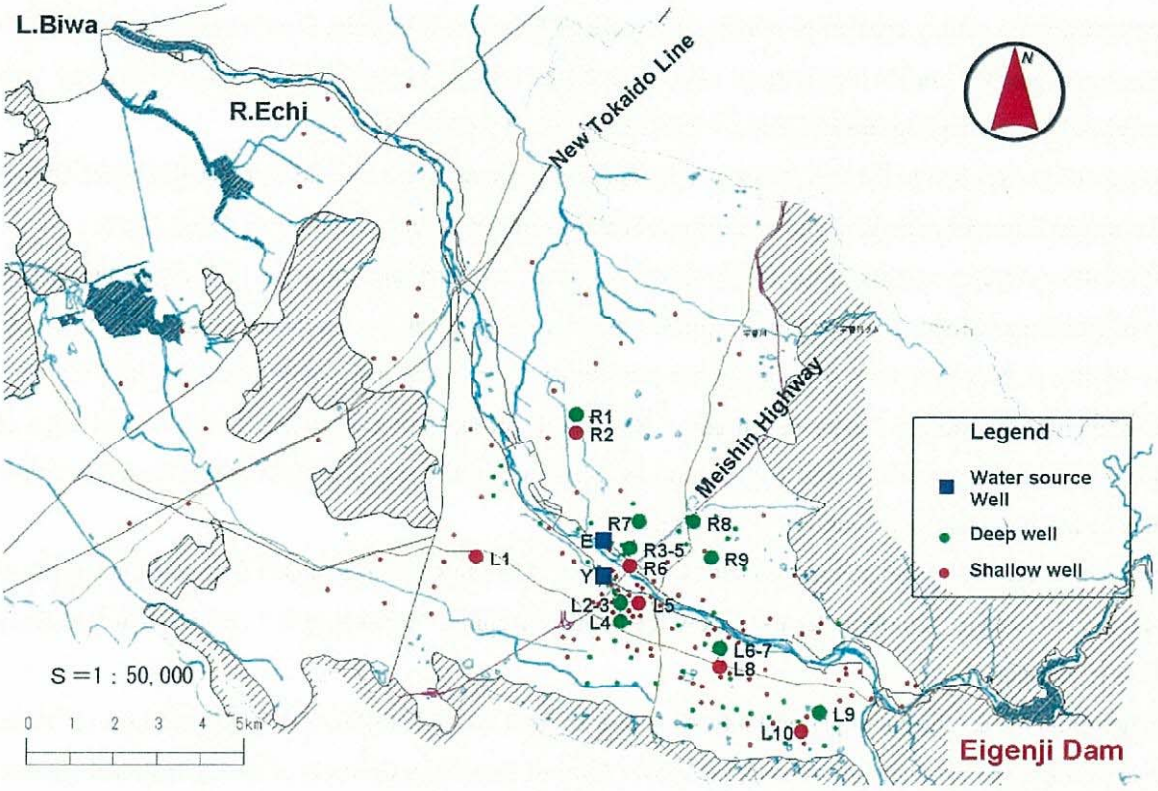

Fig.1 Outline of Echigawa Alluvial Fan

2. Geomorphology

2.1 Outline

The outline of geomorphology of the R. Echi-gawa basin is shown in Fig.2.

The Omi basin including the Lake Biwako is a tectonic basin surrounded by the north-south trend horst mountains (Okada et al., 2000). Around the Lake Biwako, some alluvial plains are found along rivers which flowing into the Lake. The Koto plain located in the southeast of Lake Biwako is the largest plain. There are some deltas and fans which were formed by R. Echi-gawa, R.Hino-gawa and R.Yasu-gawa in the Koto plain.

Fig.2 Geographical Feature of Echigawa Alluvial Fan

The Suzuka Mountain Range which is the catchments area of R. Echi-gawa runs from north to south. And two faults are runs in parallel at the both at east and west foothills. The accumulation displacement of the fault is larger at the east side fault namely Isshi fault. Besides, displacement during the Late Quaternary Period of the Isshi faults is also larger than that of west side fault. Therefore, the Suzuka Mountain Range is the tilted block mountains that western slope are slightly gentler than eastern slopes. The main ridge line which is north-south sequence of peaks with altitude 1,000 to 1,200m including Mt. Gozaisyoyama (EL.1,212m) is located in eastern part of the Suzuka Mountain Range.

The R.Echi-gawa is one of the major rivers in Shiga Prefecture with the river length of 50 km and the catchment area of approx. 204 km^2. Some rivers such as R.Oike-gawa and R.Chaya-gawa originated in the Mt.Oike-dake (EL. 1,247m), and R.Kanzaki-gawa originated in Mt.Gozaisyo-yama meet one another upstream of the Eigenji Dam reservoir, and change the name into R. Echi-gawa. R. Echi-gawa flows to west from the downstream of the Eigenji Dam and changes the direction to northwest in the lowland and flows into the east coast of Lake Biwako. Upstream area of the basin from "Eigenji" is steep mountainous area in the Suzuka Mountain Range while downstream area is flat land. The river course is relatively straight with 300-400m width, and the watercourse winds to the downstream on the inside of it with about 50m width. Some natural levees, former river beds, and

back marshes are developed at the lower river basin below EL. 100m. At the river mouth area, width of watercourse widen to 150m and a delta is formed. In the lower basin, some inselbergs of Koto rhyolites are remains and there are inner lakes of Lake Biwako, such as a "Nishiko" and Dainaka_no_ko" although they had been reclaimed.

The Echi-gawa alluvial fan has been formed by the fluvial terrace deposits which inclined gently toward northwest direction from the apex-of-fan part near "Eigenji". The terrace deposits is divided into Terrace I (upper) to Terrace V (lower). The Terrace IV (lower) and Terrace V (lowermost) might be formed in the later half of the Last Glacial Stage as evident from ^{14}C age dating (30 ka to 33 ka) of the fossil plants (Ikeda et al., 1979).

The border of the flatland and the mountains runs from north to south, and shows the shape of a terminal facet. Relative heights of this escarpment is 250-400m, and the dissection has been processed. Ravines such as R.Karyogawa has developed. The alluvial cones by small-scale debris flow are formed at the mouth of these ravines, and these cones have forms the alluvial fan compounding with terraces. This phenomenon is obvious in the mouth of R. Karyogawa.

There are four steps of bottom-of-lake terraces in the Lake Biwako, consisting of the "Buried Terrace" at 45-80m depth, the "1st Terrace" at 20m depth, the "2nd Terrace" at 10m depth, and the "3rd Terrace" at 5m depth (Koya, 1971). These are the submergence deltas formed due to retreat one after another, and the "1st Terrace" and the "2nd Terrace" connects to the "lower" and "lowermost" terrace, respectively (Uemura, 1979).

2.2 Echi-gawa alluvial fan

On the right bank of R. Echi-gawa, Terrace I is distributed at the elevation of 150m - 260m i.e. on the west of Hyakusaiji. On the left bank of R. Echi-gawa, Terrace I is distributed on the ridge of the Yokaichi hills. The Terrace I connects to the terrace surfaces around "Eigenji" such as the terraces along R.Shibukawa. The gradient of Terrace I is about 1.6% in average although it is slightly steep with 3.0 to 10.0% along R.Shibukawa and in the Yokaichi hills part.

On the R. Echi-gawa right bank area, Terrace II is extended from the mouth of valley with the elevation of EL. 220m to northwestward until the point where elevation of about EL. 150m. The slope of the Terrace II is gentle from 0.8 to 1.0%. The boundary between Terrace I and Terrace II is marked by a terrace scarp with about 10m of relative heights. On the R. Echi-gawa left bank area, Terrace II forms the basin of R. Hebisuna-gawa in the north foothill part of the Yokaichi hills. The slope is gentle varying from 1.0 to 1.3% in upstream and 0.5 to 0.7% in downstream.

On the R. Echi-gawa left bank area between R. Echi-gawa and Happukaidou highway, Terrace III is extended from the elevation of 170m near the mouth of valley to the Higashi-Omi city area. The slope of Terrace III is about 0.6% in average. Terrace III is merely distributed over R. Echi-gawa right bank area. On the R. Echi-gawa left bank area, the boundary between Terrace II and Terrace III is a terrace scarp of 2-5m relative heights.

Terrace IV forms a gentle slope from the elevation of 140m to the elevation of 100m in the R. Uso-gawa basin on the left bank of R. Inukami-gawa. The slope of Terrace IV is 0.2% in downstream area and the 0.9 to 1.0% in

upstream area. Besides, Terrace IV is correlated with the flatland in Gokasyo area at the R. Echi-gawa left bank of which slope is 0.4%. The tip of Terrace IV is buried in the alluvial plain of the Lake Biwako.

Terrace V has been formed by repeated river course change of R. Echi-gawa with lateral erosion in Terrace II, Terrace III and Terrace IV. Slope of the terrace is 0.4 to 1.0%. Relative height to the present R. Echi-gawa river course is 3m-5m, and the natural levee has been developed. The tip of Terrace V is also buried in the alluvial plain of Lake Biwako.

Alluvial cones with the about 5.0% slope have been formed at the mouth of valley of R.Wnami-gawa, R.Karyo-gawa and R.Uso-gawa and so on.

The Echi-gawa alluvial fan is the composite fan made up by combining alluvial cones and Terrace groups, which inclined toward the Lake Biwako.

Besides, alluvial plains, outer beaches, and deltas are developed at the tip-of fan area. And some natural levees are remains along the old watercourse of R. Echi-gawa.

The slopes of riverbeds of R. Echi-gawa are 8.5% at the mouth of valley in "Eigenji", 0.6% at the Kasuga Bridge (national road No. 307) and the Echi-gawa Bridge (Meishin Expressway) in the central part of the fan, and 0.2% at Tokaido Shinkansen route at the end part of the fan. On the lower R. Echi-gawa, the gradient of riverbed is less than 0.1%, and the watercourse width is about 50m.

3. General Geology

At the upstream side, the R.Echi-gawa fan area mainly consists of sedimentary rocks of Paleozoic-Mesozoic, Cretaceous welded tuff (Koto rhyolites) and granite. In the downstream side, Late Pliocene-Early Pleistocene Kobiwako Group and Late Pleistocene-Holocene deposits are distributed overlying the Koto rhyolite (Fig.3).

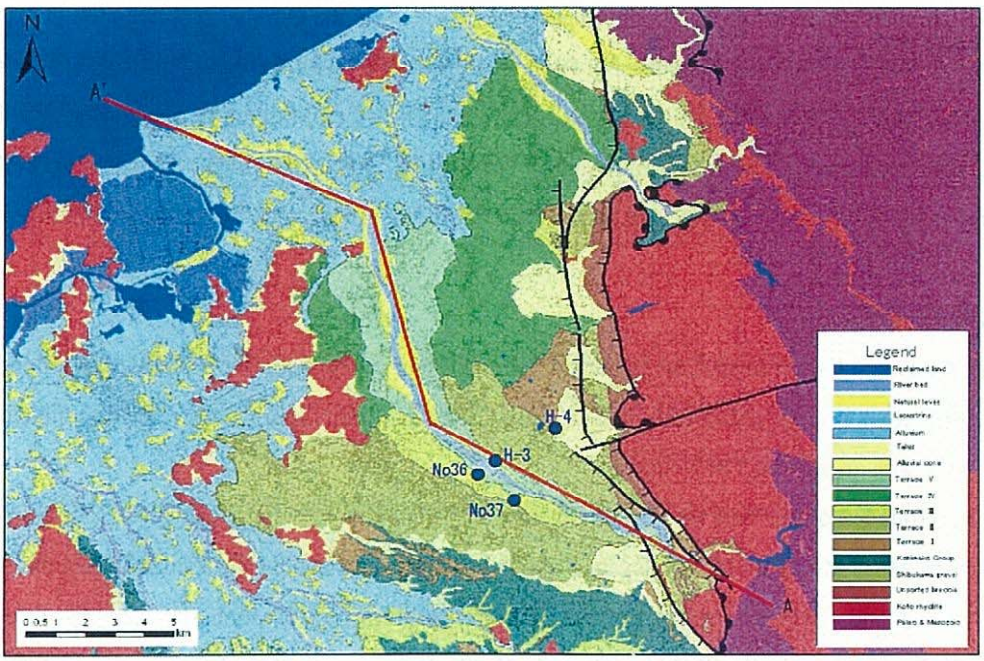

Fig.3 Hydrogeological map of the Echigawa Alluvial Fan

3.1 Basement Rocks

The Paleozoic and Mesozoic strata of the Mino-Tamba area in the R. Echi-gawa basin are divided into the greenstone-limestone facies and clastic rock facies. The greenstone-limestone facies consists of greenstone and limestone, whereas the clastic rock facies mainly of sandstone and mudstone (Harayama et al., 1989).

It is known at Late Cretaceous to Paleogene that the Felsic Igneous Activity widely occurred in the inner zone of Southwest Japan.

The granitic batholiths, such as the Hira granite, the Hiei granite, the Tanokami granite, the Yasu granite, and the Suzuka granite, are distributed around Lake Biwako, and as a matter of fact the lake is surrounded by these granite bodies.

These felsic volcanic rocks are welded tuff, quartz-porphyry, granite porphyry, volcaniclastic rock, and are named as Koto rhyolites generically. In addition, about Koto rhyolites, there are existence of the ring dykes located on circumference of 11 km and 17 km in radius centering on Yokaichi. Hence, the Koto cauldron of the Valles-type caldera is advocated (Nishikawa et al., 1983).

Furthermore, the granitic batholiths which enclose southern part of Lake Biwako form a huge ring complex measuring 60 km by 40 km. The biotite K-Ar age of those granites is concentrated within 68-75 Ma and the contemporaneity of felsic igneous activity became clear. The biotite K-Ar ages of the ring dike (Inukami granite porphyry) of the Koto cauldron are 72 Ma. The similar K-Ar age suggests that the formation of the "Koto cauldron" and the intrusion of the granites are simultaneous and that it is a double cauldron structure (Sawada et al., 1988).

Koto rhyolites are divided into three rock masses from the distribution, and are called the East Rock Mass inserted as dyke of the shape of a double arc on the east, the Main Rock Mass of the inner side, and the Plain Part Rock Mass with which it is dotted in the shape of an inselberg in the Omi basin (Miyamura et al., 1976). The west edge of the Main Rock Mass is Hyakusaiji Fault, and the relation with the Plain Part Rock Mass is made unknown (Harayama et al., 1989). Koto plain are dotted with Plain Part Rock Mass in the shape of an inselberg, such as the Mts.Okushima-yama, Okishima, Kojin-yama, Wada-yama, Kinugasa-yama, Azuchi-yama, Minotukuri-yama, Yukino-yama, Fuse-yama, Kamewari-yama, Hachiman-yama, Maruyama, Okayama, among others.

3.2 Kobiwako Group

The Kobiwako Group constitutes the Daini Setouchi Supergroup with the Osaka Group around Osaka Bay and the Tokai Group around Isewan (Ichihara ed, 1993).The Kobiwako Group is distributed at the Ueno-basin and the Omi-basin with an elevation of 70-250m.

It is surrounded on the east side by the Suzuka and Nunobiki Mountain Range (elevation 600-1,200m), south side by the Muro Mountain Mass (elevation about 1,000m), west side by the Yamato-Shigaraki plateau (elevation about 600m), and northwest side by the Hira-Hiei Mountain Range (elevation 800-1,200m). Total thickness of the Kobiwako Group amounts to 1,500m. All deposits are gravel, sand, silt and clay under the lacustrine and fluvial conditions on the inland basin from Pliocene to early Pleistocene (Nakazawa et al., 1987).

At about 4 Ma, the fracture blocking occurred in the peneplain area around the Iga basin, and the subsidence area became the Kobiwako sedimentary basin. In the Kobiwako sedimentary basin, the subsidence area shifted northwestward gradually.

By 2-3 Ma, it became as the center of the sedimentation at the Koga area and the Gamo area. Then, the Iga basin, the Koga area, and the Gamo area became an uplift region. On the other hand, since the subsidence in the present Lake Biwako area advanced, the center of the Kobiwako sedimentary basin was further shifted northwest. The sedimentary basin took the same form as of the present Lake Biwako at 1 Ma. Therefore, as for the Kobiwako Group, the lowermost part bed is distributed around the Iga basin. On the upper part bed is distributed at the northwest side of the Kobiwako sedimentary basin (Matsuoka, 1979).

On the basis of tephrochronology, the Kobiwako Group is divided into the Ueno Formation, the Iga Formation, the Ayama Formation, the Koga Formation, Gamo Formation, the Kusatsu Formation, the Katada Formation, and the Takashima Formation by the sedimentary facies from the lower (Kawabe,1989).

The results of an investigation of R. Echi-gawa fossil forest show that the Echi-gawa alluvial fan area was widely covered by Gamo formation (Hayashi et al., 1993, Amemori et al., 1993). The sedimentation age of the Gamo Formation is about 2.8 Ma - 3.6 Ma from the Fission-track age of a tephra (Yoshikawa et al., 1993).

Table 1 Geological Correlation Table on Echi-gawa alluvial fan

<table>
<tr><th colspan="3">Geogic Age</th><th colspan="3">Geologic system</th></tr>
<tr><td rowspan="11">Cenozoic</td><td rowspan="6">Quaternary</td><td rowspan="5">Holocene</td><td colspan="2">Fluvial Deposits</td><td>channel bar, natural levee, & overbank deposits</td></tr>
<tr><td colspan="2">Talus Deposits</td><td></td></tr>
<tr><td colspan="2">Lacustrine Deposits</td><td>L. Biwako</td></tr>
<tr><td colspan="2">alluvial cone</td><td>R. Karyogawa</td></tr>
<tr><td colspan="2">Terrace V</td><td rowspan="2">fan</td></tr>
<tr><td>Pleistocene</td><td colspan="2">Terrace I ~ IV</td></tr>
<tr><td rowspan="5">Neogene</td><td rowspan="4">Pliocene</td><td rowspan="4">Kobowako G.
Gamo Formation</td><td>Upper Silt</td><td>silt</td></tr>
<tr><td>Upper Gravel</td><td>sand & gravel</td></tr>
<tr><td>Middle Member</td><td>silt with sand & gravel</td></tr>
<tr><td>Lower Gravel</td><td>sandy silt, sand & gravel</td></tr>
<tr><td rowspan="2">Kobiwako G.
Basal Units</td><td colspan="2">Shibukawa Gravel Bed</td></tr>
<tr><td>Miocene</td><td colspan="3">Unsorted Sedimentary Breccia</td></tr>
<tr><td colspan="2">Paleogene</td><td colspan="3"></td></tr>
<tr><td colspan="2">Mesozoic</td><td>Cretaceous</td><td colspan="3">Koto Rhyolites & Suzuka Granite</td></tr>
<tr><td colspan="3">Pleozoic</td><td colspan="3">Paleozoic & Mesozoic strata (slate・sandstone・greenstone・chert・limestone)</td></tr>
</table>

(1) Basal Facies

The Gamo Formation and the Kusatsu formation are distributed around Echi-gawa alluvial fan area, trends northeast-southwest and dips northwestward with homoclinal structure of 3 to 10 degrees. And in the most case, the Kobiwako Group is in contact with the basement rocks of the Suzuka Mountain Range by the fault. But in part, the Kobiwako Group rests unconformably on the basement rocks. The Kobiwako-Group basal facies layers are distributed over this abutment part.

Along the Hyakusaiji fault which is the west side of Suzuka Mountain Range, a well-compacted unsorted sedimentary breccia like a talus deposit is distributed on the plain side at the piedmont area of Matsuodera-Hyakusaiji-Tokoji-Eigenji.

The unsorted sedimentary breccia is constituted by the gravel from the Koto rhyolite. The breccia of 1m of diameters is observed. The unsorted sedimentary breccia is considered as the layer deposited on the marginal part of the Gamo group sedimentary basin rapidly subsidence with activity of the Hyakusaiji fault.

And, there is a distribution of the Shibukawa Gravel Bed (Nishikawa et al., 1979) along R. Shibu-kawa. This Shibukawa Gravel Bed is constituted by rounded to sub-rounded boulders with poor sorting of about 100m thickness which overlapped the basement rocks with an unconformity. Upward, the conformable sedimentation is continued at the Gamo Formation which is alternation of gravel, mud, and sand.

These "Unsorted Sedimentary Breccia" and "Shibukawa Gravel Bed" is different from Kobiwako Group such as the Gamo Formation in sedimentary facies. The Gamo Formation is a sedimentary facies with the remarkable lateral change in the clay, silt, sand, and gravel bed. Distributions of basal facies are restricted to the piedmont near the Hyakusaiji fault and Watamukiyama fault as west edges of the Suzuka Mountain Range. In this paper, they are distinguished as the Kobiwako Group basal facies.

Unsorted Sedimentary Breccia

Shibukawa Gravel Bed

Photo 1 Basal Units of Kobiwako Group

(2) Gamo Formation

The Gamo Formation of Kobiwako Group crops out widely at the Yokaichi hills near the Echi-gawa alluvial fan. The Gamo Formation is widely distributed also under the terrace plain, and the bed is several hundreds meters thick. The Gamo Formation with interbedded silt, sand, and gravel layers, is predominant with silt. Furthermore it is accompanied by the clay layer and the lignite bed.

The silt layer is silt to pebbly-silt and the sand layer is fine-grained to coarse-grained sand. The gravel layer is granule and pebble-rich with well rounded of a several centimeters in diameter. The well-rounded pebble is mainly chert and sandstone, and there are very little granite pebbles. The gravel layer cut off the sand layer and the silt layer and has deposited as the channel structure. And the stratified structure can also be confirmed in the gravel layer. The cross lamination has been developed into the sand layer. These observations show that the Gamo Formation distributed over the Echi-gawa alluvial fan is a deposit of a fan delta (Photo 2).

In the center of the Echi-gawa alluvial fan, the four core drillings for the inspection wells of H-3 (on the Terrace V at the right bank of R. Echi-gawa), H-4 (on the Terrace II at the right bank of R. Echi-gawa), No.36 and No.37 (on the Terrace III at the left bank of R. Echi-gawa), are carried out (Photo 4).

In H-3, under the terrace gravel with 5.5m thick, the gravel layer is observed up to the depth of 28m. The silt / sand alternation layer (up to the depth of 41.5m), the gravel layer (up to the depth of 44.2m), the silt layer (up to the depth of 55m), the gravel layer (up to the depth of 76m), the silt layer (up to the depth of 84.5m), the silt / sand / gravel alternation layer (up to the depth of 92m), and the gravel / sand layer (up to the depth of 102m below) are observed.

In H-4, under the sandy surface-soil with 3m of thickness, the gravel layer is observed mainly up to the depth of 68m on the bottom of well, with intercalated layers of sand and silt with several meters of thickness.

In No.36 (No.19, No.20), under the terrace gravel with 5.5m thick, The gravel / sand / silt alternation layer is observed up to the depth of 34m. While the silt layer (up to the depth of 42m), the gravel / sand alternation layer (up to the depth of 50m), the silt layer (up to the depth of 52m), the gravel / sand alternation layer (up to the depth of 58m), and the silt layer (up to the depth of 60m below) are observed.

In No.37, under terrace gravel with 8.5m thick, the gravel / sand / silt alternation layer is observed up to the depth of 17.5m. And the silt layer (up to the depth of 31m), the gravel / sand alternation layer (up to the depth of 38m), the silt layer (up to the depth of 53m), the sand layer (up to the depth of 56m), the silt layer (up to the depth of 82m), the sand / silt alternation layer (up to the depth of 96m), and the silt layer (up to the depth of 100m below) are observed.

Also by the audit observation of the borehole core, the Kobiwako Group of the underground of an Echi-gawa alluvial fan also became clear that change of a stratigraphic facies is remarkable laterally and in the perpendicular direction, and the same layers laterally impersistent in an outcrop scale.

Photo 2 Gamo Formation of Kobiwako Group

3.3 Covered Sediments

It is classified as covered sediments which overlies the Kobiwako Group, the terrace deposit which constitutes the Echi-gawa alluvial fan, the alluvial-plain deposit which constitutes the lowland of the Lake Biwako circumference, the natural-levee deposit and backmarshes deposit of R. Echi-gawa and other rivers, the talus deposit formed on the outskirts of inselberg of Koto rhyolites, the debris flow deposits from the R.Karyo-gawa which forms an alluvial cone, the present river bed deposit of R. Echi-gawa, and the lacustrine deposits of a Lake Biwako.

In the previous investigations (Ishida et al., 1984, Yoshida et al., 2003, Harayama et al., 1989, etc.), the terrace deposit is described in proportion to each terrace. A stratigraphic facies changes with differences of the conditions of weathering, the portion having decayed gravel bed with red soil and the other portion is a relatively fresh gravel bed.

The terrace deposits, less than 10m thick, consist of abundant pebble- to cobble- size gravel and rare sand. The rounded to subrounded gravel is mainly chert with sandstone, mudstone, welded tuff, and granite originating from the basement rock. In addition, in the Echi-gawa alluvial fan, the terrace gravel as the fluvial sediment formed by the debris flow, the flood, are seen on Terrace I, Terrace III, Terrace V, and it is not distributed on Terrace II and Terrace IV.

The deposits that constitute alluvial plain are distributed over the Nishi-no-ko outskirts or the Lake Biwako coast, mainly consists of the mud and the sand, and contains the peaty mud. Moreover, in the Lake Biwako shoreline, several hundreds meters wide beach and the beach ridge are developed that consist of comparatively well sorted medium to fine grained sand with granule. The thickness of this deposit is 10-15m, and is 30m at the maximum (Yoshida et al., 2003).

The natural-levee deposit along the former river course of the river consists of the fine to medium grained sand

in many cases, in contrast to the outskirts being mud deposit, although there is almost no relative height difference with the outskirts.

The talus deposits formed on the piedmont of the steep slope of the inselberg of Koto rhyolite are aggregates of rock waste, and form the geographical feature of talus, alluvial cone, piedmont slope, etc.

The alluvial cones are formed at the mouth of valleys of R. Karyo-gawa, R. Uso-gawa, and R. Inukami-gawa by the debris flow deposits and the deposit consists of boulder and sand (Harayama et al., 1989).

The present river bed deposit of R. Echi-gawa is the gravel layer distributed even near the altitude of 90m with the sandbank formed along a riverbank, or the river-channel. The kind of gravel originates from the basement rocks, such as chert, sandstone, mudstone, greenstone, granite, and welded tuff, with subrounded to rounded shape. From the Echi-gawa bridge to the Kawabe bridge by the side of the upper stream, sorting of the gravel is poor and boulders of around 1m of diameters are scattered. Near the Miyuki bridge by the side of the lower stream, the sorting of gravel becomes relatively good and there is little boulder. Grain size of the river bed near Miyuki bridge is granule- to pebble-size and mixed cobble-size (Yoshida et al., 2003).

The lacustrine deposits of the bottom of the Lake Biwako near the R. Echi-gawa river mouth area, are Late Pleistocene sandy littoral sediments formed under the conditions of wave-induced current as same as the present conditions. The lake ward parts show regular pro-gradation of sediments with dips angles similar to those in the present shore-face slope, and they represent shore-face (partly deltaic) features. The sedimentary sequences which suggest the relative water-level rise, barrier-growth, lagoon-filling, over-wash, transgressive lag deposits, and coastal onlaps around sequence boundaries suggest the stepwise rise in water-level. During the last 25 thousand years, the average amplitude and cycle of lake-level rise are estimated as 3.5 m and 3,500 years, respectively (Miyata et al., 1990).

Photo 3 Watamukiyama Fault

3.4 Faults in between which Alluvial Fan was formed

The west edge of the Suzuka Mountain Range is separated by some faults the plain, it is in contact with the plain with Hyakusaiji Fault (Okada et al., 2000), Watamukiyama Fault (Okada et al., 2000), and Kouzubata Fault (Harayama et al., 1989) around the Echi-gawa alluvial fan. Besides, the Kobiwako Group distributed over the plain side shows the monoclinic structure which inclines northwestward with 3 to 10 degrees of dip as a whole, While near the fault on the west edge of the Suzuka Mountain Range, several hundreds meters of width inclines steeply, and an overturned structure is also seen on Kouzubata Fault at R. Wanami-gawa.

Nishikawa et al.(1979) has reported the "Koto rhyolite gravel bed" (Yokoyama et al., 1991) located in the Suzuka Mountain Range below the Kobiwako Group, and the distribution of those gravel beds are of about ten places, but are restricted. The gravel beds like the "Sasagatani gravel bed" (Nishikawa et al., 1979) are distributed over the west foot part of Suzuka Mountain Range, and is assigned to the "talus breccia" and the "Shibukawa gravel bed" as basal layers of the Kobiwako Group.

The Hyakusaiji Fault forms the terminal facet on the west edge of the Suzuka Mountain Range in a north direction from "Eigenji" to a Hyakusaiji and Matsuodera. The fault outcrops cannot be checked, but the dip of the Kobiwako Group distributed over the neighborhood is steep with 10 to 30 degrees. And the "talus breccia" of the basal layer of the Kobiwako Group is formed by this fault activity, and it is considered that it is involved also in formation of the sedimentary basin of the Kobiwako Group.

The Kozubata Fault is a fault extended in the direction of northwest-southeast which carries out the boundary of the Koto rhyolites and the Kobiwako Group on the right bank of R. Wanami-gawa. The Kobiwako Group distributed near this fault dip to west at about 60 degrees (Harayama et al., 1989). In addition, the linear terrace scarp which makes the boundary of Terrace I and Terrace II on the right bank of R.Echi-gawa is suggestive that the fault which goes side by side to Kozubata Fault is related by their formation.

The Watamuki-yama Fault (Photo 3) was continuing Kozubata and Shibukawa from the west foot of Mt.Watamukiyama, it is the low angled thrust fault with direction of N18E/62S, and boundary between the bedrock and the Kobiwako Group was confirmed at the channel floor of R. Wanami-gawa near Kozubata.

3.5 Formation of Alluvial Fan

The fault activity at the west edge of the Suzuka Mountain Range is closely related to formation of Echi-gawa alluvial fan as mentioned above. The sedimentary basin was made in the Pliocene at the Koto area by the faulting, subsidence on the west side area and uplift on the east side area. The talus breccia accumulated under the fault scarp and the pebble bed deposited in the surrounding area. The uplifted area on the east actualized and the Suzuka Mountain Range was formed. Many rivers flowed out westward and the fan delta was materialized in the mouth of valley. The fan delta progressed in the direction of west-northwest, and extended the sedimentary basin (Lake Gomoko), and the Kobiwako Group of Gamo Formation and Kusatsu formation deposited in the Early Pleistocene. Then, subsidence of the present Lake Biwako region started and the place of the sedimentation of Kobiwako Group was moved around the Lake Biwako. The emergence of the Koto area was carried out. The rise

of the Suzuka Mountain Range continued. Between the uplift movements, the old R. Echi-gawa extended the catchment area and made the gravel flow into a plain from the mouth of valley near "Eigenji". With the rise of the Suzuka Mountain Range that progressed gradually, the water way of old R. Echi-gawa changed and this area became a fan. Furthermore, it became a terrace during late period of the Last Glacial Stage (about 30,000 years before). At present R. Echi-gawa is kept up by Eigenji Dam and it became impossible to make a gravel flow out. Until very recently, the R. Echi-gawa produced the gravel flow out and distributed the gravel of the present river deposit material even near the elevation of 90m near the Lake Biwako shore.

4. Hydrogeology

In the R. Echi-gawa area, the groundwater is widely utilized. The irrigation and industrial waters are taken from the several hundreds shallow wells along the former river course of R. Echi-gawa and also many discharge wells from the aquifer in the Kobiwako Group on the terrace. Besides, there are flowing well systems so called "Dokkoisyo". The water from "Dokkoisyo" is the confined water in the terrace gravel beds under the alluvial plain (Takaya et al., 1964). In the fan area, the spring water is observed under the terrace scarp from near the surface of unconformity of a terrace gravel bed and Kobiwako Group. It is considered that the unconfined groundwater in a terrace gravel bed is gushing out.

Most groundwater used in the Echi-gawa alluvial fan area is groundwater embedded in the Kobiwako Group. According to the well data (non-core) including wells for agriculture, personal wells, wells for Waterworks of Echi Regional Administration Cooperative and Higashi-Omi City, some sand and gravel beds as the aquifers are distributed in wide range. Based on the observation of core samples of inspection wells in which the drilling and installation were carried out by Echi Regional Administration Cooperative Waterworks and Higashi-Omi City Waterworks, except for the surface terrace gravel bed, there are many sand and gravel beds with several silt layers in the Kobiwako Group, and the trace of flows dividing into several layers are also observed such as discolored brown layers in these sand and gravel beds (Photo 4). However, the sedimentary facies of the Kobiwako Group on outcrops around the study area shows that the continuity of gravel bed is limited. The silt beds which are impermeable layers are also intermittent. Therefore, as shown in Fig.4, rough classification of aquifer is conducted into three layers assuming the intermediate layer with an alternation of silt and gravel, such as H-3 : 28.0m-76.0m, H-4 : 22.4m-68.4m, No.36 : 33.6m- , No.37 : 17.8m-57.8m. The upper is the Shallow Aquifer and the lower is the Deep Aquifer. The Medium Aquifer is in the intermediate layer. The groundwater is flowing through the gravel beds and the groundwater flows in the up-and-down direction across the aquifers are also expected. It is noted that the hydrogeology below 150m depth is unclear due to poor data.

The Shallow Aquifer corresponds to surface layers of Kobiwako Group and the terrace gravel layers. Although the aquifer extends to whole alluvial fan, its thickness changes remarkably at downstream side of Meishin Expressway in the center-of-alluvial-fan part and around the JR Tokaido Line in the apex-of-fan part. From the apex-of-fan part to the center-of-alluvial-fan part, the aquifer is in the sand and gravel beds of which thickness is 20m-30m. The sedimentary facies and aquifer thickness change remarkably at the center-of-fan part, and the

thickness becomes 50m-60m at the toe-of-fan part which is mostly identical with the distribution on the east edge of the inselberg of the Koto Rhyolites. At the apex-of-fan part to the center-of-fan part, the Shallow Aquifer is covered by the upper silt with a thickness of several meters which derived from the deposit of R. Echi-gawa riverbed, and the groundwater is confined in nature.

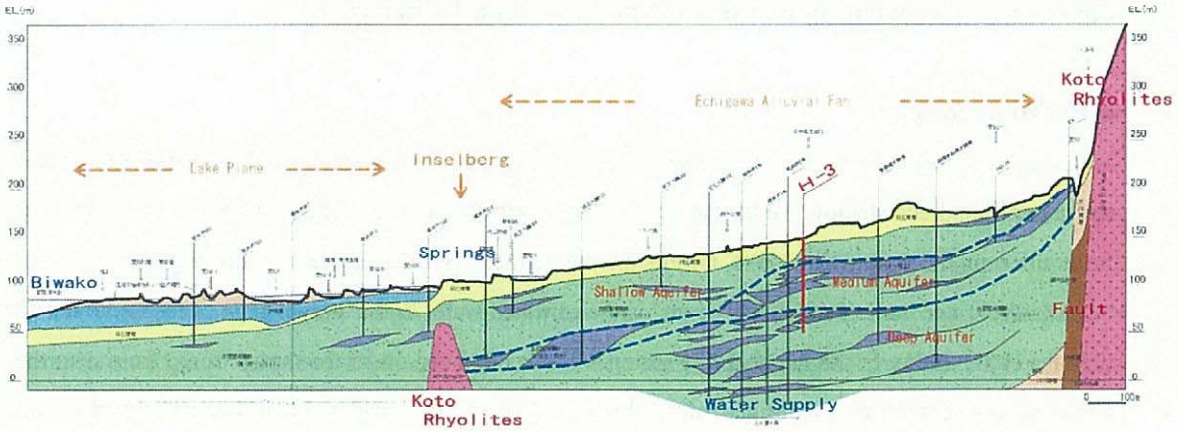

Fig.4 Hydrogeological Schematic Profile of Echi-gawa Alluvial Fan

Table 2 Measurement Results of Groundwater Level

Well	Screen (m)	Geology		Aquifer	Piezometric surface	
H-3-P	92.0m - 102.0m	Kobiwako G.	gravel	Deep	GL -10.19	EL.138.21
H-3-T1	55.0m - 78.0m	Kobiwako G.	gravel	Medium	GL -9.69	EL.138.71
H-3-T2	41.0m - 44.0m	Kobiwako G.	gravel	Medium	GL -9.31	EL.139.09
H-3-T3	1.5m - 15.0m	Terrace V	sand & gravel	Shallow	GL -3.82	EL.144.58
H-4-P	60.0m - 68.0m	Kobiwako G.	gravel	Medium	GL -21.00	EL.146.00
H-4-T1	28.0m - 34.0m	Kobiwako G.	gravel	Medium	GL -19.00	EL.148.00
H-4-T2	4.5m - 10.0m	Terrace I	sand & gravel	Shallow	GL -4.00	EL.163.00
No.36	43.5m - 52.85m	Kobiwako G.	gravel	Medium	GL -2.46	EL.140.60
No.37-1	93.0m - 95.25m	Kobiwako G.	gravel	Deep	Flow out	EL.168.00
No.37-2	31.0m - 33.2m	Kobiwako G.	gravel	Medium	GL -3.01	EL.164.99
No.37-3	11.5m - 17.6m	Kobiwako G.	gravel	Shallow	GL -2.50	EL.165.50

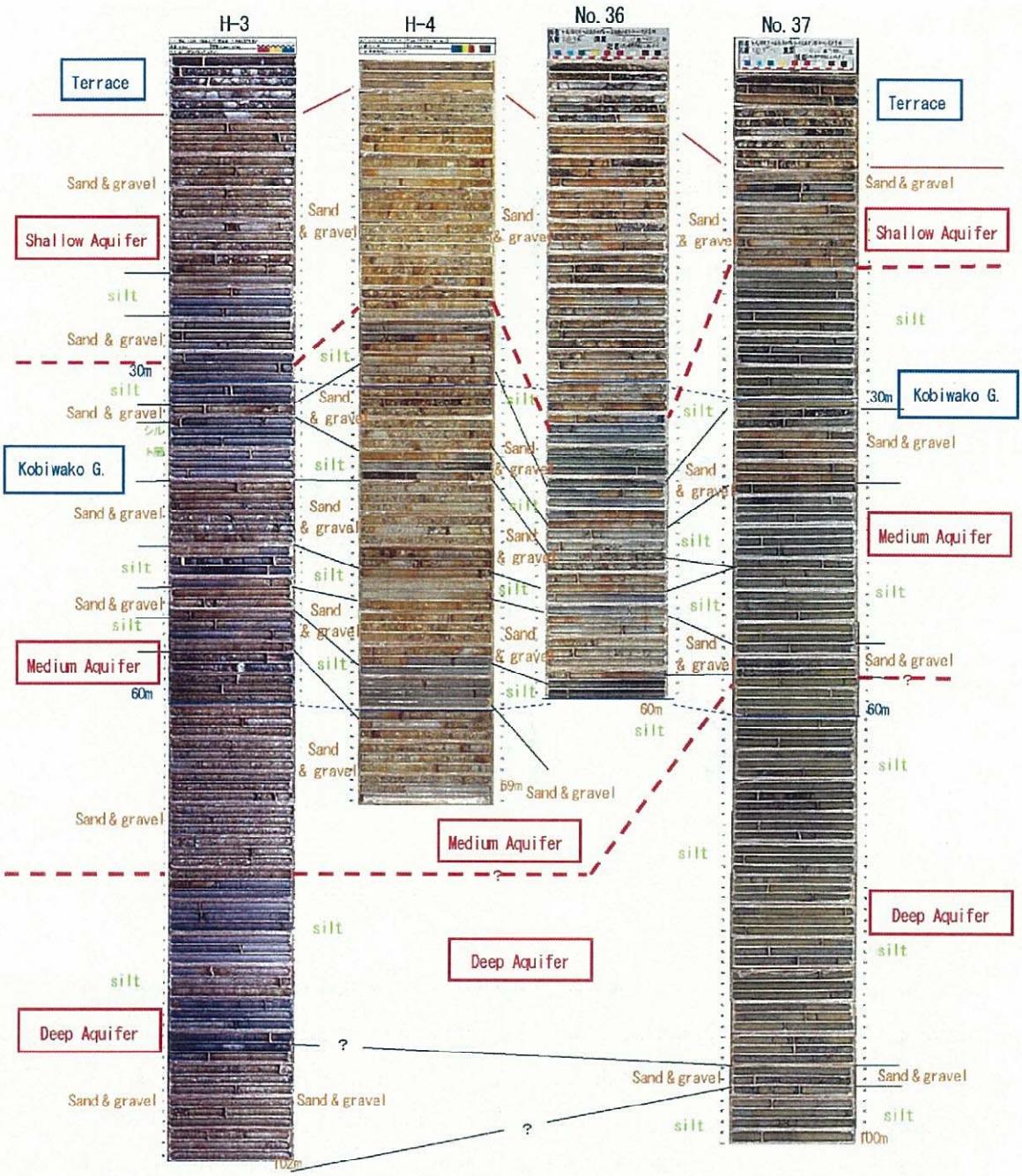

Photo 4 Core Conditions of Observation Wells

The groundwater levels of each aquifer based on the inspection wells data are shown in Table 2 and Fig.5. As shown in Table 2 and Fig.5, lower aquifer gives lower water level. Therefore, it is expected that the groundwater of in the Echi-gawa alluvial fan is permeated downward from ground surface.

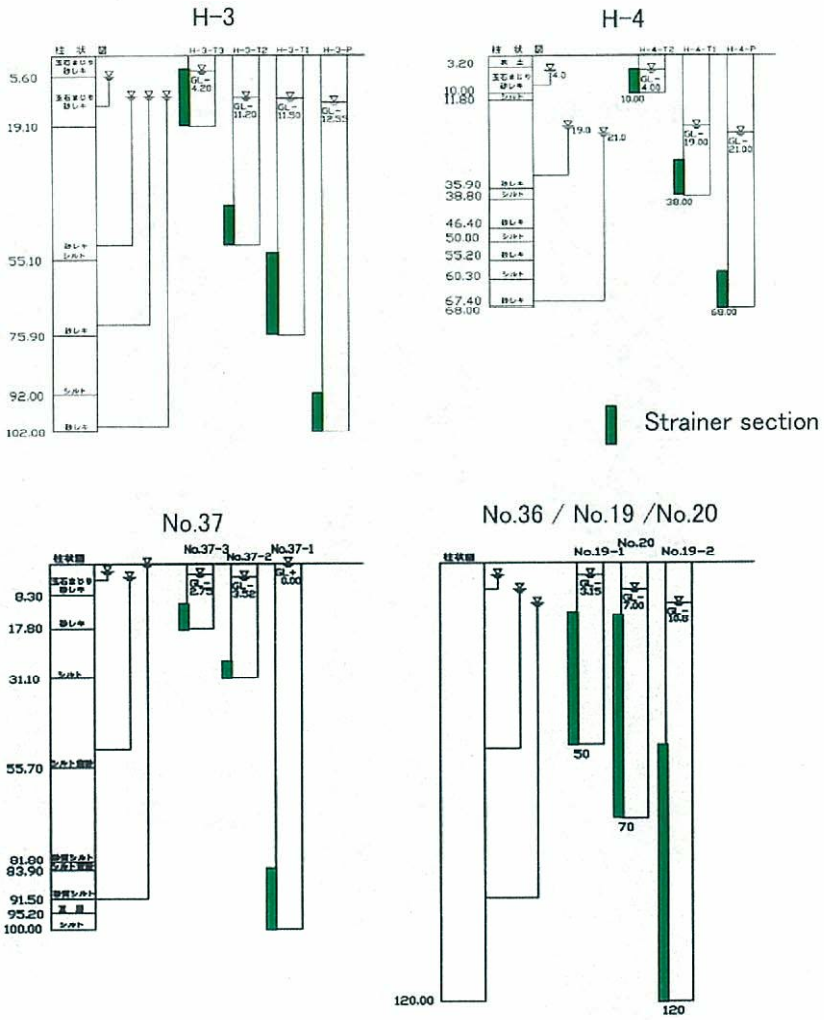

Fig.5 Groundwater Head

5. Permeability

The in-situ permeability test was carried out in the inspection wells by the Echi Regional Administration Cooperative Waterworks and the Higashi-omi City Waterworks. The test results are shown in Table 3.

The Shallow Aquifer consists of the terrace gravel beds and the upper gravel beds of Kobiwako Group. The permeability of the terrace gravel bed is very high with the coefficient of permeability of 3.7×10^{-1} to 1.0×10^{-2} cm/sec. Judging from the coefficient of permeability which varies from 1.5×10^{-2} to 4.0×10^{-4} cm/sec and 1.0×10^{-3} cm/sec order in average, the permeability of the upper gravel bed of Kobiwako Group is relatively high and good as groundwater aquifer. On the other hand, the upper silt bed of the Kobiwako Group is considered as the aquiclude with the coefficient of permeability of 1.6×10^{-6} cm/sec.

The Medium Aquifer is constituted by the alternate beds of silt and gravel. The coefficient of permeability of silt bed is 7.4×10^{-5} to 1.6×10^{-6} cm/sec, and classified into aquiclude. The coefficient of permeability of a gravel bed is 2.1×10^{-3} to 7.1×10^{-4} cm/sec.

In the gravel bed of Deep Aquifer, the coefficient of permeability is 1.2×10^{-2} to 5.8×10^{-4} cm/sec. And the coefficient of permeability showed 2.6×10^{-6} cm/sec in sandy silt bed.

Table3 Result of Permeability Test

Well	Depth (m)	Permeability (cm/sec)	Geology		Aquifer	Method	Groundwater Level
H-3	4.0-5.0	1.00×10-2	Terrace V	sand & gravel	Shallow	Rising-head	GL -2.19
H-3	12.0—13.0	1.99×10-3	Kobiwako G.	gravel	Shallow	Rising-head	GL -3.70
H-3	27.0—28.0	4.00×10-4	Kobiwako G.	sand	Shallow	Steady State	GL -3.68
H-3	39.0—40.0	1.57×10-6	Kobiwako G.	silt	Medium	Injection	GL -3.25
H-3	42.0—43.0	1.48×10-3	Kobiwako G.	gravel	Medium	Rising-head	GL -3.02
H-3	49.0—50.0	1.27×10-5	Kobiwako G.	sandy silt	Medium	Injection	GL -5.83
H-3	58.0—59.0	1.31×10-3	Kobiwako G.	gravel	Medium	Rising-head	GL -10.59
H-3	75.0—76.3	3.63×10-3	Kobiwako G.	gravel	Deep	Rising-head	GL -10.41
H-3	77.0—78.0	2.57×10-6	Kobiwako G.	sandy silt	Deep	Injection	GL -6.65
H-3	92.0—102.0	5.80×10-4	Kobiwako G.	alreted sand & gravel	Deep	Rising-head	GL -10.55
H-4_T2	8.0-9.0	5.06×10-2	Terrace I	sand & gravel	Shallow	Rising-head	GL. -2.30
H-4	8.5-9.5	1.57×10-3	Kobiwako G.	silty gravel	Shallow	Injection	GL. -3.62
H-4	17.0—18.0	5.35×10-4	Kobiwako G.	gravel	Shallow	Injection	GL. -8.06
H-4	26.9—27.9	2.16×10-4	Kobiwako G.	coarse sand	Medium	Injection	GL. -3.59
H-4	33.0—34.0	4.71×10-4	Kobiwako G.	gravel	Medium	Injection	GL. -15.80
H-4	53.1—54.1	9.81×10-4	Kobiwako G.	gravel	Medium	Injection	GL. -18.90
H-4	62.8—63.8	5.35×10-4	Kobiwako G.	gravel	Medium	Injection	GL. -14.70
No.36	5.9—6.6	1.52×10-2	Kobiwako G.	gravel	Shallow	Rising-head	GL. -2.62
No.36	17.6—19.2	1.99×10-3	Kobiwako G.	gravel	Shallow	Rising-head	GL. -3.60
No.36	44.0—45.1	7.05×10-4	Kobiwako G.	silty gravel	Medium	Rising-head	GL. -7.68
No.36	44.0—45.1	4.12×10-4	Kobiwako G.	silty gravel	Medium	Injection	GL. -7.68
No.36	52.0—52.9	2.12×10-3	Kobiwako G.	silty gravel	Medium	Rising-head	GL. -8.38
No.36	52.0—52.9	4.69×10-4	Kobiwako G.	silty gravel	Medium	Injection	GL. -8.38
No.37	5.0—6.0	1.46×10-2	Terrace III	sand & gravel	Shallow	Rising-head	GL. -4.08
No.37	16.0—17.6	2.19×10-2	Kobiwako G.	gravel	Shallow	Rising-head	GL. -3.57
No.37	19.0—21.0	1.56×10-6	Kobiwako G.	upper silt	Shallow	Steady State	GL. -3.57
No.37	31.1—33.2	7.63×10-4	Kobiwako G.	silty gravel	Medium	Rising-head	GL. -3.88
No.37	31.1—33.2	7.41×10-5	Kobiwako G.	silty gravel	Medium	Steady State	GL. -3.88
No.37	91.3—93.3	1.21×10-2	Kobiwako G.	gravel	Deep	Injection	GL. -0.30
ET-2	5.0—5.5	5.21×10-2	Terrace I	clayey gravel	Shallow	Injection	GL. -4.60
EY-3_1	26.5—27.0	5.87×10-3	Kobiwako G.	gravel	Shallow	Rising-head	GL. -6.30
EY-3_2	5.0—5.5	3.67×10-1	Terrace V	sand & gravel	Shallow	Rising-head	GL. -3.90

6. Conclusion

The hydrogeology of Echi-gawa alluvial fan is summarized as follows;

(1) The Echi-gawa alluvial fan is constituted by silt, sand, and gravel of the Gamo Formation of the Kobiwako-Group which were formed on the old Lake Biwako as a fan delta facies based on Koto rhyolites, and the overlying Terrace gravel.

(2) The Echi-gawa alluvial fan extends to northwestward from the mouth of a valley near Eigenji. The slope of ground is 0.5% to 5.0%. The Echi-gawa alluvial fan was formed by fault activity of the Hyakusaiji fault, the Watamukiyama fault, and the Kozubata fault which are extending in the direction from north to south at the west edge of Suzuka Mountain Range.

(3) Silt, sand, and gravel layers are stratified repeatedly in the Kobiwako Group and the continuity of each layer is scarce. In addition, there are some parts in the intermediate part which silt layer is predominating.

(4) Three aquifers, namely the Shallow Aquifer, the Medium Aquifer, and the Deep Aquifer, are formed in the sand and gravel beds of the Kobiwako Group.

(5) As for the result of the groundwater-level measurement, there is a tendency that the lower aquifer gives lower water level. The flow of the groundwater from the surface to the lower part in the whole alluvial fan is expected.

(6) The permeability of each aquifer is summarized in Table 4.

Table 4 Conclusion of Hydrogeology of Echigawa Alluvial Fan

Geogic Age			Geologic system			Permeability (cm/sec)	Aquifer
Cenozoic	Quaternary	Holocene	Fluvial Deposits		channel bar, natural levee, & overbank deposits		Shallow
			Lacustrine Deposits		L. Biwako		
		Pleistocene	Terrace I ~ V		fan	3.7×10-1~1.0×10-2	
	Neogene	Pliocene	Kobowako G. Gamo Formation	Upper Silt	silt	1.6×10-6	
				Upper Gravel	sand & gravel	1.5×10-2~4.0×10-4	
				Middle Member	silt	7.4×10-5~1.6×10-6	Medium
					sand & gravel	2.1×10-3~7.1×10-4	
				Lower Gravel	sandy silt	2.6×10-6	Deep
					sand & gravel	1.2×10-2~5.8×10-4	
			Kobiwako G. Basal Units	Shibukawa Gravel Bed			
				Unsorted Sedimentary Breccia			
		Miocene					
	Paleogene						
Mesozoic	Cretaceous			Koto Rhyolites			

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