3-3. Conprehensive Analysis of Obtained Hydrogeological Data

3-3-1 Outline

Considering all the hydrogeological investigation results, aquifer distribution, nature and water use in the investigation area are summarized as shown in Figure 3-3-1-2 The water head distribution and groundwater movement are inferred as shown in Figure 3-3-1-1. Hereunder, their conditions are explained by item.

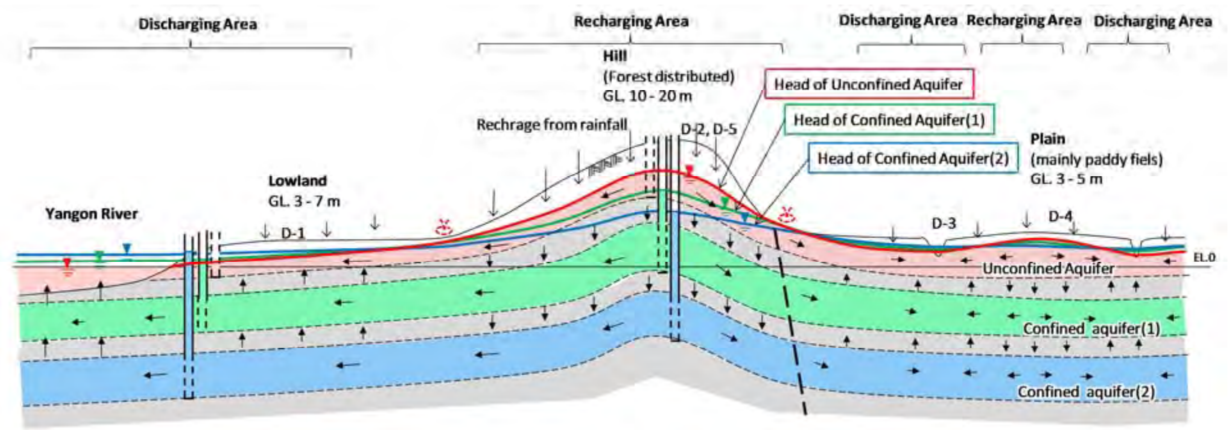


Figure 3-3-1-1 Schematic Profile of Groundwater Head Distribution and Movement

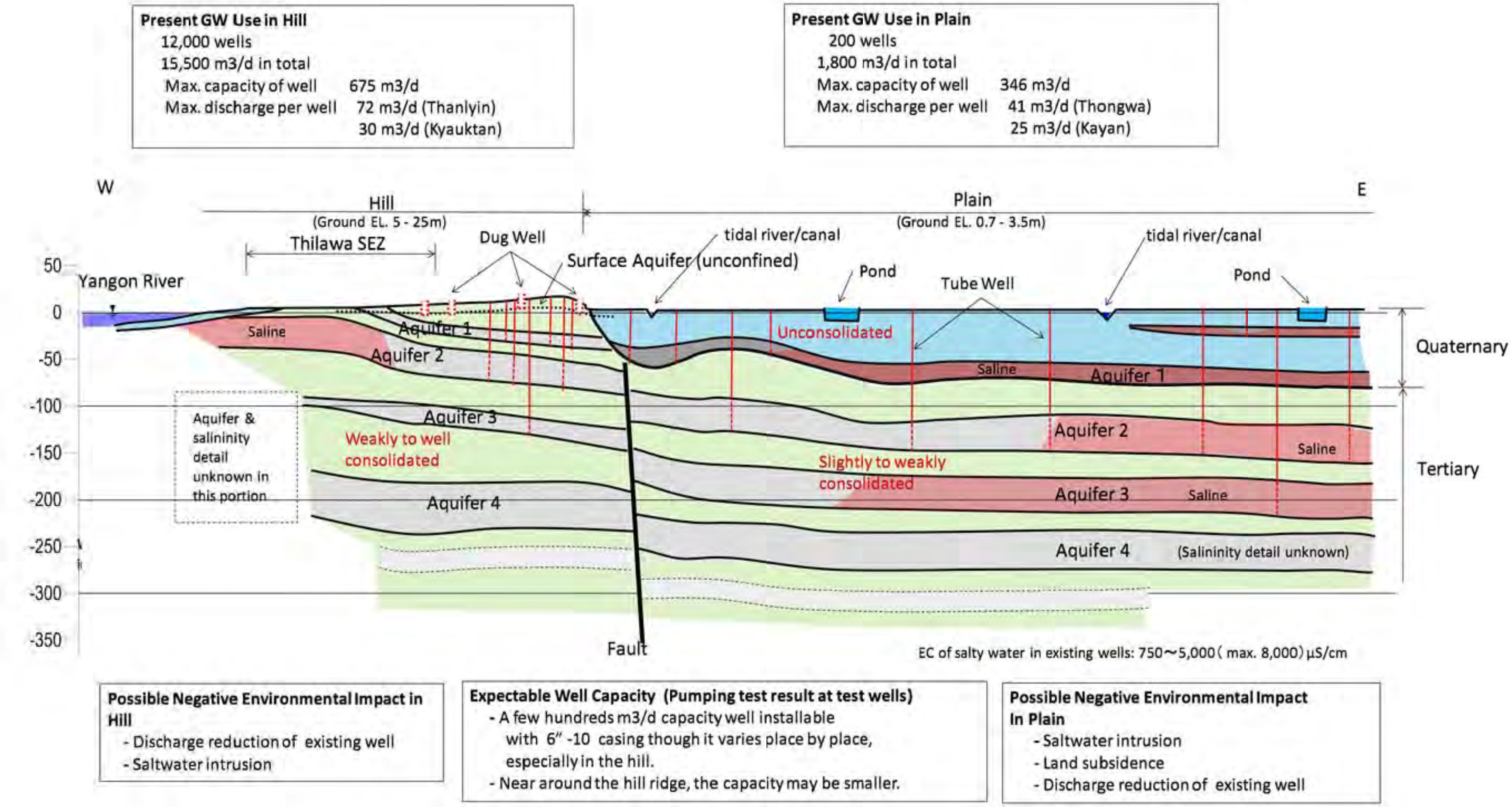


Figure 3-3-1-2 Schematic Profile of Aquifer Distribution, Nature and Water Use

3-3-2 Aquifer Distribution and Its Nature

3-3-2-1 Aquifer Identification and Correlation

Figure 3-3-2-1 and Figure 3-3-2-2 show the location of core boring, test well drilling and geophysical survey. From the core boring and test well drilling results, the aquifer distribution and nature on the Tertiary hill and the Quaternary plain are inferred as shown in Figure 3-3-2-3 and Figure 3-3-2-4. Figure 3-3-2-5 and Figure 3-3-2-6 show hydrogeological interpretation of resistivity profiles in E-W and N-S directions created by geophysical survey results. Figure 3-3-2-7 and Figure 3-3-2-8 show aquifer profiles around the central part of Thilawa SEZ based on the test well drilling results.

Identified aquifers and their nature are shown in Table 3-3-2-1 to Table 3-3-2-3.

As shown in Figure 3-3-1-2, the survey area is hydrogeologically divided into two areas, the hill and the plain, as well as topographically. The boundary between the areas is a fault which supposedly runs along the eastern edge of the hill.

Judging from the core boring and test well results, it is considered that an unconfined surface aquifer and four (4) semi-consolidated confined aquifers distribute in the hill. They are slightly folded or tilting to the east.

Under the plain, four (4) unconsolidated or weakly consolidated confined aquifers may lie. The uppermost confined aquifer is the basal coarse materials of Quaternary deposits. The surface unconfined aquifer does not develop well. The layers lie mostly flat.

In between the surface unconfined aquifer and the 1st confined aquifer, there is an unconsolidated clayey layer 30 to 50 m in total thickness (the light blue part in Figure 3-3-1-2). It consists of a fine alternation of very fine sand, silt and clay: Because the organic and very soft clays are little included, the subsidence by consolidation per a unit thickness is considered to be small. However since the total thickness is large, the land subsidence by groundwater development should be cared.

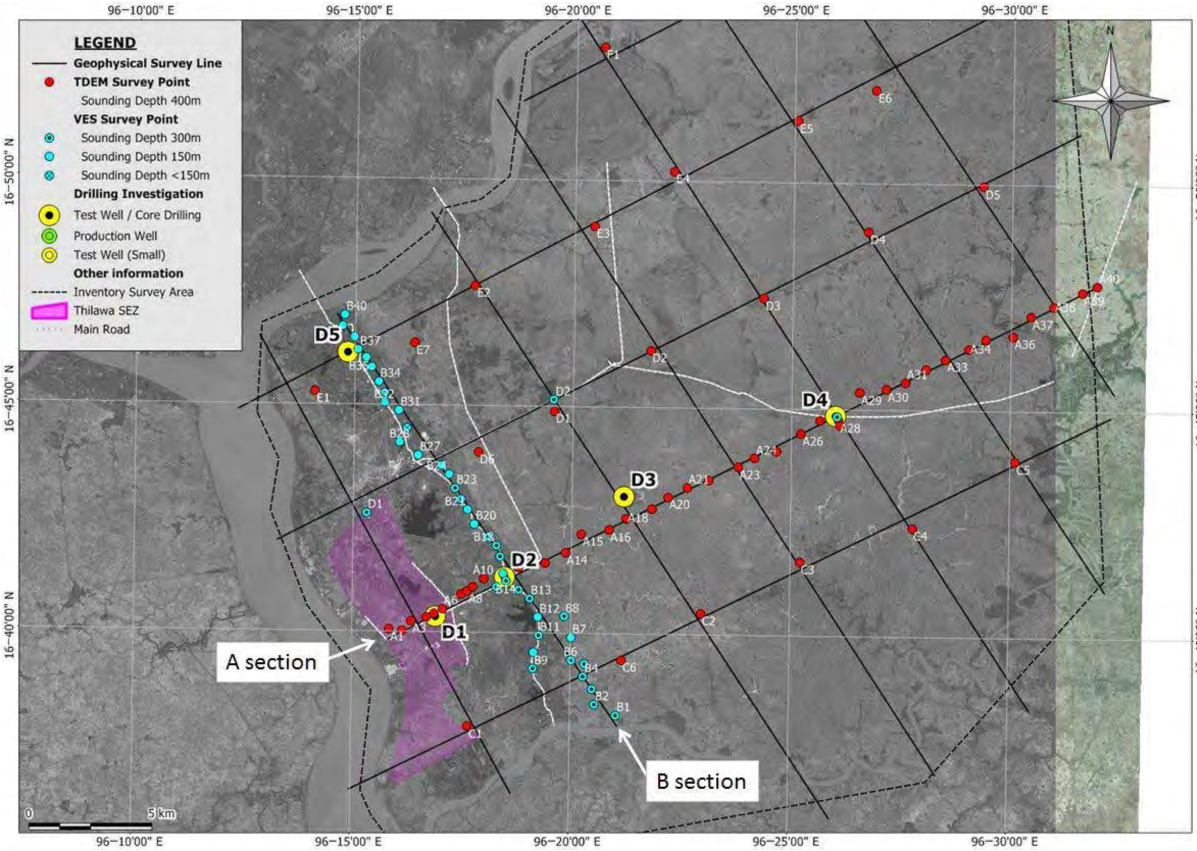


Figure 3-3-2-1 Location of Aquifer Investigation

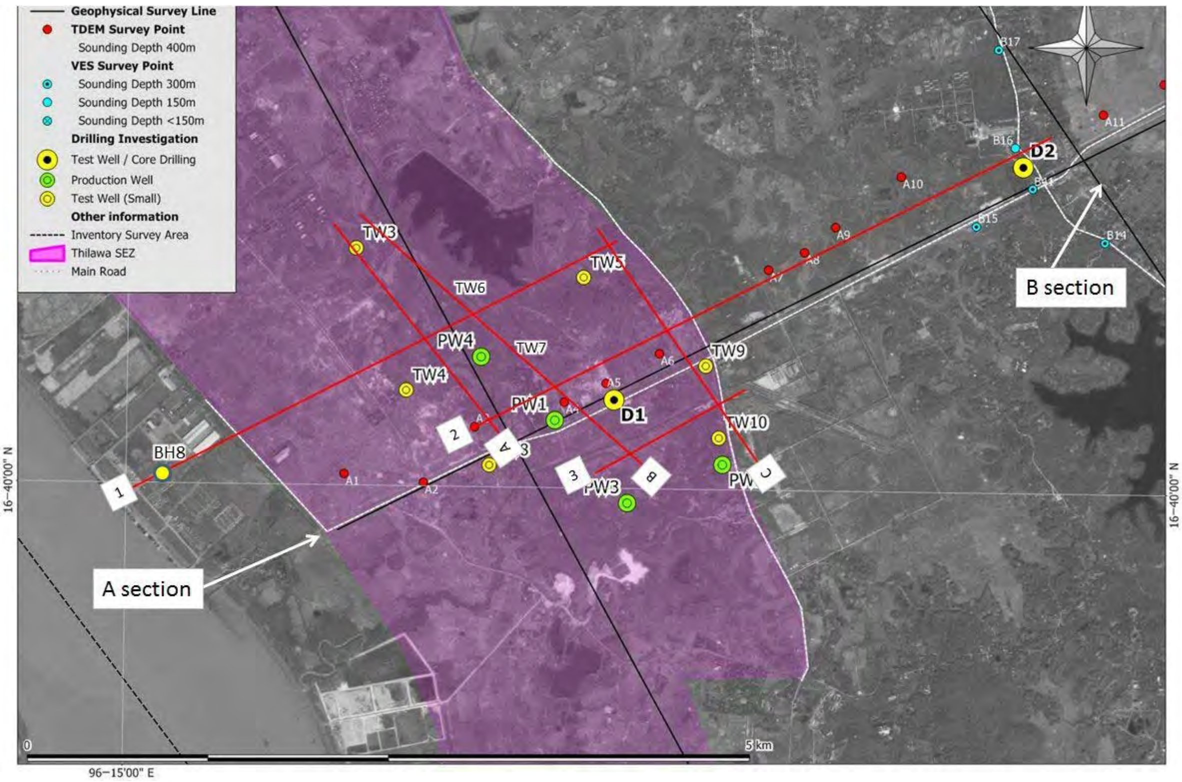


Figure 3-3-2-2 Location of Aquifer Investigation (near Central Part of Thilawa SEZ)

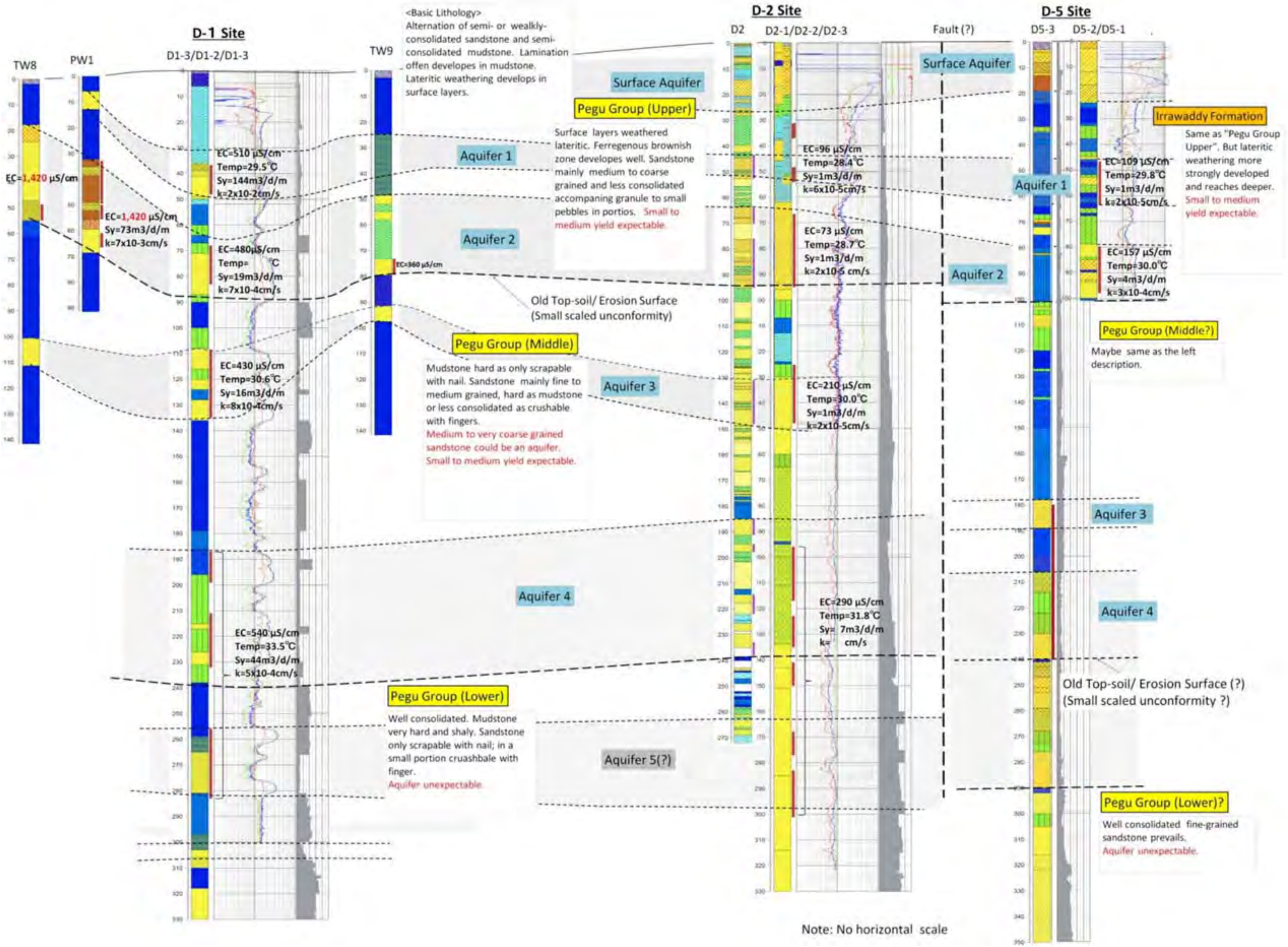


Figure 3-3-2-3 Results of Aquifer Investigation in Tertiary Hill and Inferred Aquifer Profile

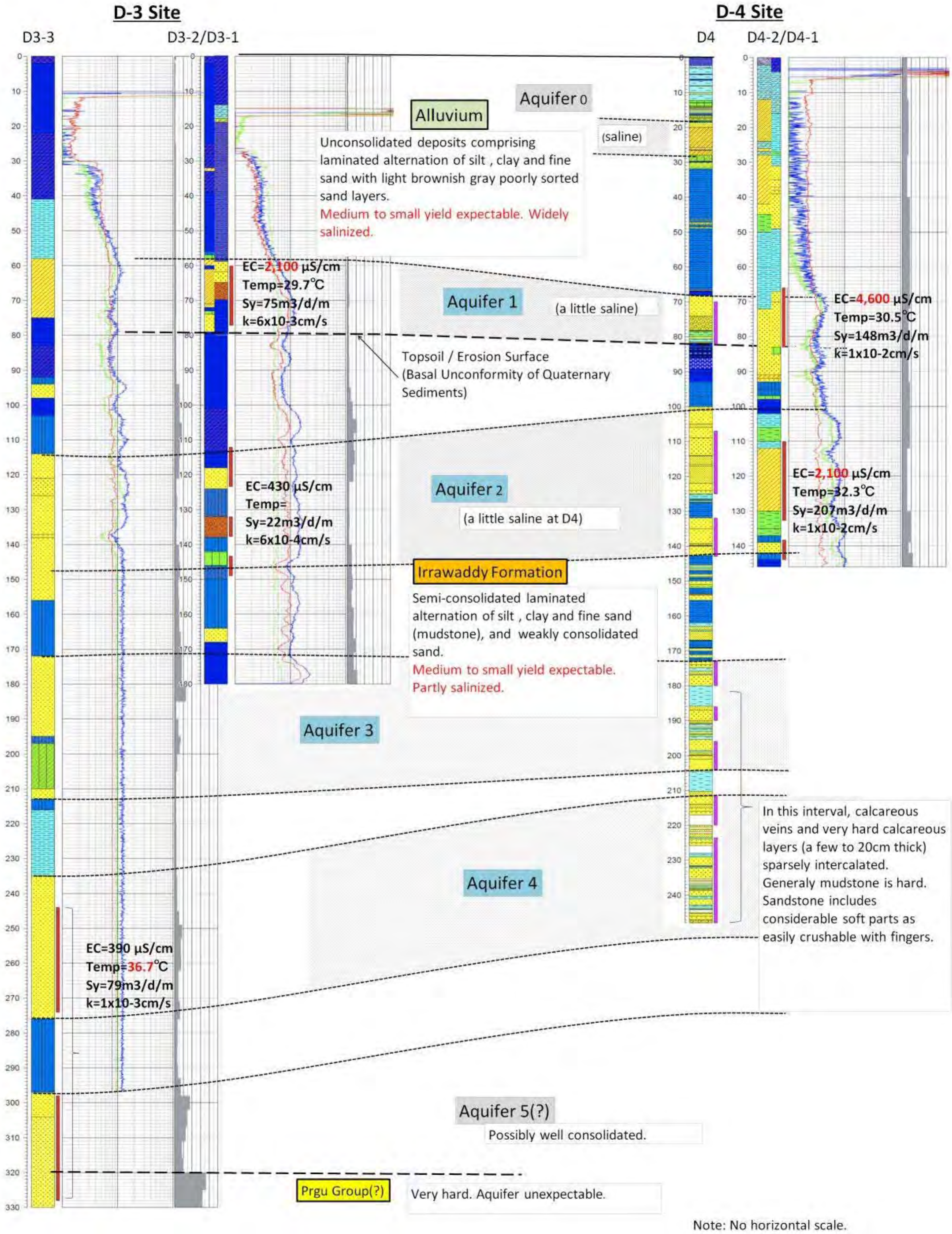
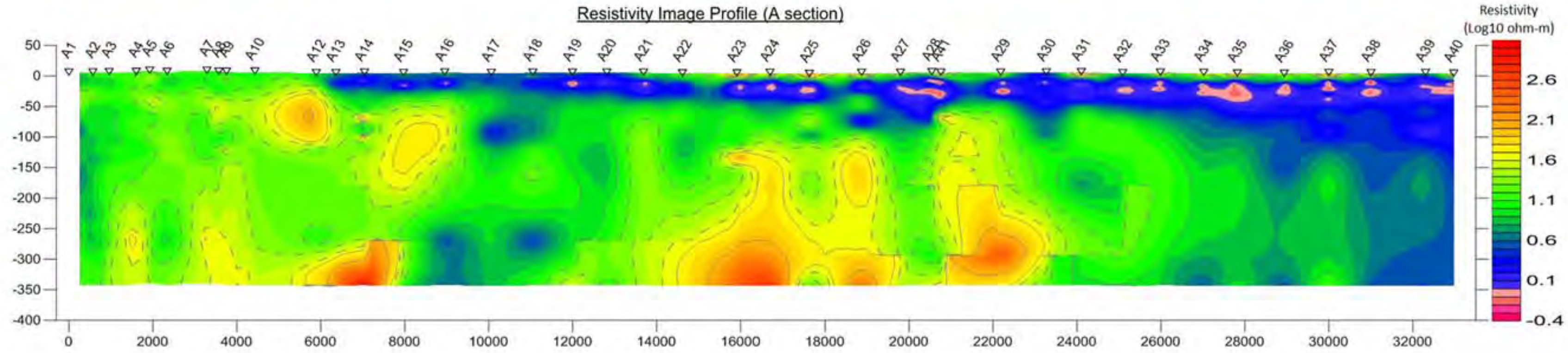


Figure 3-3-2-4 Results of Aquifer Investigation in Quaternary Plain and Inferred Aquifer Profile



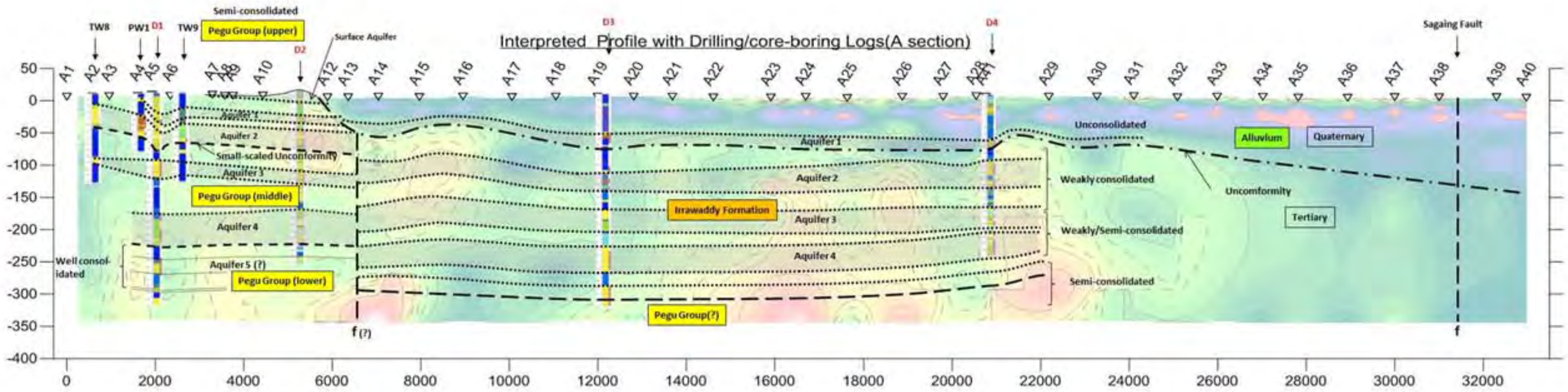


Figure 3-3-2-5 Resistivity and Inferred Aquifer Profile along E-W Direction (A Section)

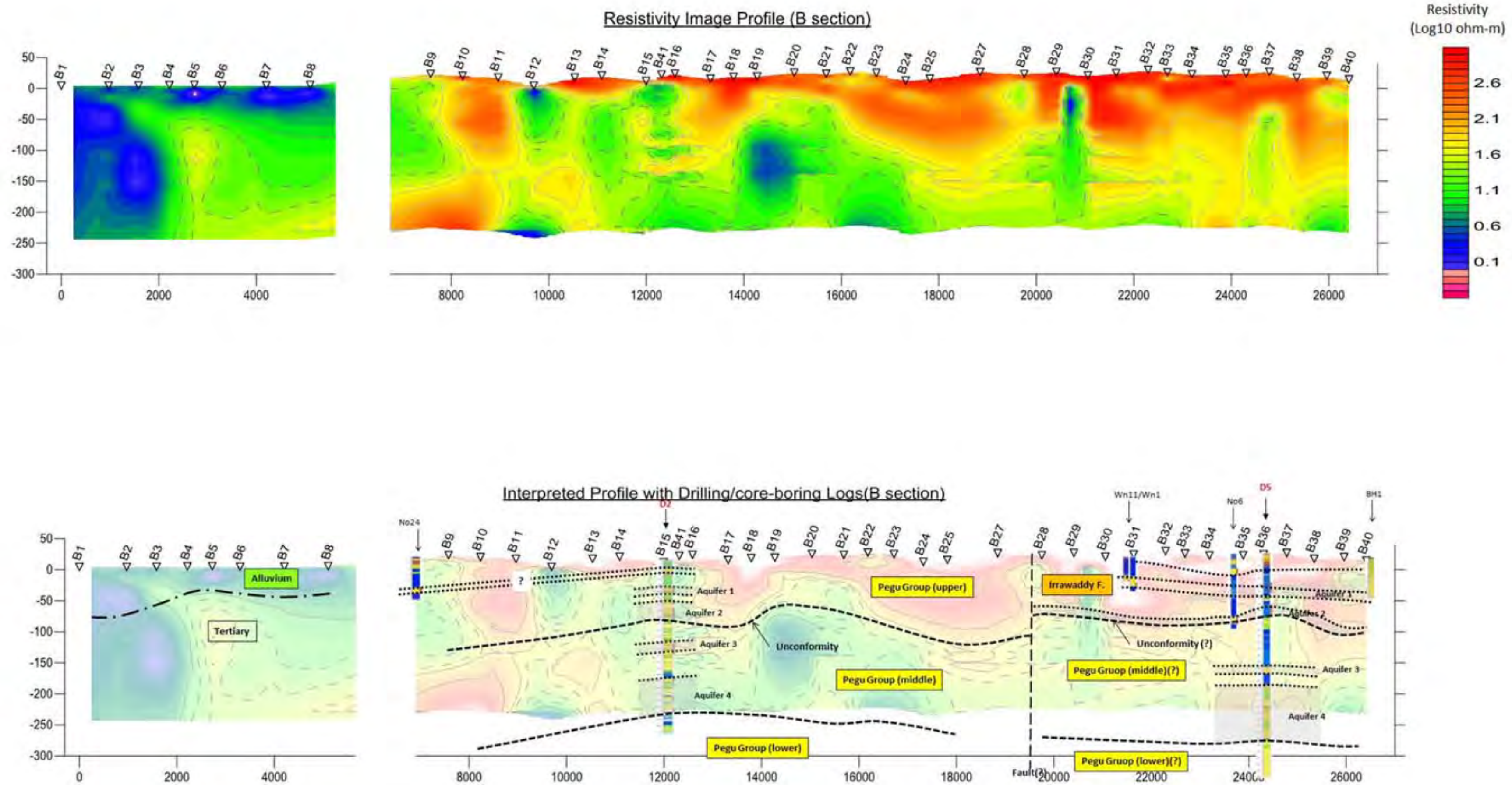
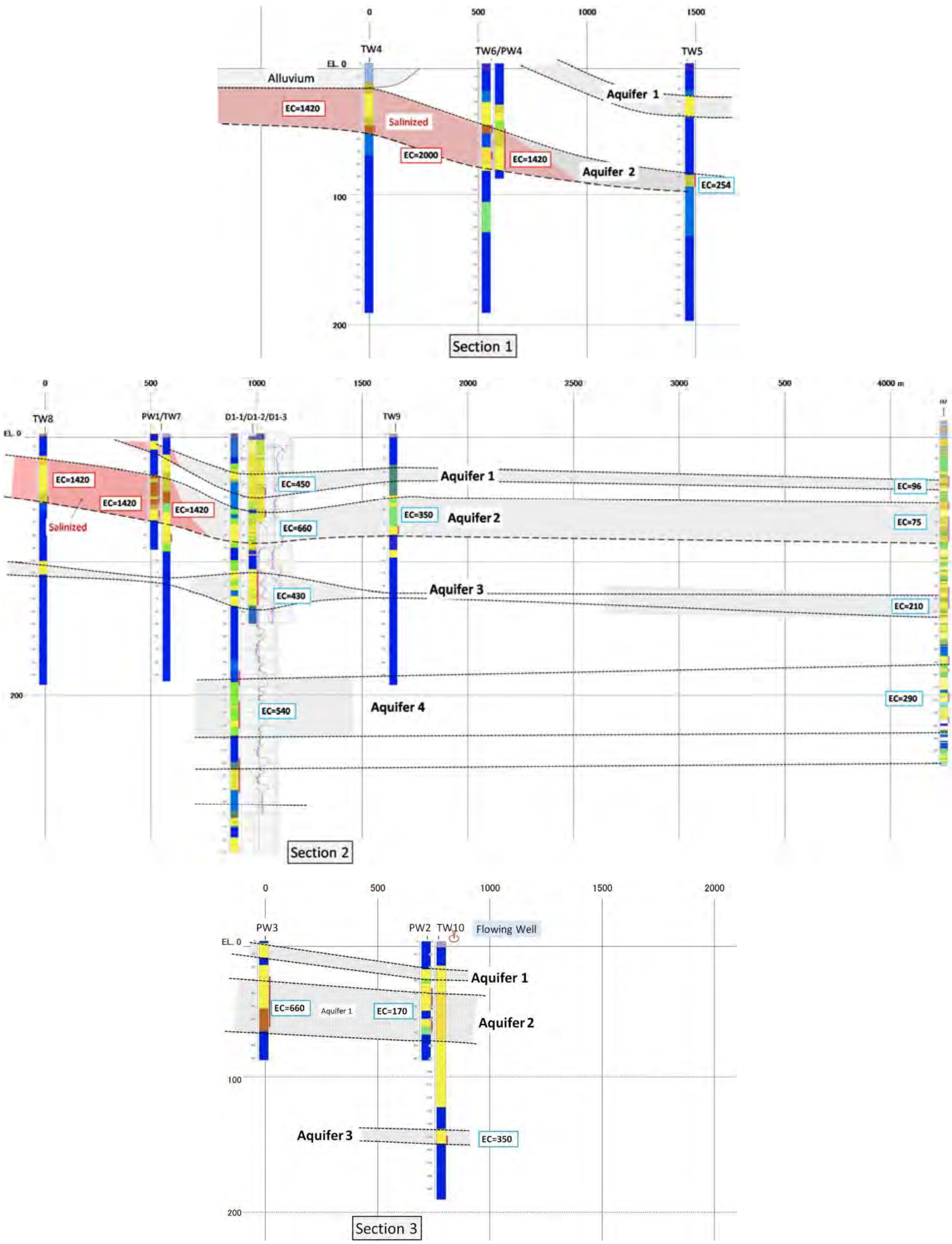
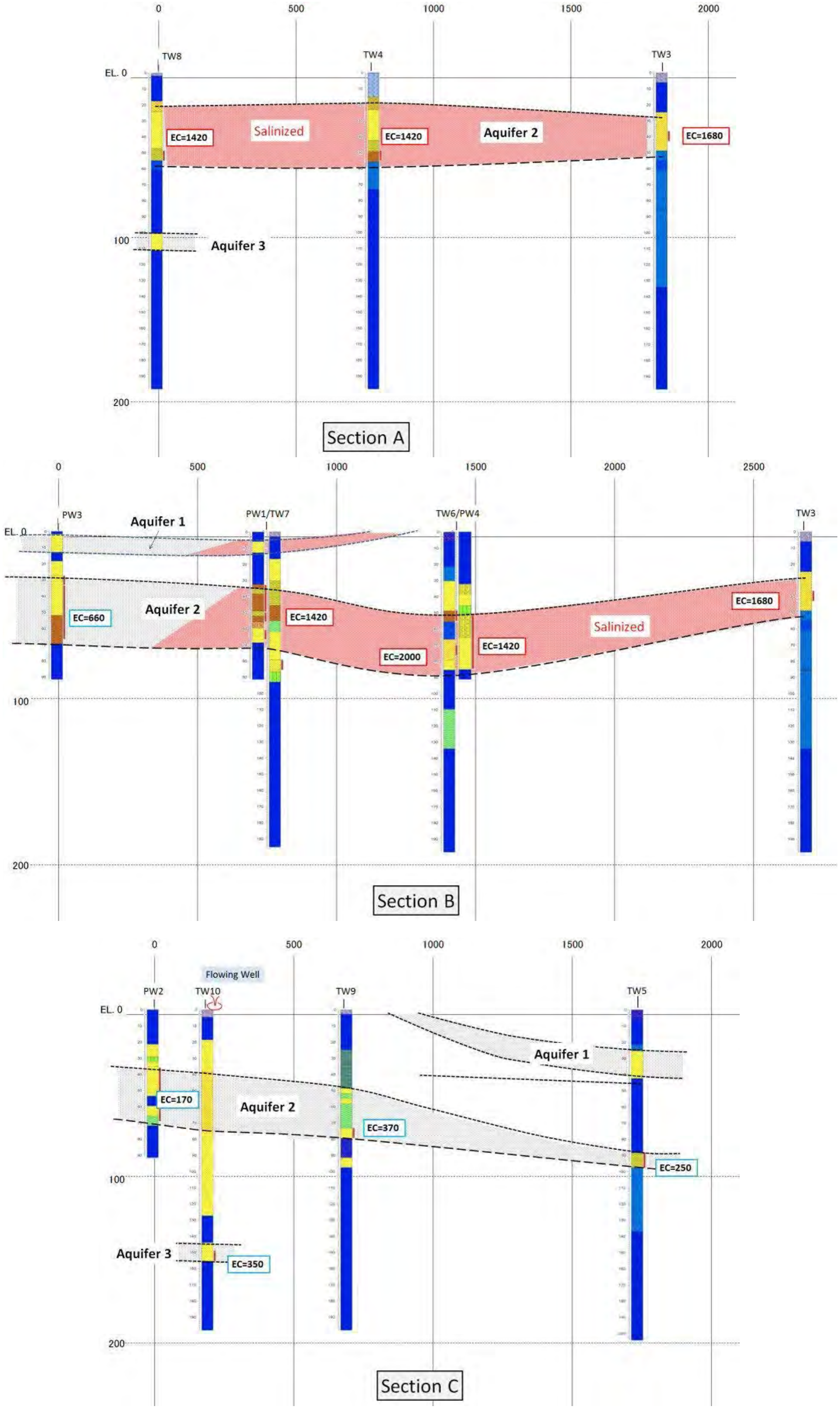


Figure 3-3-2-6 Resistivity and Inferred Aquifer Profile along N-S Direction (B Section)



Note: Unit of EC – μ S/cm; Unit of distance – meter.

Figure 3-3-2-7 Inferred Aquifer Profile in and around Central Part of Thilawa SEZ (1)



Note: Unit of EC – μS/cm; Unit of distance – meter.

Figure 3-3-2-8 Inferred Aquifer Profile in and around Central Part of Thilawa SEZ (2)

Table 3-3-2-1 Aquifer and its Nature by Region – the Hill near the Central Part of SEZ

Central Part of the Hill near and in SEZ

Aquifer Name	Approx. Depth (m)	Approx. Thickness (m)	Geologic Formation	Facies	Specific Capacity (m3/d/m)	Permea-bility (cm/s)	Diacharge at Pumping Test (m3/d)	Water Quality (EC:µS/cm)	Present Water Use (Estimation with inventory survey result)	Test Well /Source of Data
Surface Auifer	0 ～20-30	20～30	Pegu Group (Oligocene?～ Miocene)	Weakly consolidated sand, weathered					Main aquifer for many dug wells	
Aquifer 1	30～50	8～15		Weakly consolidated sand～granule, partially weathered	144 1	3x10-2 1x10-4	858 19	EC=96, 510 pH<6.5	One of main aquifers for many tube wells	D-1-0 D-2-0
Aquifer 2	65～95	30		Weakly consolidated sand～granule, partially weathered	19 1 73 20 63 15	1x10-3 8x10-5 7x10-3 1x10-3 4x10-3 8x10-4	544 39 653 653 653 653	EC=73, 480, 170, 660 EC=**1420,1420** **(Salinized in the western part of SEZ)** pH<6.5	One of main aquifers for many tube wells.	D-1-1 D-2-1 PW1 PW2 PW3 PW4
Aquifer 3	100～150	10～25		Weakly consolidated sand, joints in moderately consolidated sandstone	16 1	2x10-3 3x10-5	383 29	EC=210、430	Partially used through tube well	D-1-2 D-2-2
Aquifer 4	185～240	30			44 7	9x10-4 1x10-4	670 220	EC=540, 290 pH>8.5 High Zinc concentration	Unused	D-1-3 D-2-3

Note: GW often contains high concentration of iron.

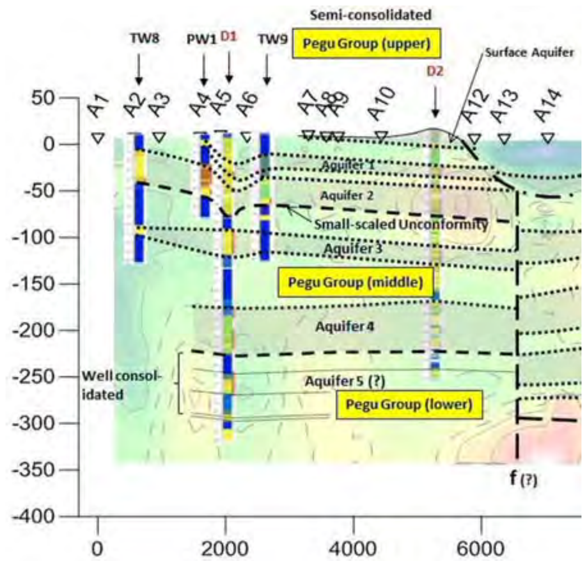
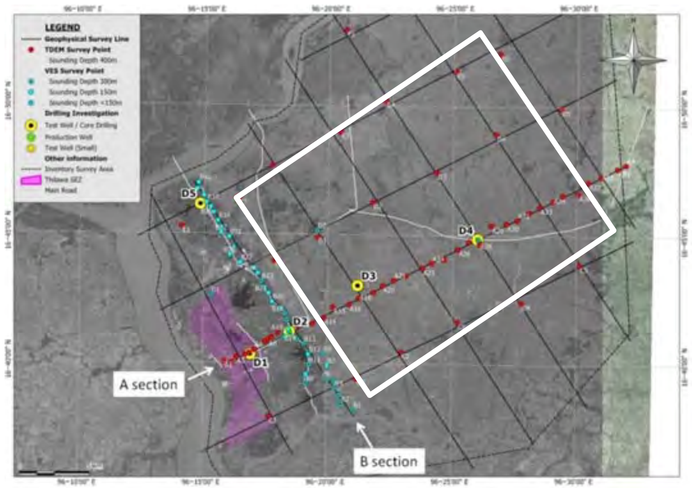


Table 3-3-2-2 Aquifer and its Nature by Region – the Plain

The Plain

Aquifer Name	Approx. Depth (m)	Approx. Thickness (m)	Geologic Formation	Facies	Specific Capacity (m3/d/m)	Permea-bility (cm/s)	Diacharge at Pumping Test (m3/d)	Water Quality (EC:µS/cm)	Present Water Use (Estimation with inventory survey result)	Test Well /Source of Data
Surface Auifer		(5)	Alluvium (Quaternary)	Unconsolidated silty sand				**Mostly salinized**	Not used (no dug well distributs)	
(Aquifer 0)	15〜40	0〜 10〜25		Unconsolidated sand					Used only in limited small area	
Aquifer 1	55〜85	15〜20		Unconsolidated medium grained sand〜granule	75 148 34	6x10-3 2x10-2 7x10-2	812 812 206	EC=**2100, 4600** **Salinized except western area near the hill**	Not used in Thongwa and Kayan due to salinization. Main aquifer for tube wells in the western part near the hill (ex. Esat Yangon University wells).	D-3-1 D-4-1 THA-8-5116
Aquifer 2	100〜150	25	Irrawaddy Formation ? (Pliocene?)	Slightly to weakly consolidated medium to coarse grained sand	22 207	1x10-3 2x10-2	383 890	EC=430, **2100** **Partially salinizad**	Main aquifer in the plain	D-3-2 D-4-2
Aquifer 3	170〜210	20							Only used through a few tube wells	
Aquifer 4	210〜275	30			79	2x10-3	812	EC=390 pH>8.5 Water Temp. =**37℃** High Zinc concentration	Unused	D-3-3

Note: GW often contains high concentration of iron.



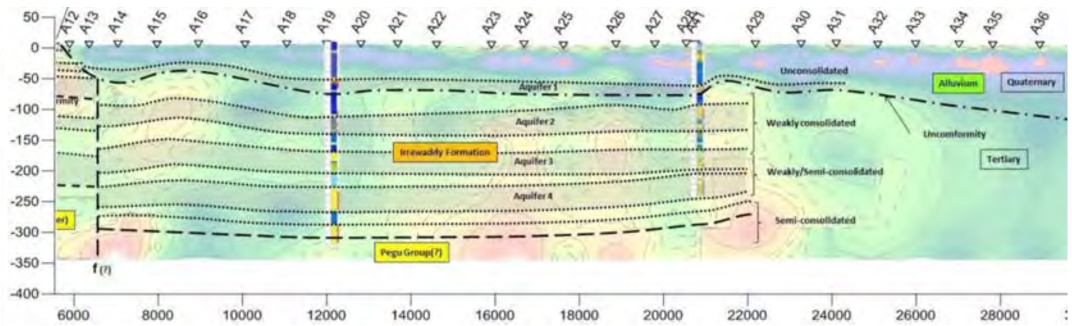
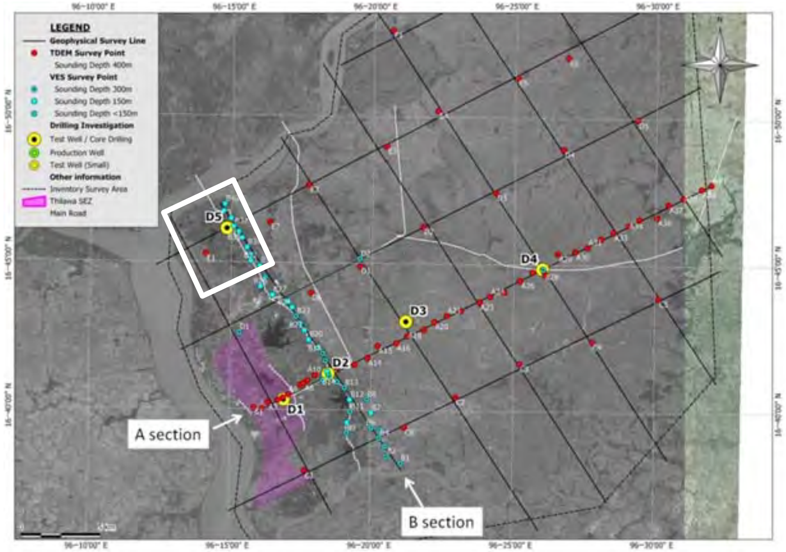


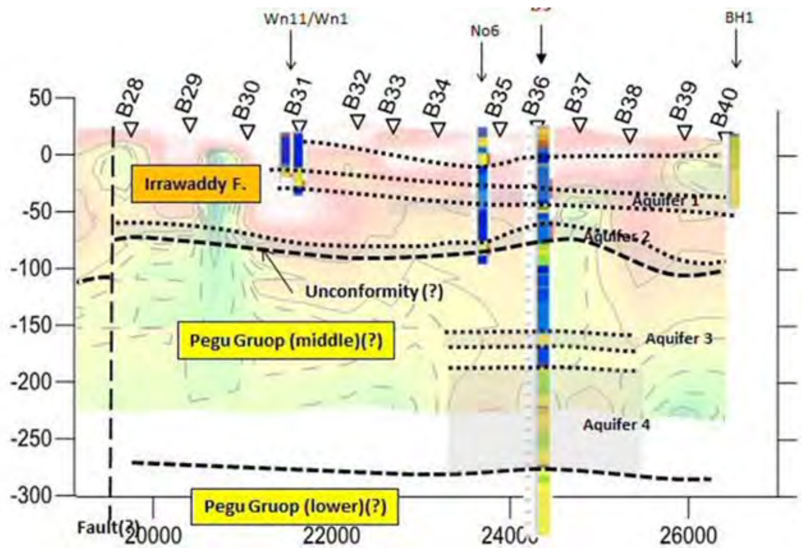
Table 3-3-2-3 Aquifer and its Nature by Region – Northern Part of the Hill

Norther Part of the Hill

Aquifer Name	Approx. Depth (m)	Approx. Thickness (m)	Geologic Formation	Facies	Specific Capacity (m3/d/m)	Permea-bility (cm/s)	Diacharge at Pumping Test (m3/d)	Water Quality (EC:µS/cm)	Present Water Use (Estimation with inventory survey result)	Test Well /Source of Data
Surface Auifer	0 ～20-25	20～25	Irrawaddy Formation （Pliocene？）	Weakly consolidated sand, weathered		0.5～ 1.4x10-3			Main aquifer for many dug wells	THA-27-8653
Aquifer 1	45～65	20		Weakly consolidated sand～granule, partially weathered	1	4x10-5	19	EC=110 pH<6.5	One of main aquifers for many tube wells	D-5-1
Aquifer 2	80～100	20		Weakly consolidated sand～granule	4 (much bentonite put to stop large leakage in drilling) 10～160	5x10-4 nx10-3	68 (200～1090)	EC=160 pH<6.5	One of main aquifers for many tube wells; **In overdraft condition** at the central part of Thanlyin (SWL <EL.0m at D-5-2)	D-5-2 Win Naing et al.(1991)
Aquifer 3	180～190	10	Pegu Group ? (Oligocene?～ Miocene）	Weakly consolidated sand, joints in moderately consolidated sandstone	13	1x10-4	157	EC=420 pH>8.5 High Zinc Concentration	Partially used through tube well. **In overdraft condition** at the central part of Thanlyin (SWL <EL.-10m at D-5-3)	D-5-3
Aquifer 4	205～270	30								

Note: GW often contains high concentration of iron.





3-3-2-2 Inference of Spatial Aquifer Distribution

Figure 3-3-2-9 and Figure 3-3-2-10 show the location of lines along which aquifer profiles were made considering all geologic and geophysical logs, and depth of existing wells. Figure 3-3-2-11 to Figure 3-3-2-15 shows the main profiles of the survey area. Figure 3-3-2-16 to Figure 3-3-2-20 shows the profiles of the hill. (See the enlarged profiles in the attached CD for the details)

All aquifer boundaries on all profiles were digitized and the boundary contour maps were created to build a 3-D aquifer conceptual model which will be explained later.

The available geologic logs are limited. The main data source to infer aquifer positions is the existing wells. They are large in number, but do not provide geological information but their depths. It is assumed that the screen is installed at the well bottom with a 10 to 20 ft. length and an aquifer is located around there. On a profile, wells within some distance from the profile line are projected. The distance is small on the hill and large in the plain depending on the distribution density of wells and reflecting to that the layers are more or less folded in the hill and lie mostly flat in the plain.

The resistivity log obtained by the geophysical survey (TDEM and VES) provided useful information about the distribution of unconsolidated Quaternary sediments which show low resistivity because they consists mainly of silty materials and contain salty water. The logs did not serve to identify aquifer position.

The information is few for the deeper aquifers. The real relationship between aquifers on both sides of the boundary fault is unknown.

Considering the quantity and quality of the data, it could be said that this work to create the aquifer profiles is a kind of daring one to make a first approximate aquifer model in the area. The profiles shall be revised based on the data obtained by future investigations.

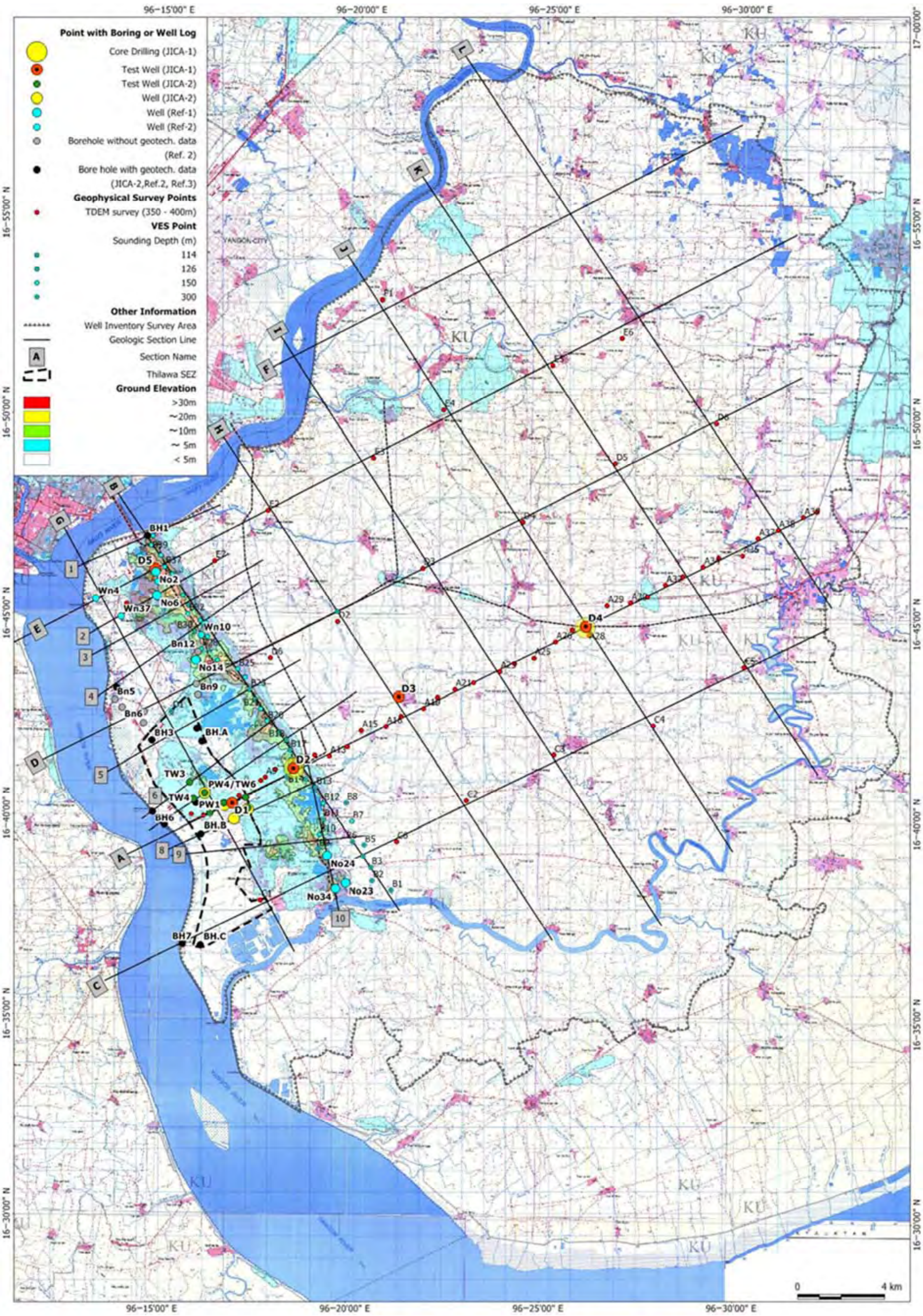


Figure 3-3-2-9 Lines of Aquifer Profile (1)

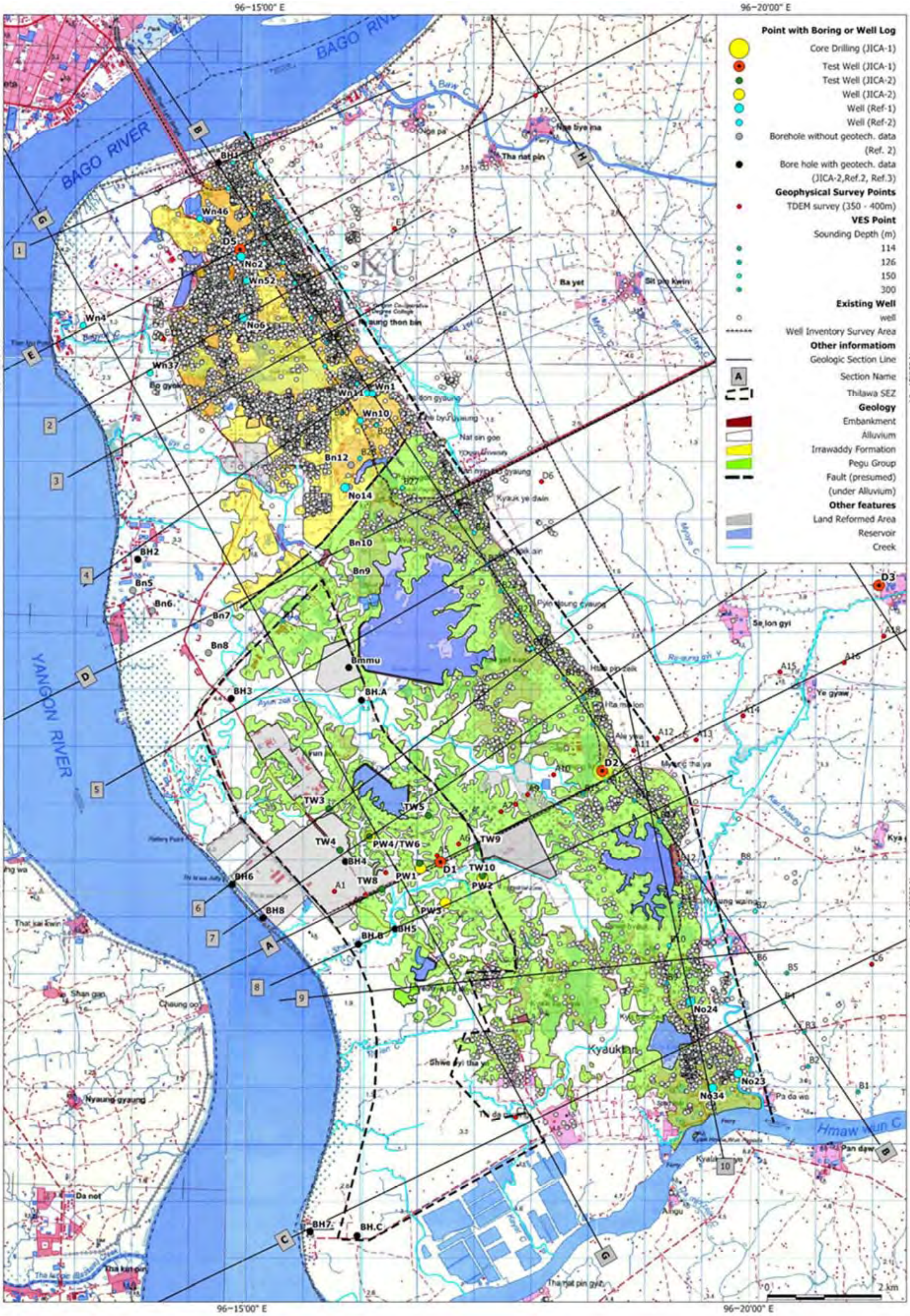
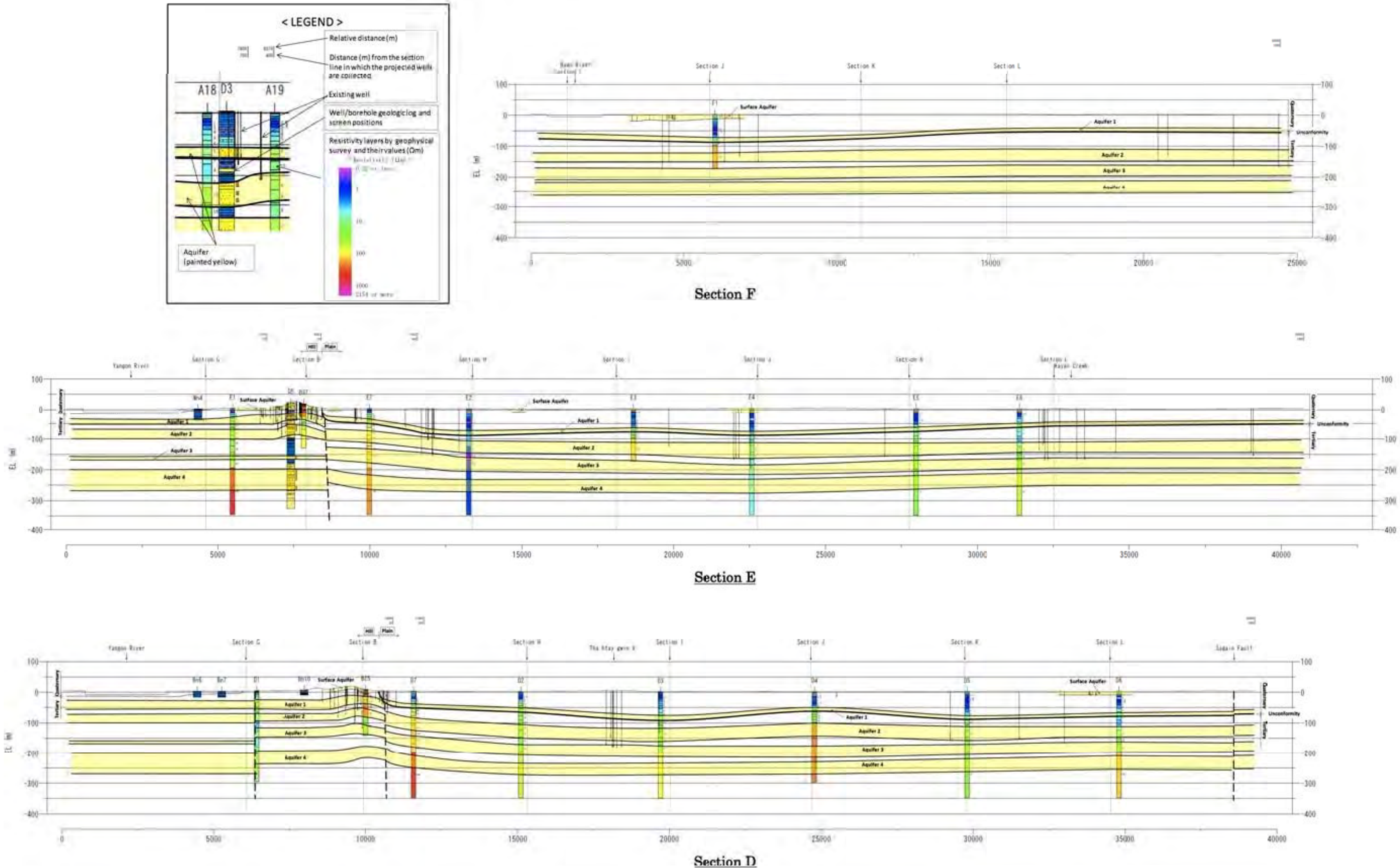
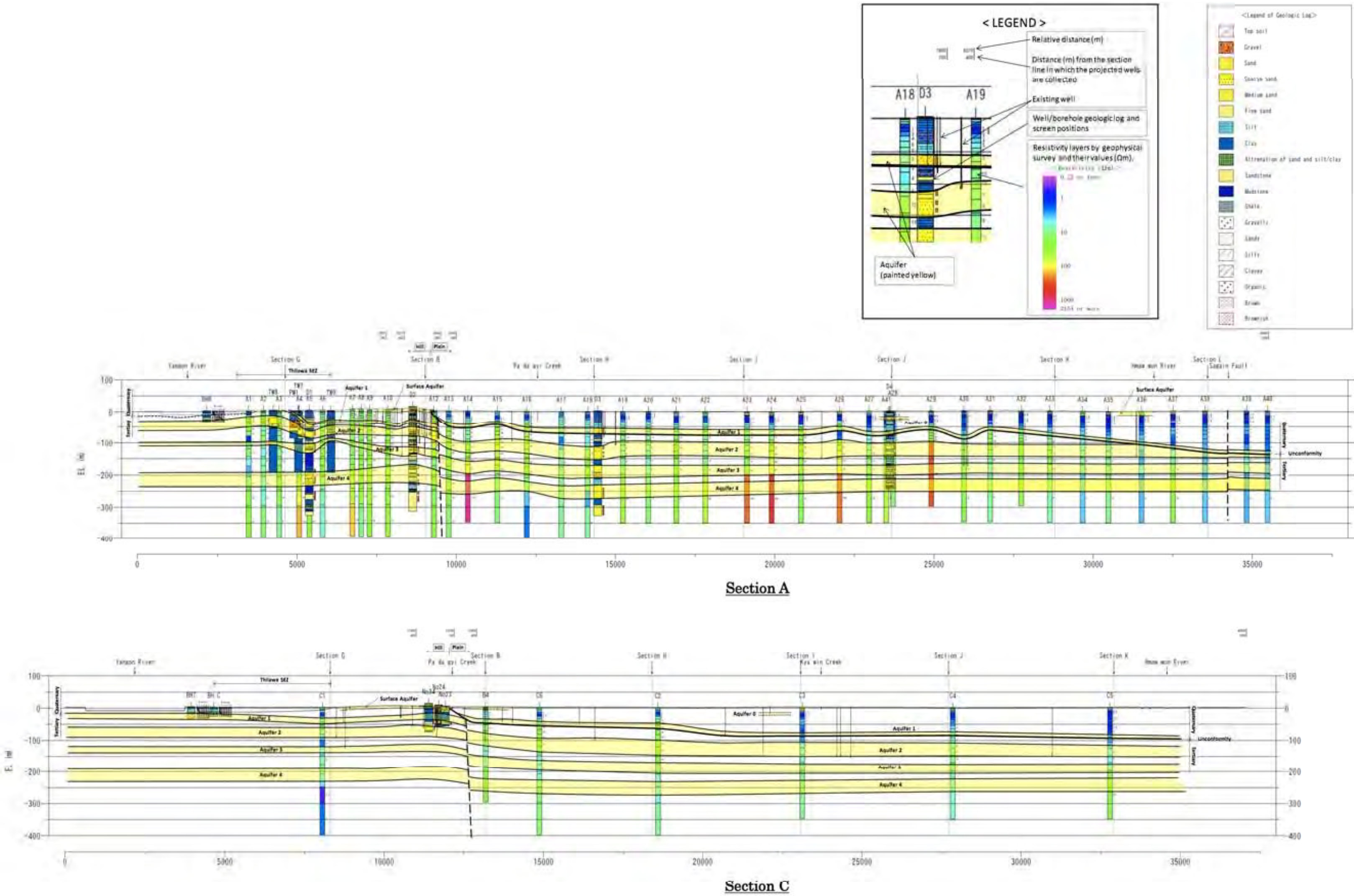


Figure 3-3-2-10 Lines of Aquifer Profiles (2)



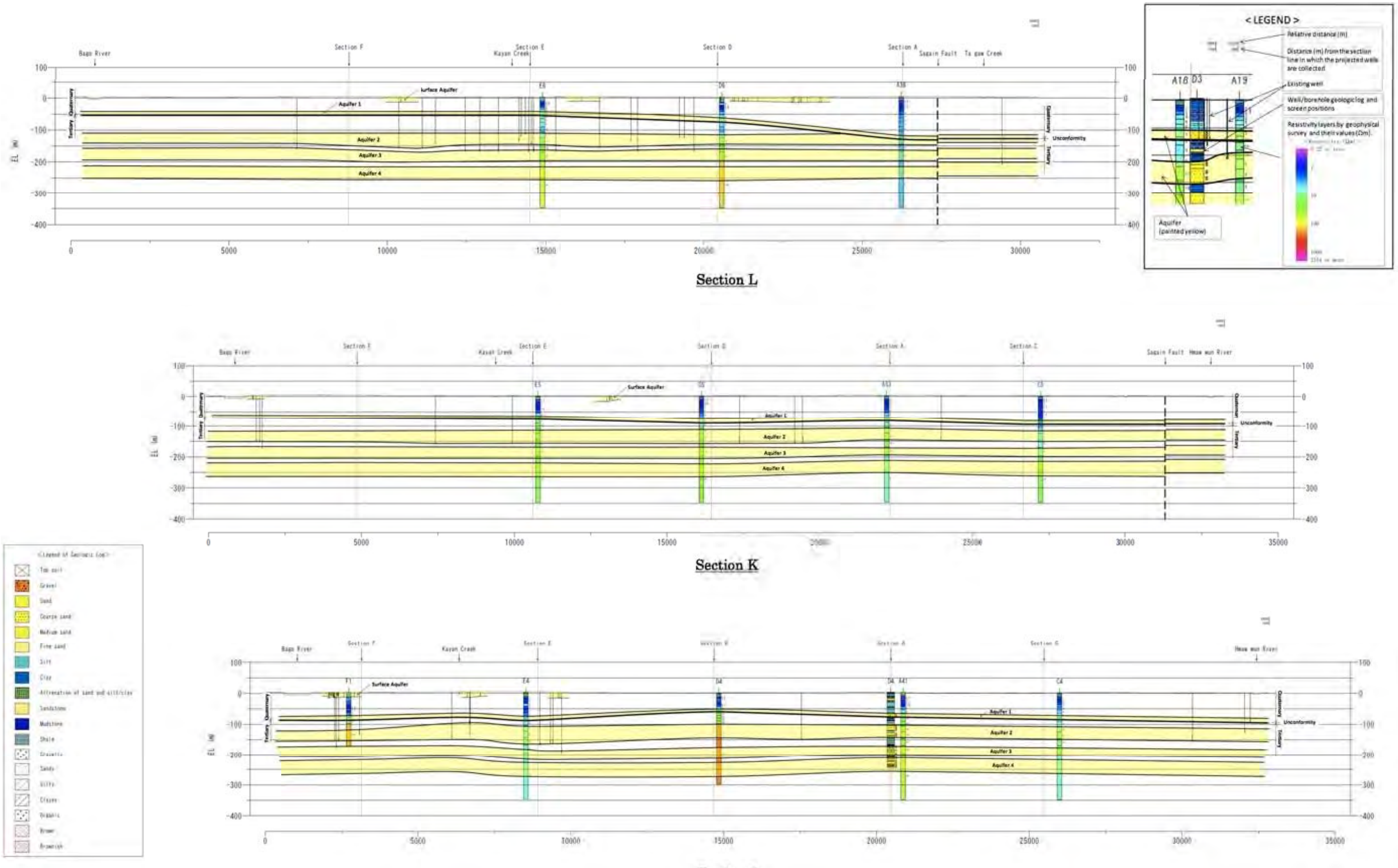
Note: Unit of distance and elevation – meter (m)

Figure 3-3-2-11 Aquifer Profile – WSW-ENE Sections (1)



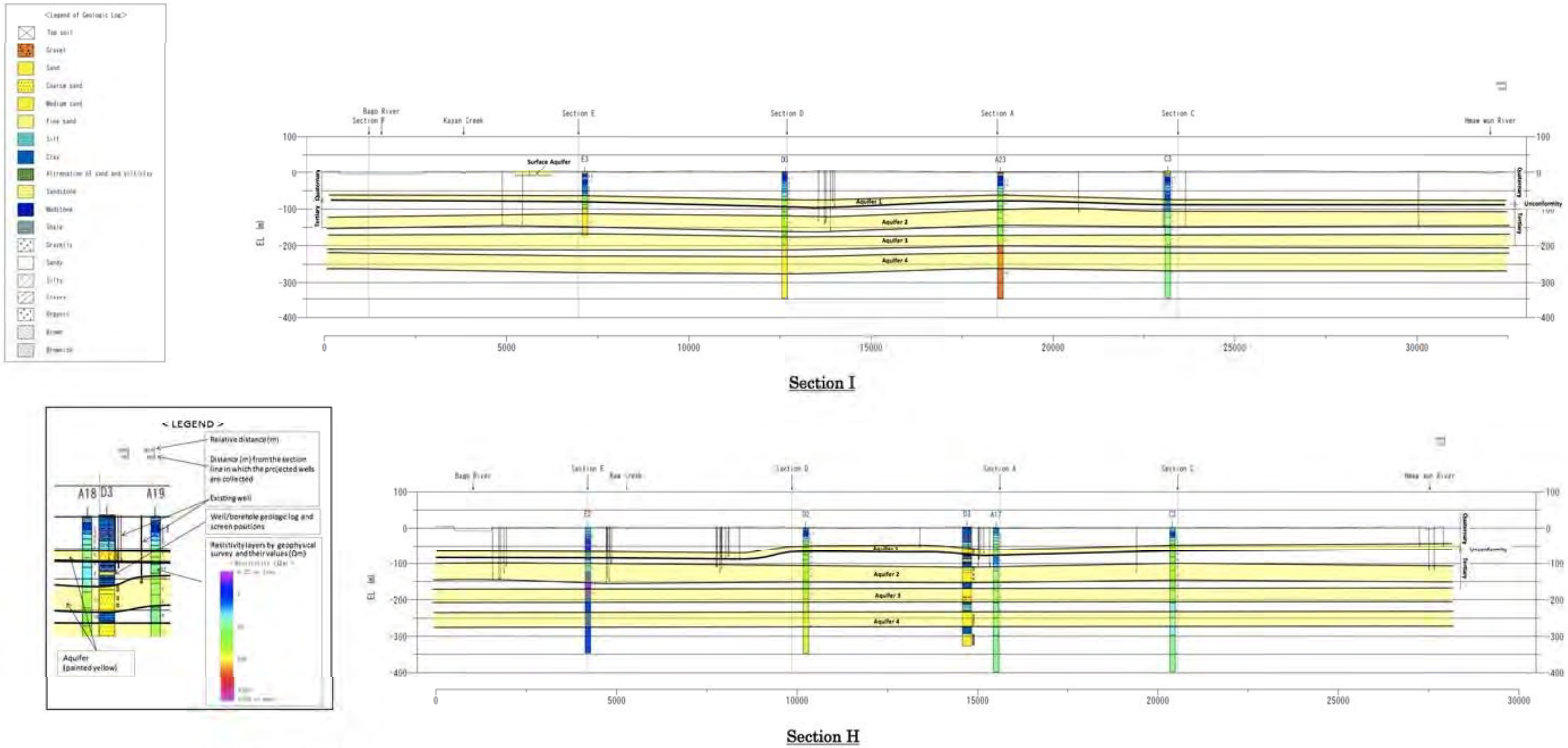
Note: Unit of distance and elevation – meter (m)

Figure 3-3-2-12 Aquifer Profile – WSW-ENE Sections (2)



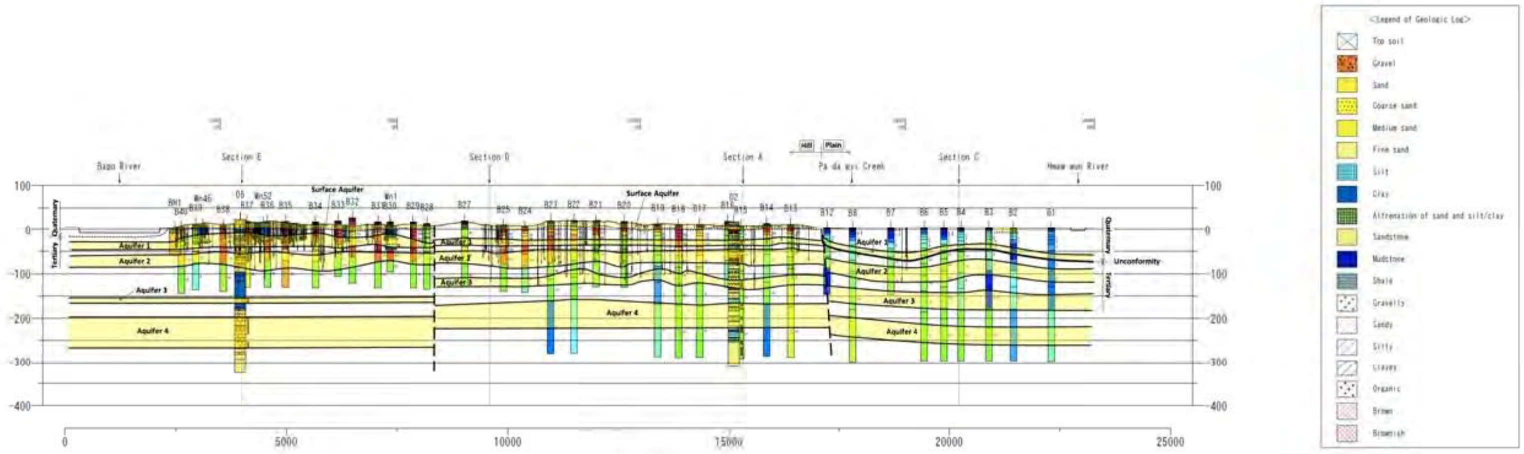
Note: Unit of distance and

Figure 3-3-2-13 Aquifer Profile – NNW-SSE Sections (1)

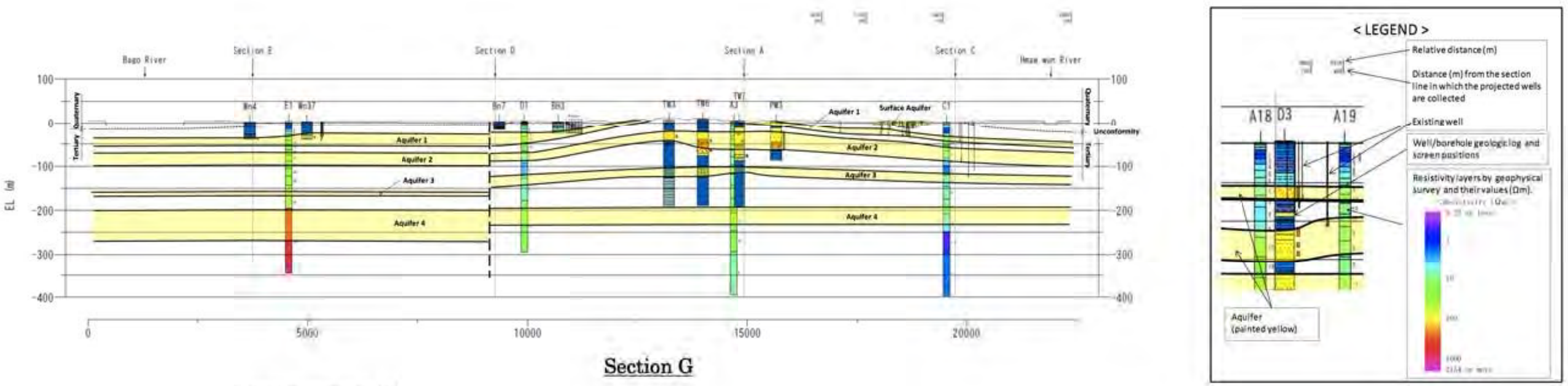


Note: Unit of distance and elevation – meter (m)

Figure 3-3-2-14 Aquifer Profile – NNW-SSE Sections (2)



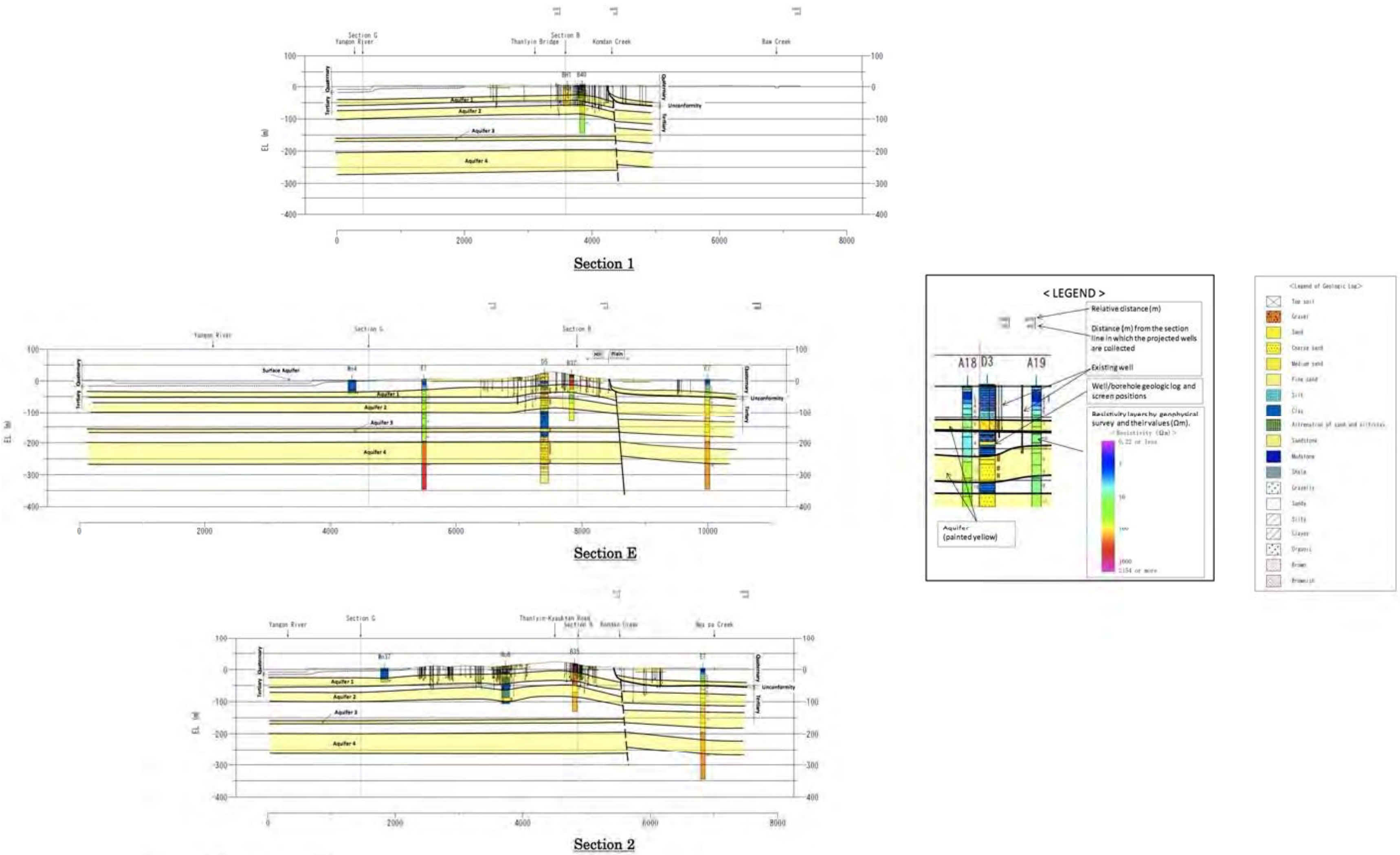
Section B



Section G

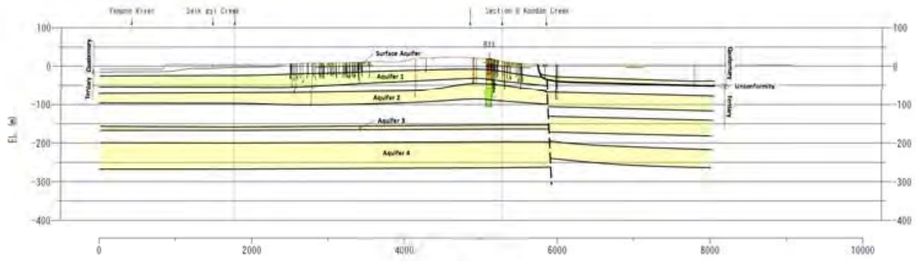
Note: Unit of distance and elevation – meter (m)

Figure 3-3-2-15 Aquifer Profile – NNW-SSE Sections (3)

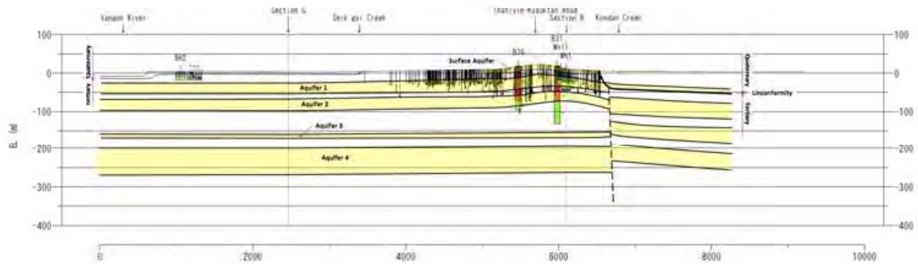


Note: Unit of distance and elevation – meter (m)

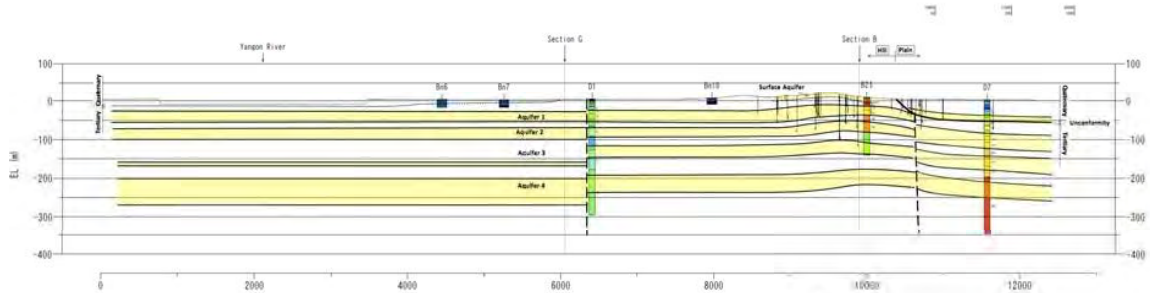
Figure 3-3-2-16 Aquifer Profiles of the Hill (1)



Section 3



Section 4



Section D

Note: Unit of distance and elevation – meter (m)

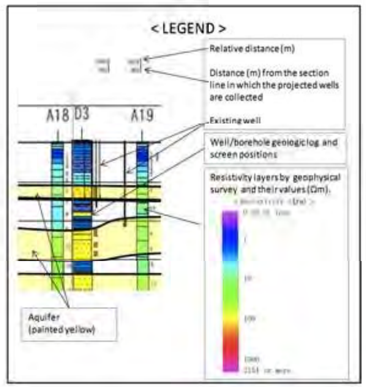
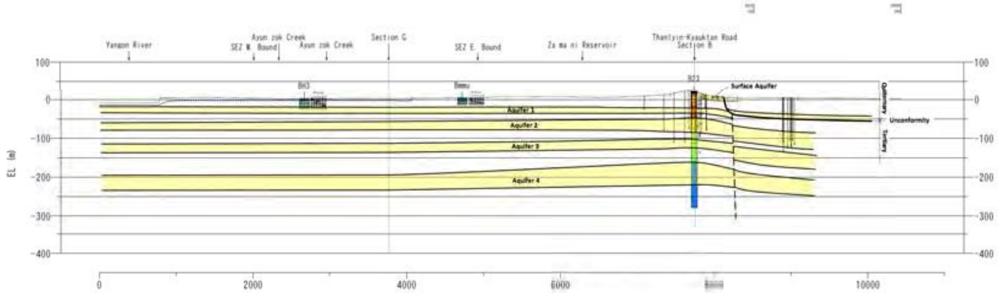
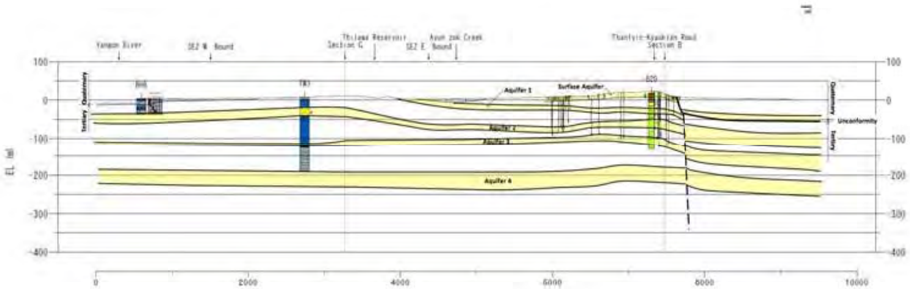


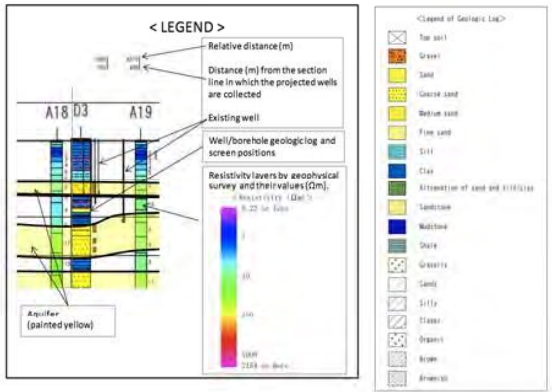
Figure 3-3-2-17 Aquifer Profiles of the Hill (2)

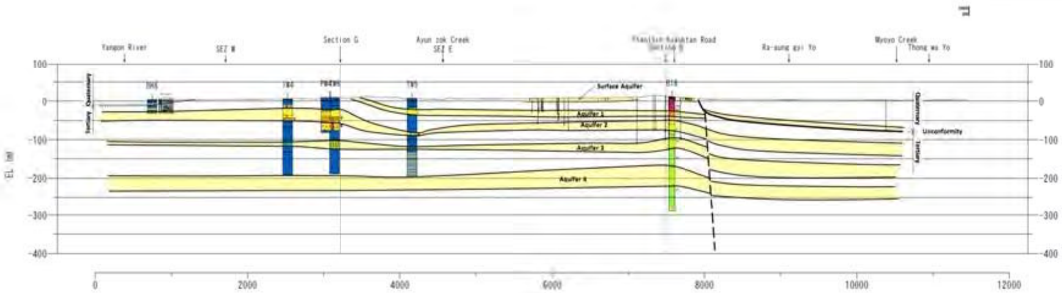


Section 5



Section 6

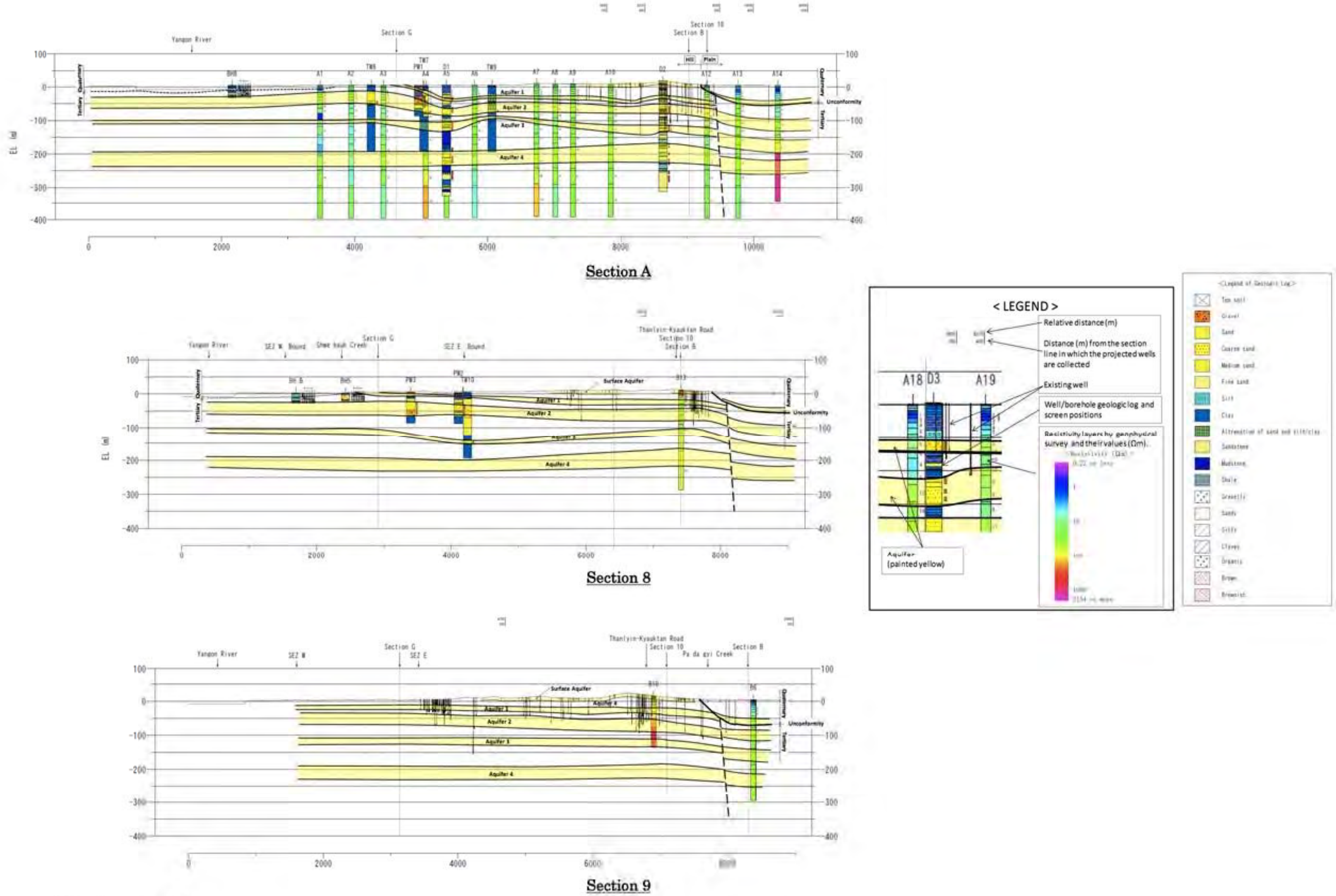




Section 7

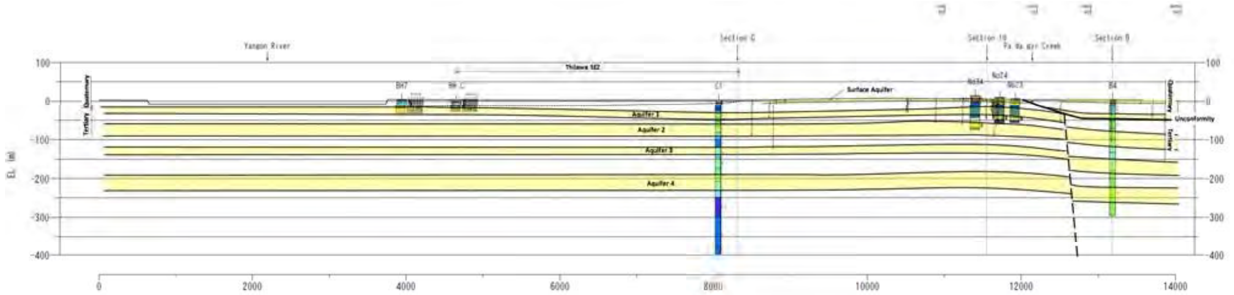
Note: Unit of distance and elevation – meter (m)

Figure 3-3-2-18 Aquifer Profiles of the Hill (3)

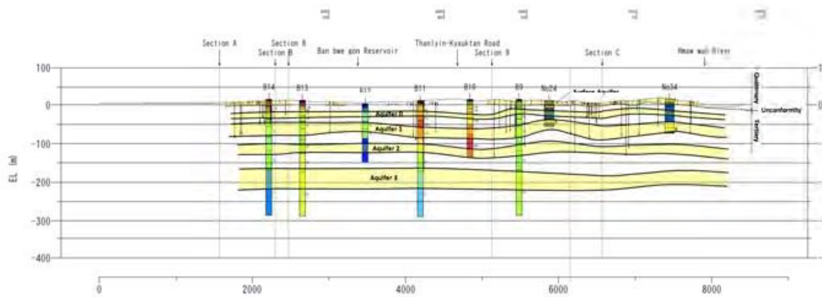


Note: Unit of distance and elevation – meter (m)

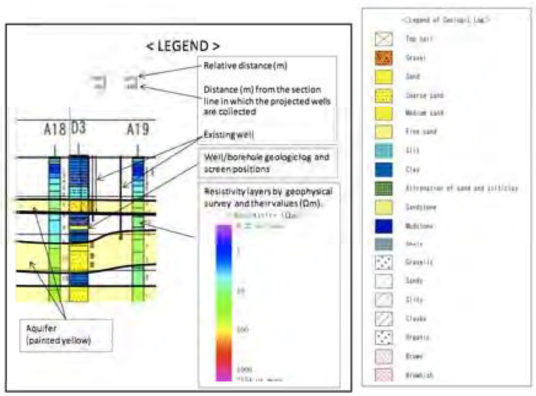
Figure 3-3-2-19 Aquifer Profiles of the Hill (4)



Section C



Section 10



Note: Unit of distance and elevation – meter (m)

Figure 3-3-2-20 Aquifer Profiles of the Hill (5)

3-3-2-3 Hydraulic Ability

To grasp the hydraulic ability in the survey area, the following results are available:

- The constant pumping test at the test wells by the present survey team (Table 3-2-6-3),
- The pumping test at four test wells in the SEZ by another JICA team (Table 3-2-6-5),
- The pumping test at three existing wells by the present survey team (Table 3-2-13-2), and
- The well data in the existing reports (Table 3-2-2-5).

Table 3-3-2-4 shows the specific capacity by those pumping tests and the well data. It is nearly equal to the transmissivity and represents the hydraulic ability of the aquifer. The value is relatively large in the plain and the western foot of the hill, but small in the hill ridge area. The average permeability obtained by the pumping tests mainly ranges from n x 10^{-5} cm/s to 2 x 10^{-2} cm/s. The capacity of the test well ranges from 20 m^3/day to 890 m^3/day. The maximum capacity of existing wells is 675m^3/day on the hill and 346 m^3/day on the plain. These values suggest that the aquifers are minor in hydraulic ability considering a good aquifer has a few hundred m^3/day/m of specific capacity and a few thousand m^3/day of well capacity.

Table 3-3-2-4 Specific Capacity (m^3/day/m) in Survey Area

Topographic Location	Hill								Plain		
	Foot		Ridge								
Location	SEZ		East of SEZ	Thanlyin			Kyauktan				
Well / Aquifer	D-1 site wells	PW wells	D-2 site wells	D-5 site wells	Wing Naing et. al (1991)	Existing Dug Well	Wing Naing et. al (1991)	Existing Dug Well	East Yangon Univ.	D-3 site wells	D-4 site wells
Surface Aquifer	-	-	-	-	-	(k=1x10^{-3} cm/sec)	-	(k=3x10^{-3} cm/sec)	-	-	-
1st Aqiifer	146		1	1	11 ~ 150	-	2 ~31	-	179	75	148
2nd Aqiifer	19	15, 20, 63, 70	1	4		-		-	-	22	207
3rd Aqiifer	16	-	1	13	-	-	-	-	-	-	-
4th Aqiifer	44	-	7		-	-	-	-	-	79	-

Source: JICA survey team

3-3-3 Groundwater Use

According to the well inventory survey, there are about 12,000 wells in the area and about 17,000 m^3/day of groundwater is extracted as shown in Figure 3-3-3-1. There are two types of wells, the “dug well” and the “tube well” as shown in Figure 3-3-3-2. Figure 3-3-3-4 and Figure 3-3-3-5 shows their distribution. Figure 3-3-3-6 and Figure 3-3-3-7 shows the areal density of wells and discharge respectively. Most wells distribute and most extraction is made on the hill and nearby area. For the most part, only tube wells distribute in the plain. Table 3-3-3-1 and Figure 3-3-3-8 to Figure 3-3-3-12 shows the water use by aquifer. The extraction is conducted mainly in the surface unconfined aquifer and the upper two confined aquifers.

Wells are increasing in these 20 years and about 700 wells (1,000 m^3/day in total discharge) were added every year during a few recent years as understood from Figure 3-3-3-3.

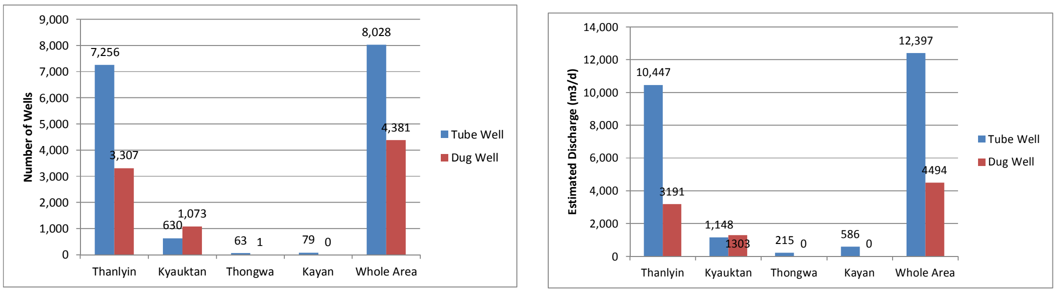


Figure 3-3-3-1 Number of wells and Total Discharge

Figure 3-3-3-2 Dug Well (left) and Tube Well (right)

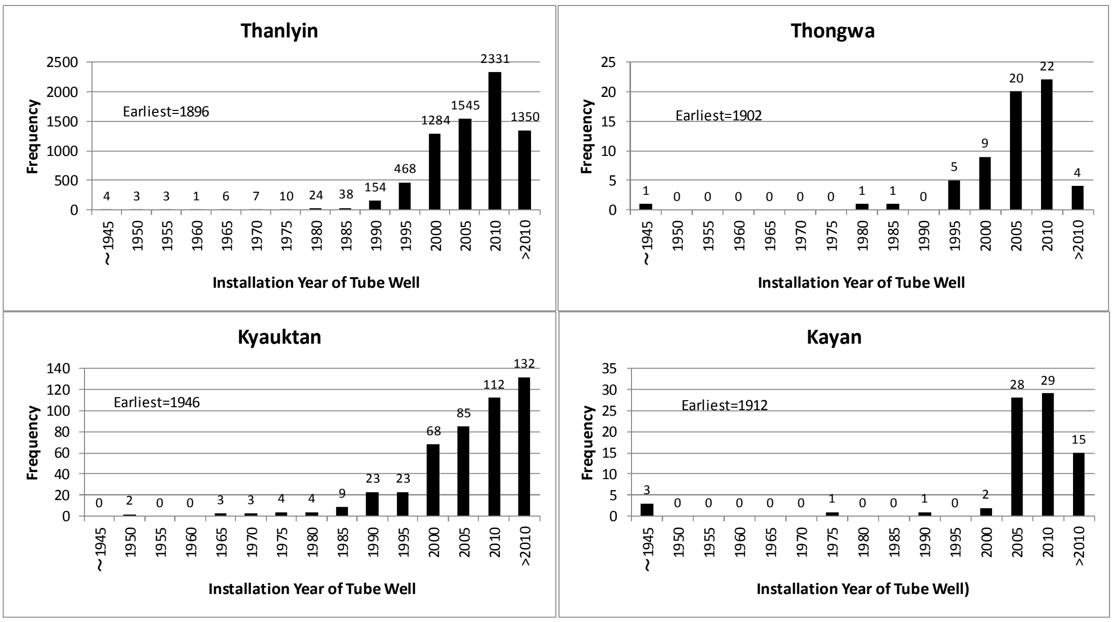


Figure 3-3-3-3 Installation Year of Tube Wells

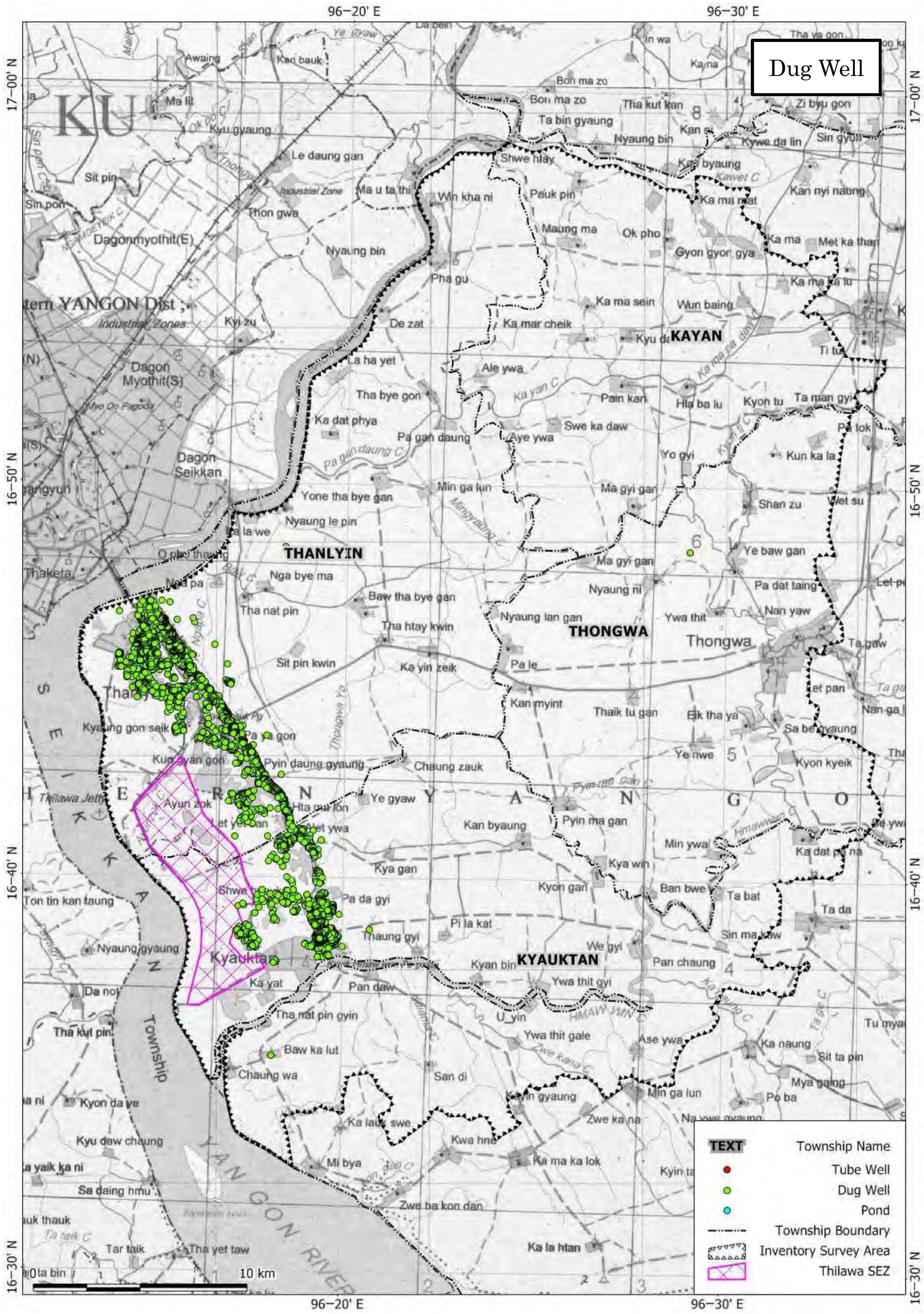


Figure 3-3-3-4 Distribution of Dug Well

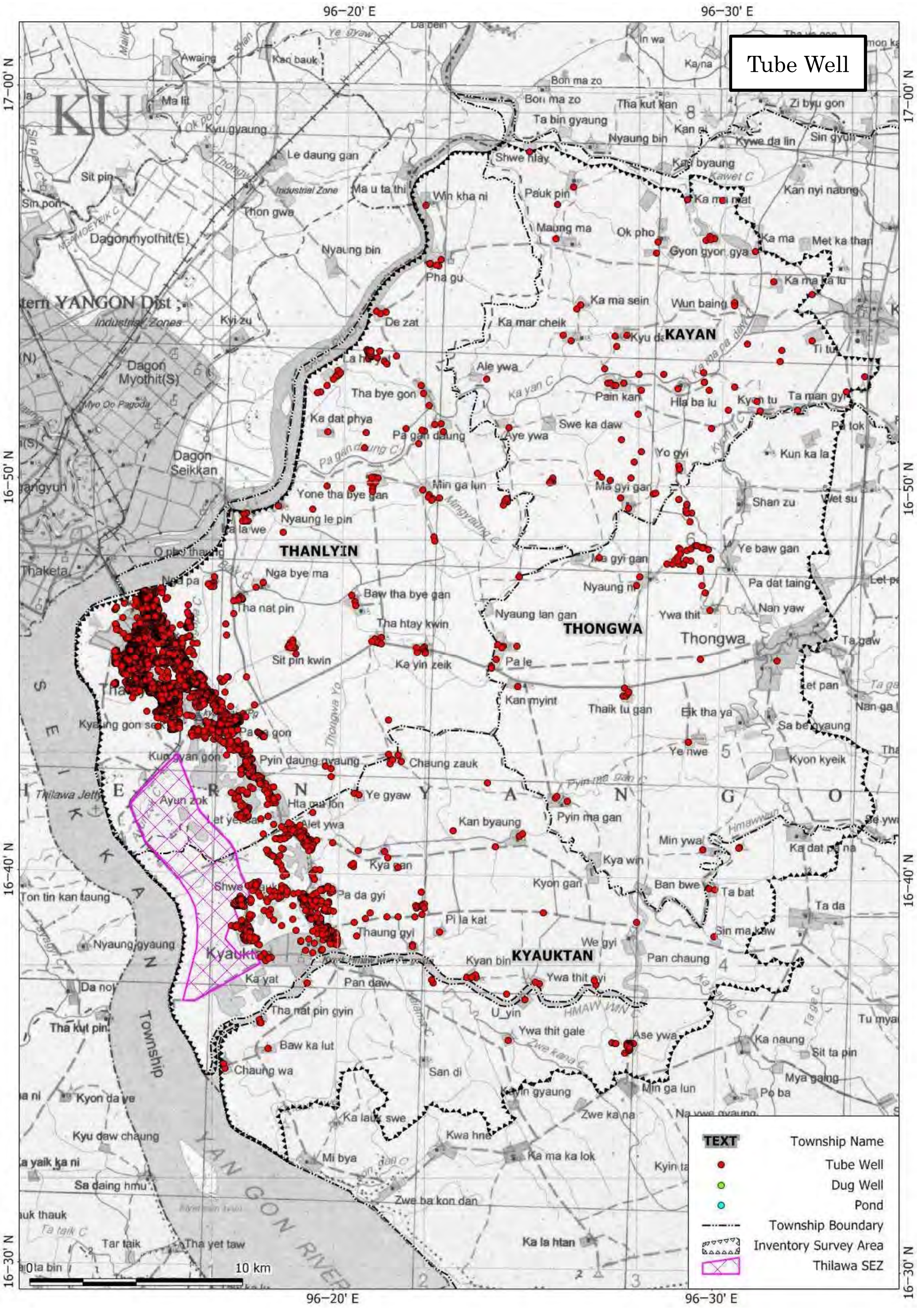


Figure 3-3-3-5 Distribution of Tube Well

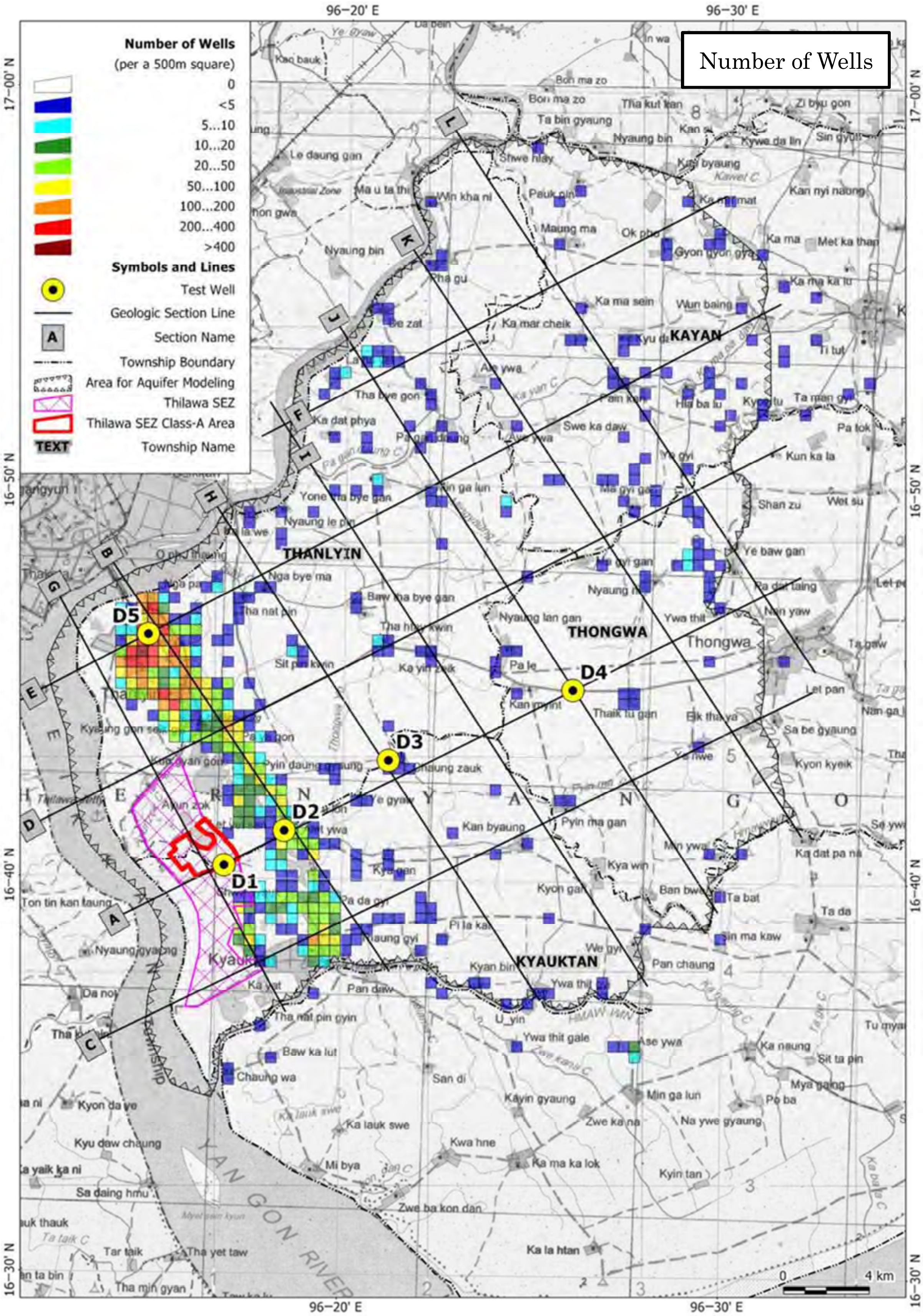


Figure 3-3-3-6 Areal Density of Wells by 500 m Square

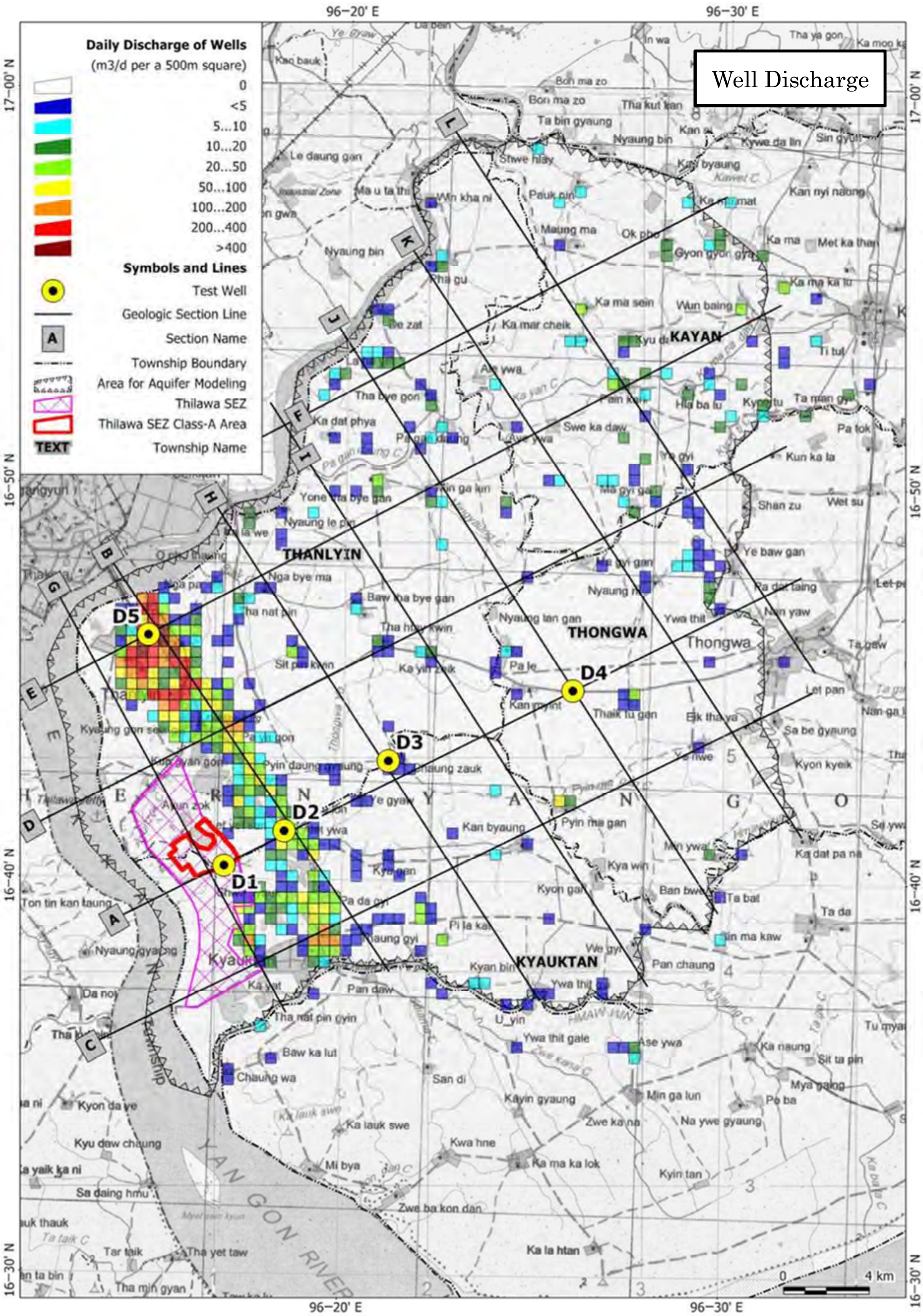


Figure 3-3-3-7 Areal Density of Well Discharge by 500 m Square – All Aquifers

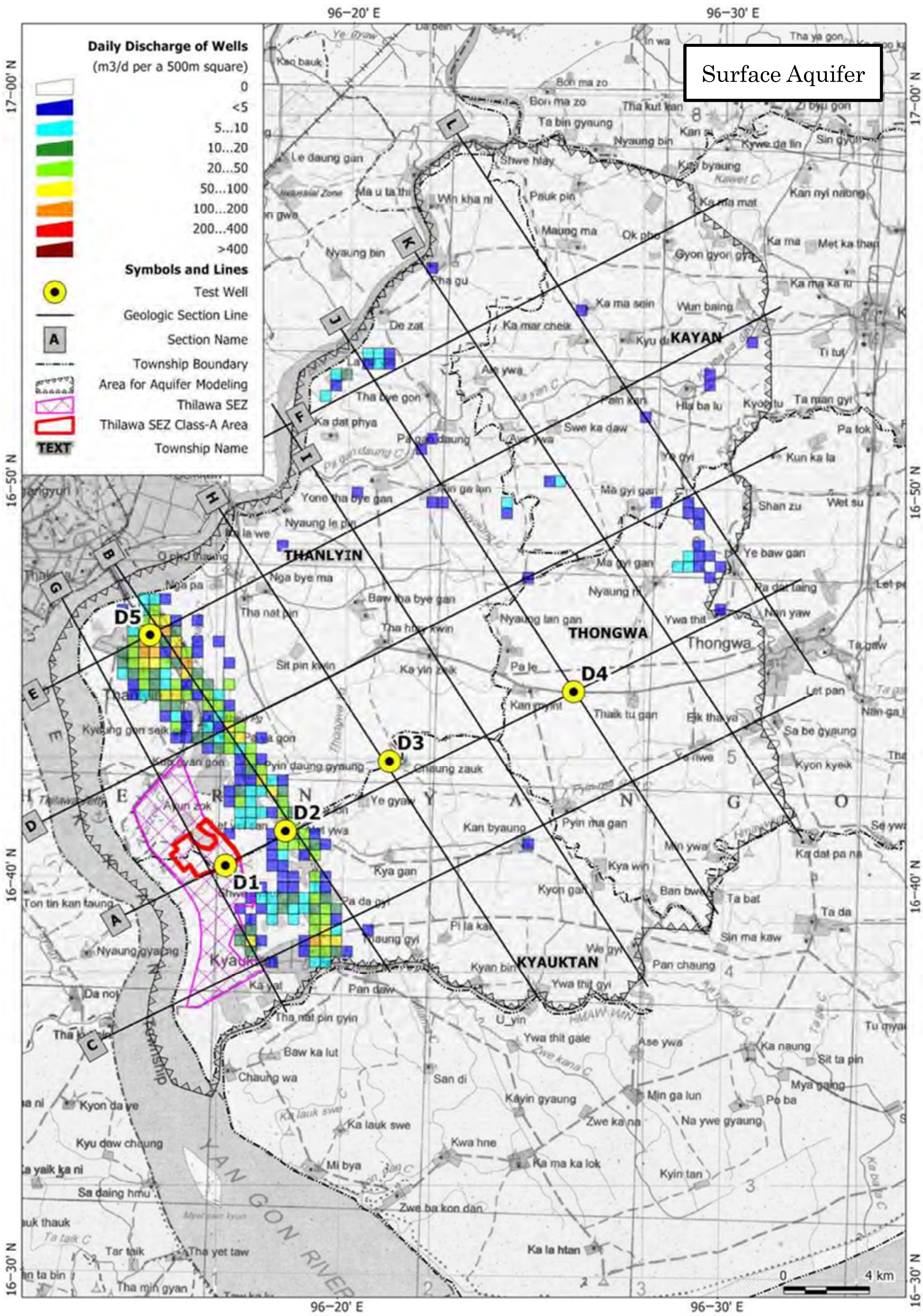


Figure 3-3-3-8 Areal Density of Well Discharge by 500 m Square – Surface Aquifer

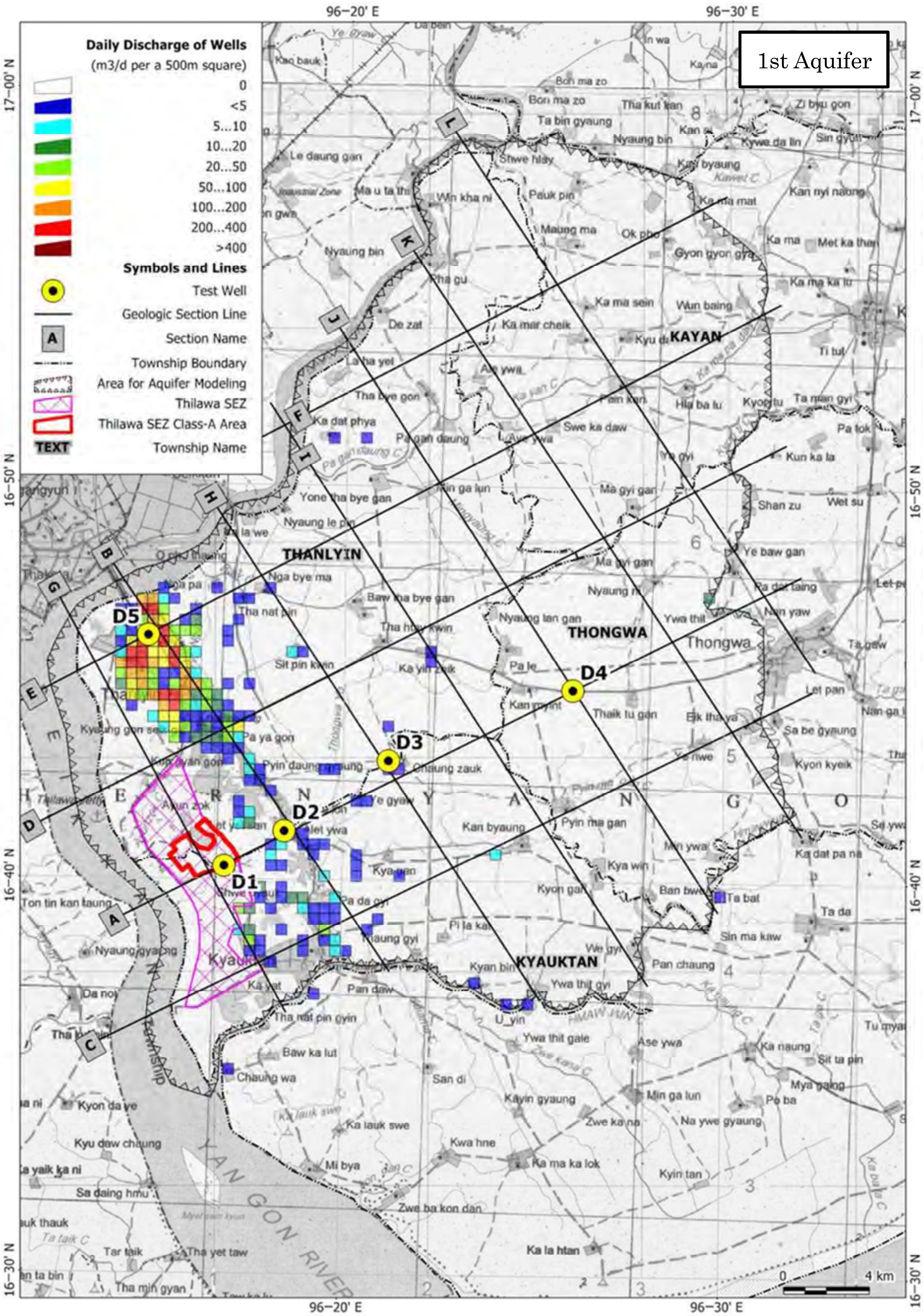


Figure 3-3-3-9 Areal Density of Well Discharge by 500 m Square – 1st Aquifer

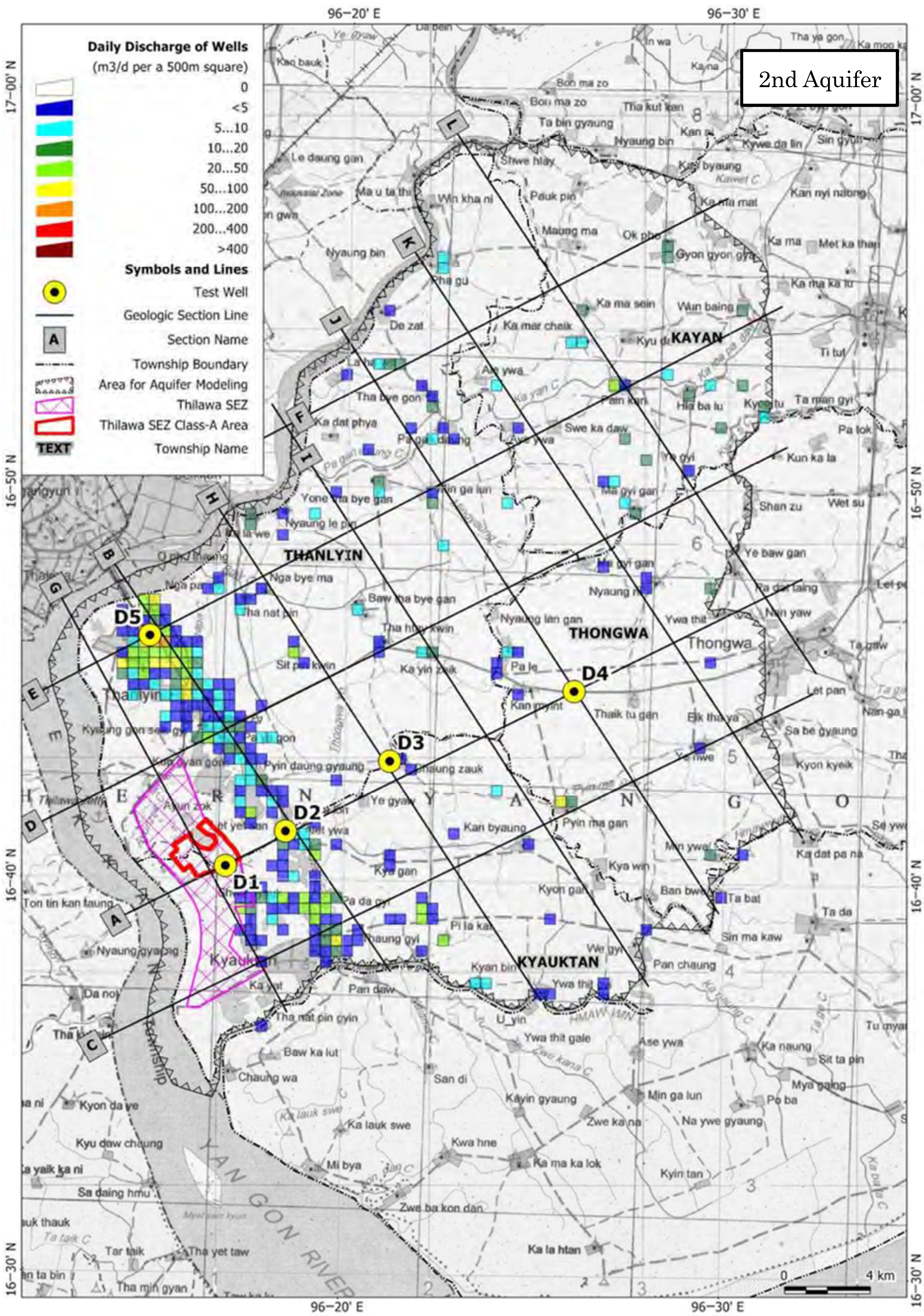


Figure 3-3-3-10 Areal Density of Well Discharge by 500 m Square – 2nd Aquifer

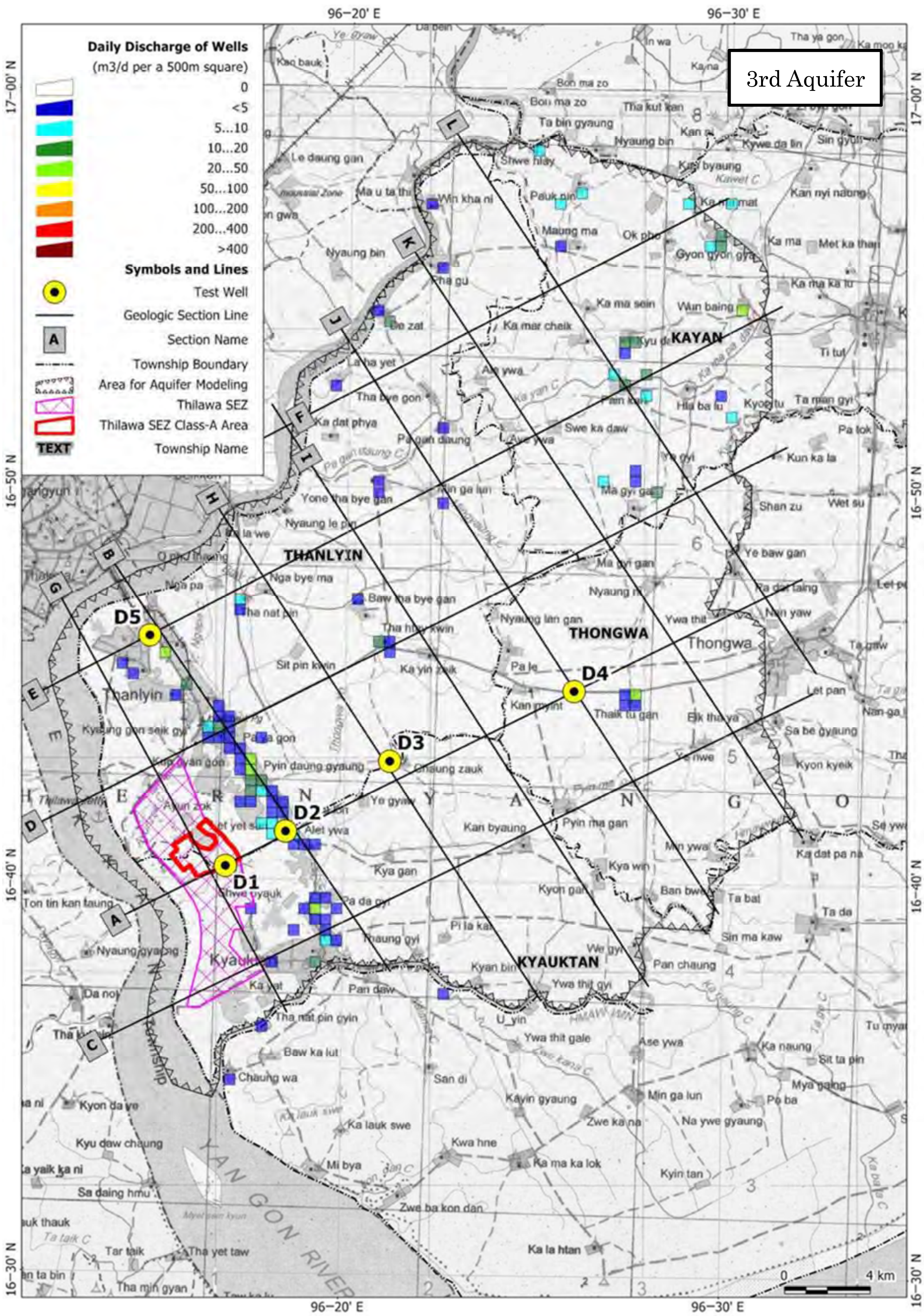


Figure 3-3-3-11 Areal Density of Well Discharge by 500 m Square – 3rd Aquifer

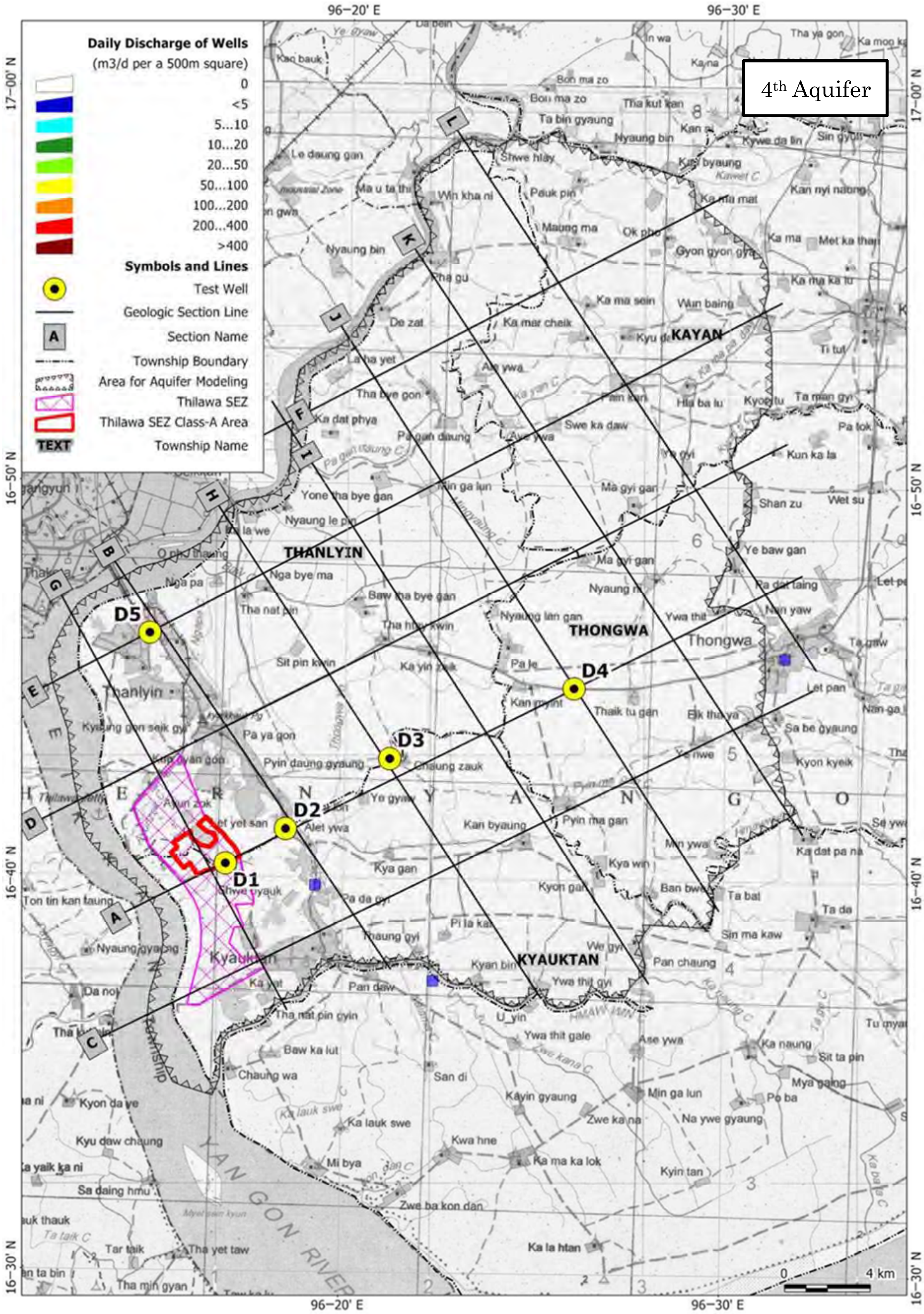


Figure 3-3-3-12 Areal Density of Well Discharge by 500 m Square – 4th Aquifer

Table 3-3-3-1 Groundwater Use by Aquifer

Aquifer Name	Tube Wells		Dug Wells		All Wells			
	Number	Discharge (m^3/day)	Number	Discharge (m^3/day)	Number	Numer (%)	Discharge (m^3/day)	Discharge (%)
Surface Aquifer	176	242.7	4349	4442.8	4525	36.6	4685.5	27.1
1st Aquifer	6001	8568.0	21	23.3	6022	48.7	8591.3	49.6
2nd Aquifer	1630	3405.4	0	0.0	1630	13.2	3405.4	19.7
3rd Aquifer	181	619.6	0	0.0	181	1.5	619.6	3.6
4th Aquifer	3	3.6	0	0.0	3	0.0	3.6	0.02
Total	7991	12839.3	4370	4466.1	12361	100.0	17305.5	100.0

Note: Discharge of a well calculated by (hourly well capacity) x (daily pumping hours)
Unknown discharge of a well is assumed as the average 1.59 m^3/d for deep well and 1.01 m^3/d for dug well.
Some wells located in the margin unable to be classified.
Source: JICA survey team

3-3-4 Water Quality

3-3-4-1 Summary of Water Quality of Aquifers

Table 3-3-4-1 summarizes results of the water quality test at the test wells. The following characteristics are found:

1) The shallower aquifers in the ridge have less pH, EC and iron concentration. This suggests that not much time has passed after the rain water infiltrated into the aquifer.
2) Salty water distributes in the shallower aquifers under the plain.
3) Iron concentration is generally high and water taste is bad.
4) The deep aquifer (4th) has high pH and high zinc concentration.
5) Lead concentration exceeded the WHO drinking water guideline at three monthly measurements or more in the shallower aquifers in the ridge.

Table 3-3-4-1 Summary of Water Quality of Test Wells

Topographic Location	Hill											Plain					Remarks
	Foot				Ridge												
Test Well Name	D-1-0	D-1-1	D-1-2	D-1-3	D-2-0	D-2-1	D-2-2	D-2-3	D-5-1	D-5-2	D-5-3	D-3-1	D-3-2	D-3-3	D-4-1	D-4-2	
Screen Depth (m)	37-48	66-83	110-138	187-283	31-54	67-95	125-148	196-301	46-63	81-98	180-240	60-77	112-149	244-328	66-83	110-144	
Target Aquifer No.	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**	**1**	**2**	**3, 4**	**1**	**2**	**4**	**1**	**2**	
pH < 6.5	-	-	-	-	×	×	-	-	×	×	-	-	-	-	-	-	
pH > 8.5	-	-	-	×	-	-	-	×	-	-	×	-	-	×	-	-	
EC < 150 μ S/cm	-	-	-	-	○	○	-	-	○	○	-	-	-	-	-	-	Very fresh water sign
EC > 750 μ S/cm	-	-	-	-	-	-	-	-	-	-	-	×	-	-	×	×	Salty water sign; Correspond to Cl ion >250mg/l)
Fe ion > 0.3 mg/l	×	×	×	×	-	×	×	×	×	×	×	×	-	×	×	×	General threshhold of acceptability by WHO Guideline p.228
Taste	Iron	Iron	Slightly iron	A little iron	○	○	○	Iron	Iron	Iron	Iron	Salty	Sulfuric	Iron	Salty, sulfuric	Salty	
Zinc > 3 mg/l	-	-	-	×	-	-	-	×	-	-	×	-	-	×	-	-	General threshhold of acceptability by WHO Guideline p.229
Lead > 0.01 mg/l	-	-	-	-	×	×	-	-	×	×	-	-	-	-	-	-	Exceeded WHO guideline three times or more

Note: ○ Good quality sign, × Bad quality sign, -: Out of the specified range   Source: JICA survey team.

3-3-4-2 Distribution of Salty Water

Here, salty water is defined as water with EC > 750 μS/cm, which is approximately equivalent to Cl-ion > 250 mg/l (see Figure 3-2-2-9).

(1) Sectional Distribution

Considering EC values obtained by the water quality survey and small-resistivity values measured by the geophysical survey, EC distribution is inferred on the main aquifer profiles as shown in Figure 3-3-4-1 to Figure 3-3-4-5. (See the enlarged profiles in the attached CD for the details)

On the profile, the EC values painted in yellow, orange and red exceed 750 μS/cm. The resistivity values less than 1.0 Ωm are painted in red and inferred to be a high-salinity water which are mainly found in the surface Quaternary layer in the plain.

(2) Areal Distribution by Aquifer

Figure 3-3-4-6 and Figure 3-3-4-7 shows salty water distribution in each aquifer inferred from EC measurement at the existing wells and the test wells. The salty water may distribute widely under the plain and the western lowland along the SEZ. The fresh water distributes mainly in the hill and its nearby area. Under the plain, the second aquifer may have largest amount of fresh water among the aquifers. In the central area of the Thilawa SEZ, salty water is confirmed to distribute in the western 2/3 of the area as shown in Figure 3-3-4-8.

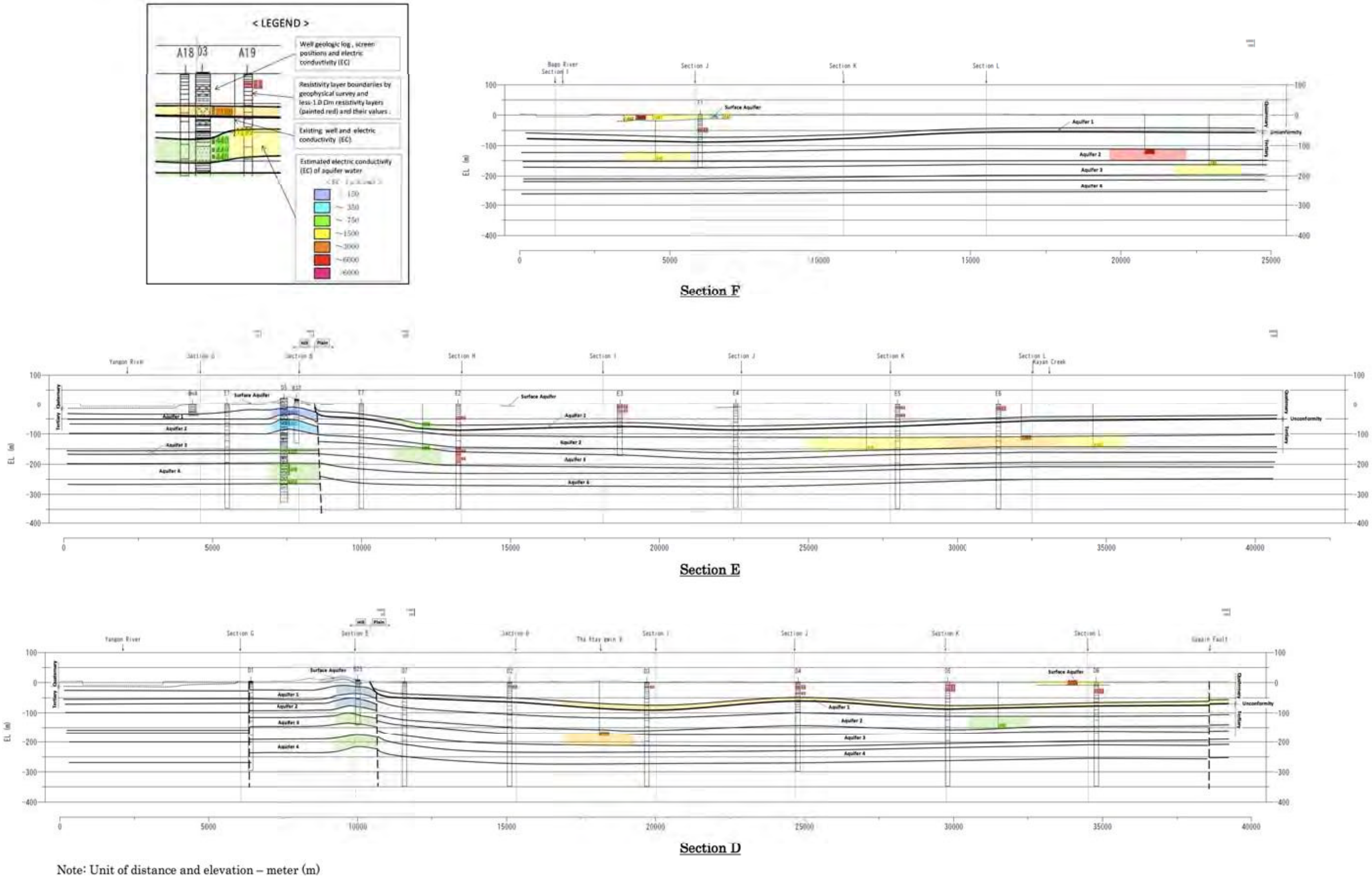
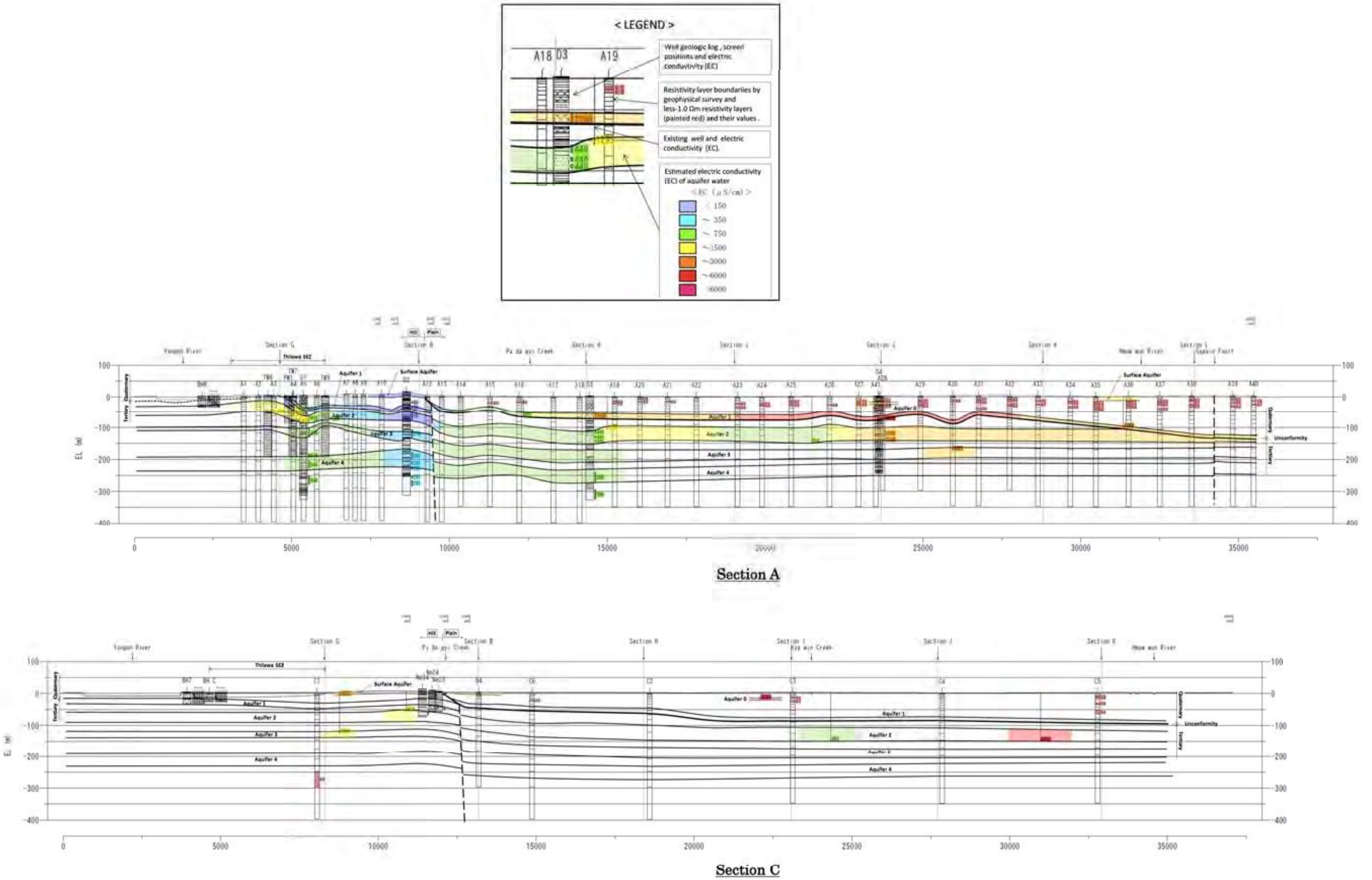
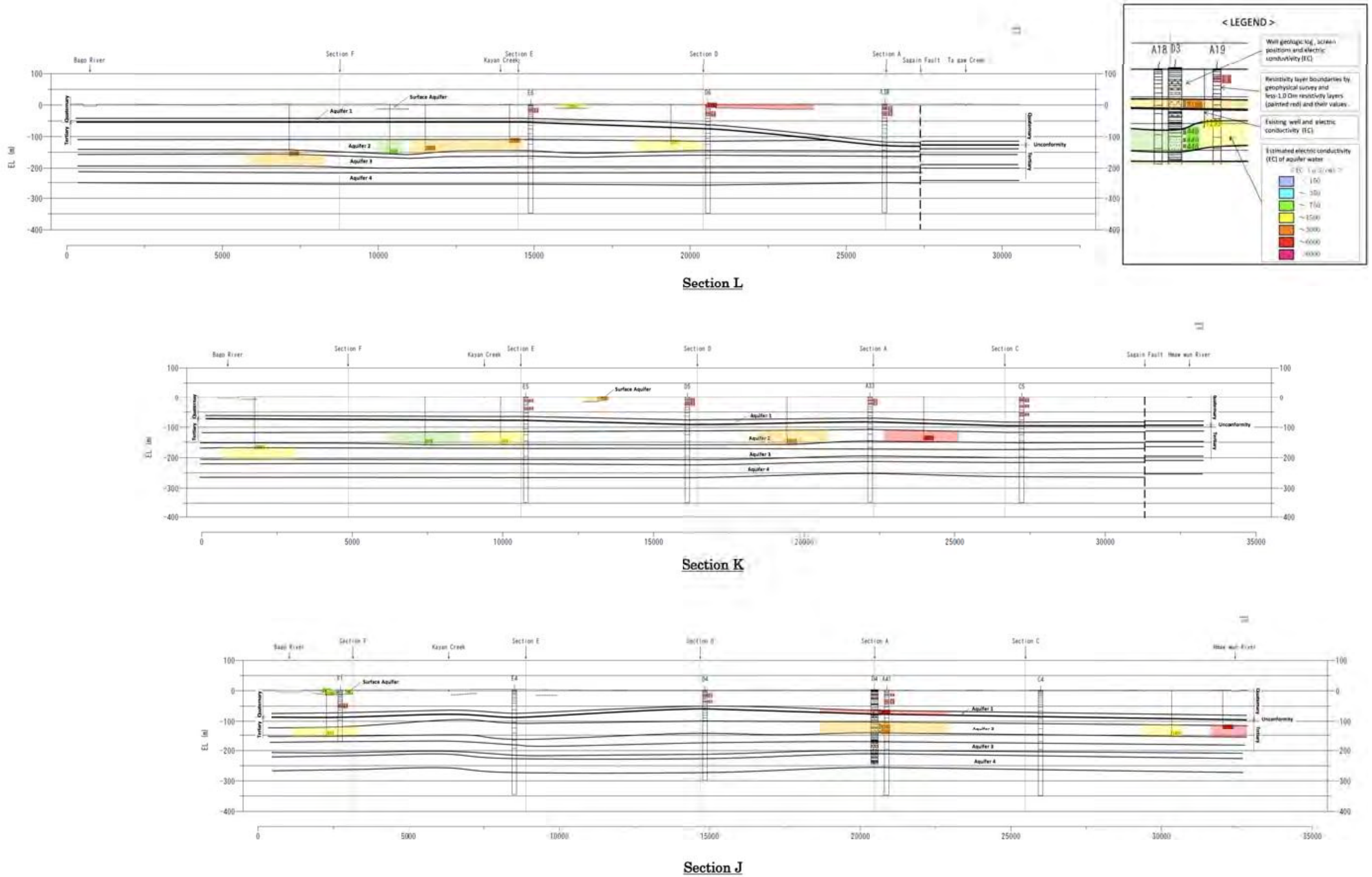


Figure 3-3-4-1 Electric Conductivity (EC) Distribution on Aquifer Profile – WSW- ENE Direction (1)



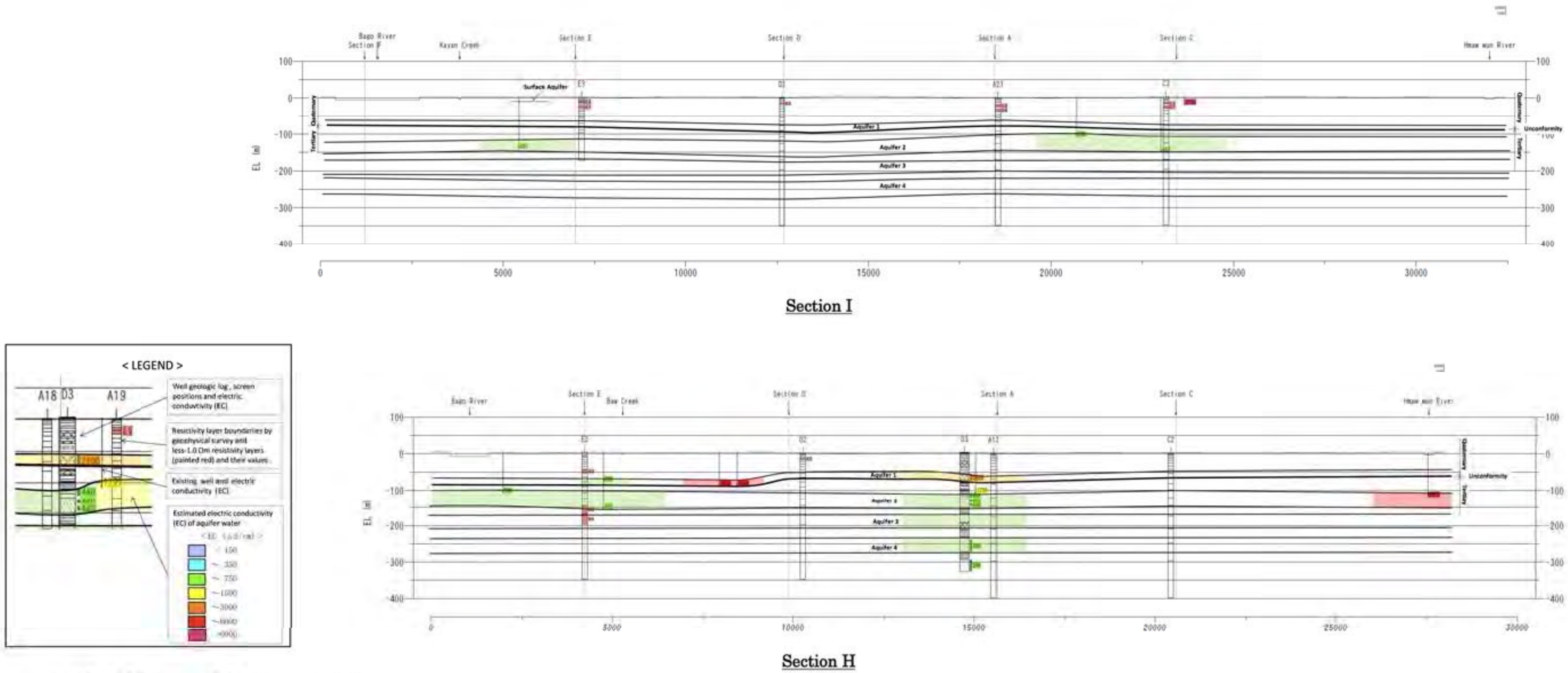
Note: Unit of distance and elevation – meter (m)

Figure 3-3-4-2 Electric Conductivity (EC) Distribution on Aquifer Profile – WSW- ENE Direction (2)



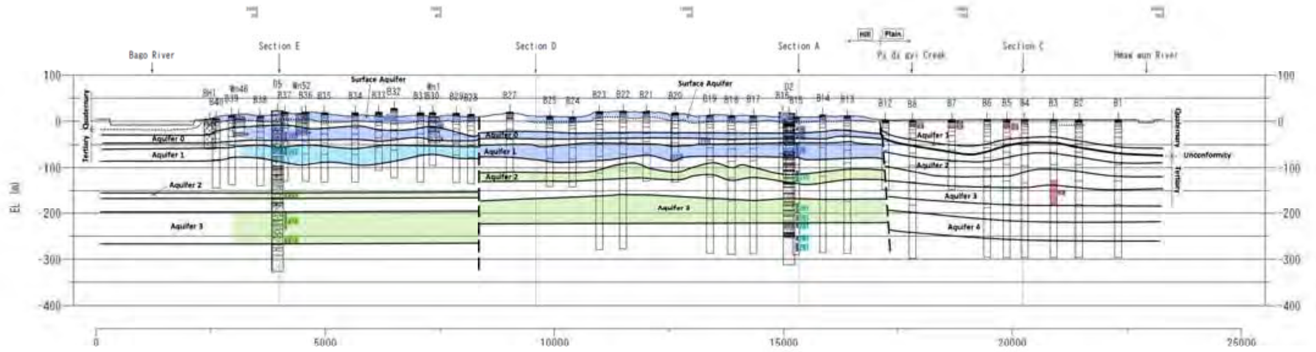
Nc

Figure 3-3-4-3 Electric Conductivity (EC) Distribution on Aquifer Profile - NNW - SSE Direction (1)

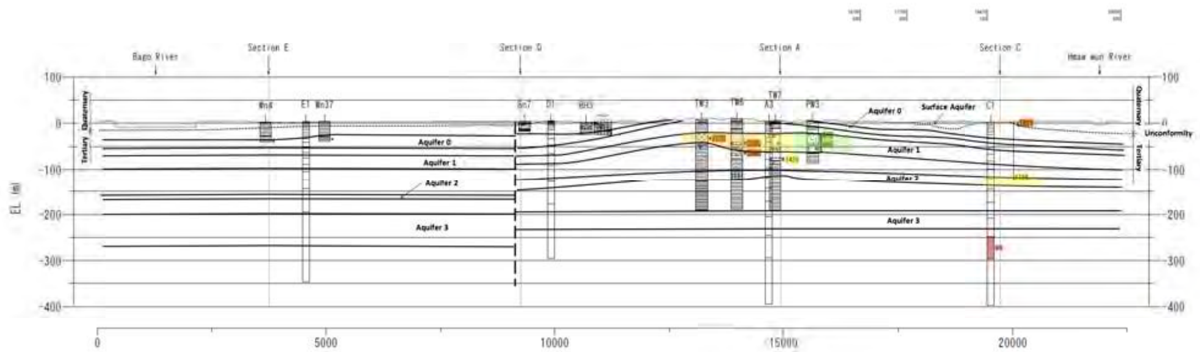


Note: Unit of distance and elevation – meter (m)

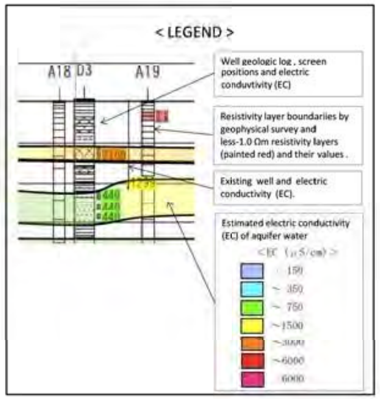
Figure 3-3-4-4 Electric Conductivity (EC) Distribution on Aquifer Profile - NNW - SSE Direction (2)



Section B



Section G



Note: Unit of distance and elevation – meter (m)

Figure 3-3-4-5 Electric Conductivity (EC) Distribution on Aquifer Profile - NNW - SSE Direction (3)

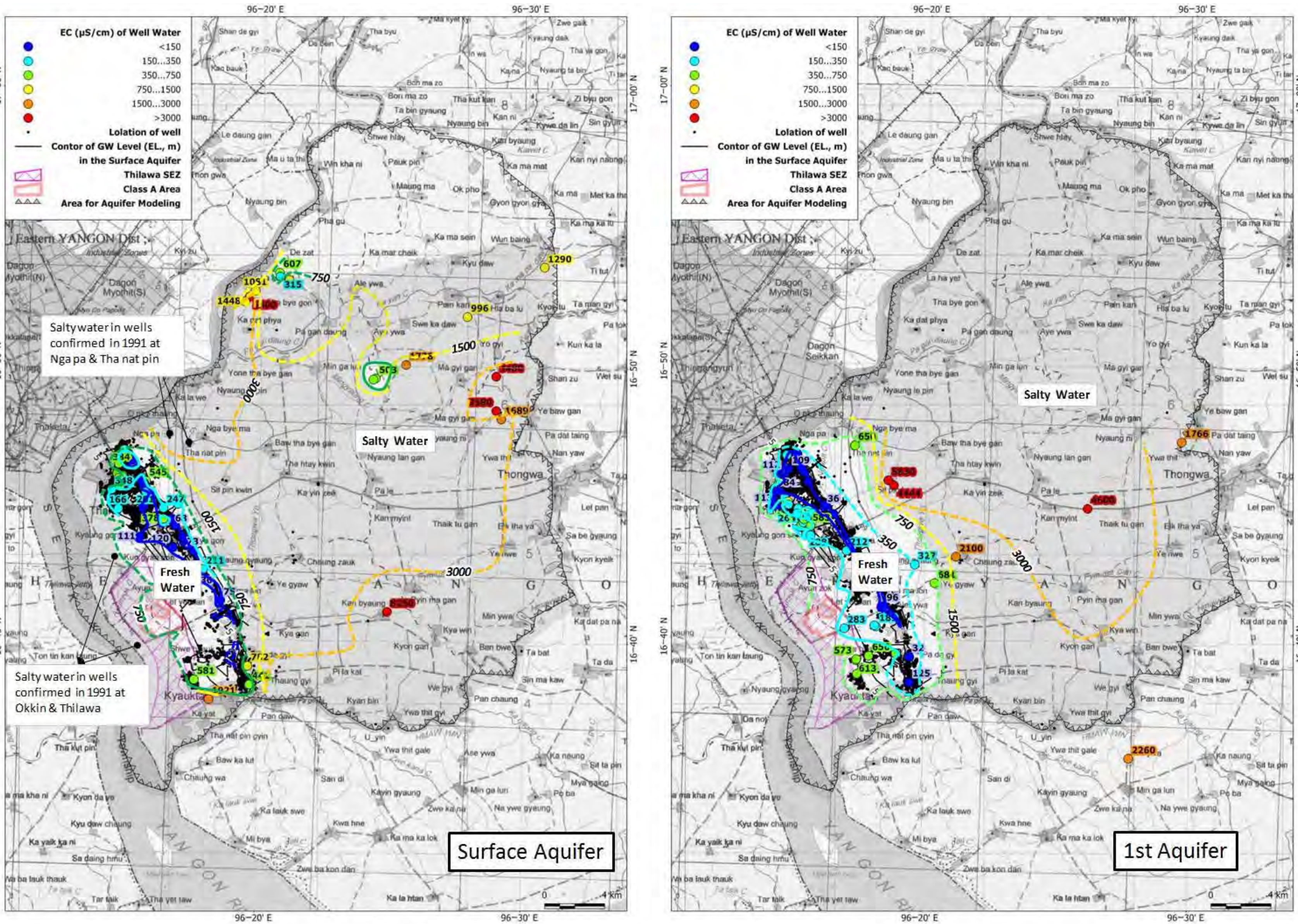


Figure 3-3-4-6 Inferred Salty Water Distribution by Aquifer (1)

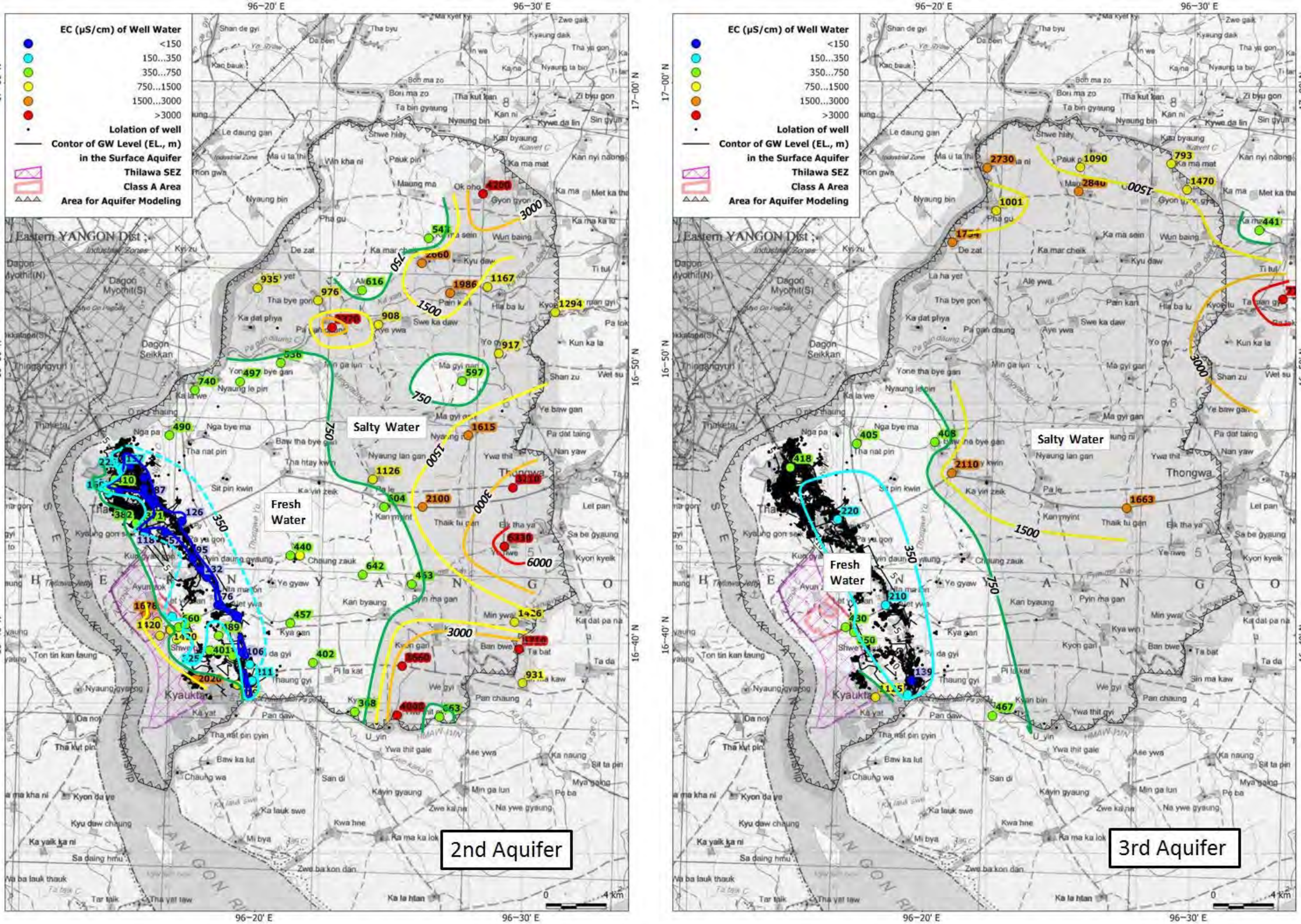


Figure 3-3-4-7 Inferred Salty Water Distribution by Aquifer (2)

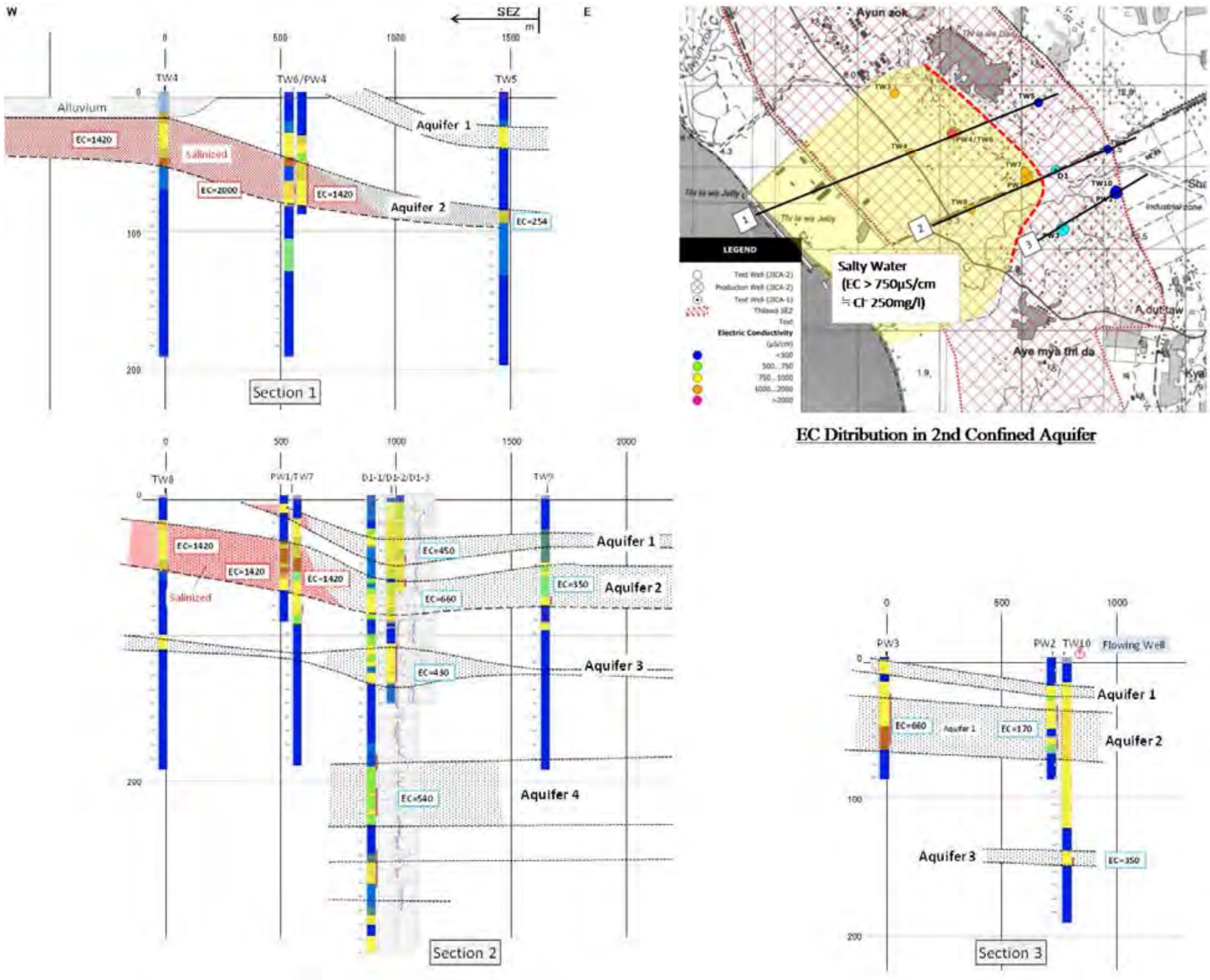


Figure 3-3-4-8 Aquifer Section and Salty Water Distribution under Thilawa SEZ

3-3-5 Groundwater Head and Movement

(1) Groundwater Movement Direction

From the groundwater table contour map estimated with the groundwater table depth in dug wells (see Figure 3-2-10-1), it is inferred that the groundwater moves from the hill center to both sides in the surface unconfined aquifer.

(2) Recharging and Discharging Areas

Figure 3-2-9-2 and Figure 3-2-9-3 show the groundwater head and its fluctuation in the confined aquifer at the 16 test wells. At the D-2, D-5 and D-4 sites, a deeper aquifer has a lower head. They are located on the hill ridge or the ridgy portion on the plain. On the contrary, at the D-1 and D-3 sites, a deeper aquifer has a higher head. They are located at a foot of the hill or near a creek. This means that the former sites are located in the recharging area and the latter ones in the discharging area, as schematically shown in Figure 3-3-1-2.

(3) Overdraft in Thanlyin Town

At the D-5 site, the groundwater head in D-5-2 (2nd confined aquifer) and D-5-3 (3rd&4th confined aquifers) is kept mostly lower than EL. 0m throughout the year. The Thanlyin area where the D-5 site is located is near the Bago and Yangon Rivers in which the sea water comes up. In such a circumstance, it is hydraulically possible for the salty water to intrude into the aquifers as schematically shown in Figure 3-3 13. Even if the head of aquifer is lower than EL. 0 m, if the minus value is small, the intrusion may not occur because the head may remain higher than EL.0 m in between the extraction area and the river as shown in the middle figure. However, the intrusion likely occurs in this area because the head value of minus is large, as shown in the lower figure. Therefore, the aquifers are considered to be in an “overdraft” condition.

(4) Aquifer Condition around D1 Site

At the D-1 site, it is notable that the head in D-1-0 (1st confined aquifer) fluctuates differently from that in the other three deeper wells. The first aquifer is probably connected to the surface unconfined aquifer near the site.

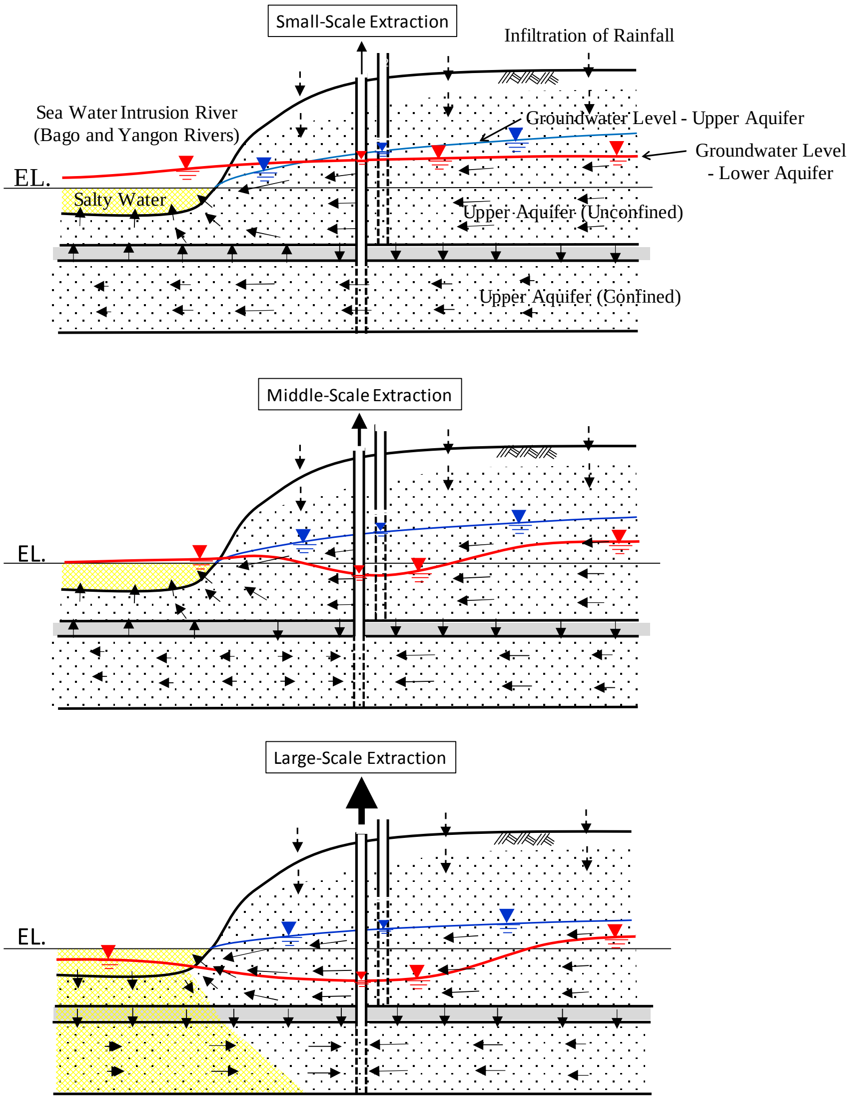


Figure 3-3-5-1 Schematic Explanation of Relationship between Extraction Scale and GW Head Drawdown near Sea Water Intrusion River

3-4. Groundwater Recharge and Exploitation Rate

3-4-1 Estimation of Groundwater Recharge Rate by Tank Model

3-4-1-1 Estimation Method

The main groundwater recharge source is considered to be the rainfall on the hill around the Thilawa SEZ from the following reasons:

Topography, Surface Geology and Land Cover

The hill is underlain by lateritic soil (see Figure 3-2-12-1 to Figure 3-2-12-3) with 2800 mm of annual rainfall and is covered widely with forest (Figure 3-2-11-1). This implies that there is much infiltration of rain water. Especially in the north, less-consolidated sandstone mainly distributes and the infiltration capacity is considered to be large. The ground elevation is about 20 m at the ridge. This allows the infiltrated water to store and flow laterally in the hill with about 20 m of head difference between the hill center and the flowing-out waterways around.

Whereas, the plain/lowland are covered with a thick clayey layer (Figure 3-2-5-2) and the infiltration capacity is considered to be small. The ground elevation is about a few meters and the head difference between the ground and the well-developed flowing-out waterways is small. Therefore the infiltrated rain water hardly stores and may flows out to the nearby waterways or inundates the land.

Groundwater Head Fluctuation

As understood from the groundwater level observation results (Figure 3-2-9-2 and Figure 3-2-9-3), the annual groundwater head change responding to rainfall is about 5m ~ 10m in the hill (D-2 and D-5 site) and from 0.2 m to 0.7 m in the plain (D-3, D-4 sites) and the western lowland (D-1 site). This head change means that the seasonal water stock which originates in rainfall is large in the hill and small under the plain/lowland.

Groundwater Use

The groundwater use (extraction) is conducted mainly on the hill (Figure 3-3-3-6). Because the groundwater level recovers in the wet season, it is inferred that the considerable amount of water is recharged in the area. In the plain/lowland, groundwater use is small and the forcing recharge by extraction is rarely produced.

Groundwater Age Estimated by Isotope Analysis

According to the isotope analysis, Helium 4 age of groundwater is as young as a few ten years in the shallower aquifers in the hill and as old as a few hundreds or thousands years in the plain (Figure 3-2-8-7). This suggests that the seepage velocity of infiltrated water is large in the hill and very small in the plain.

The main part of the annual groundwater recharge is the above-said seasonal storage. The total annual groundwater recharge includes the annual total amount of groundwater use and groundwater runoff in addition to the storage.

To estimate the annual groundwater recharge in the survey area, a tank model simulation was carried out with the observed time-series groundwater head data as a verification data of the model. Figure 3-4-1-1shows the schematic tank model expression of the aquifers in the survey area. The surface-water series of tanks and the surface-unconfined-aquifer tank were used for the present analysis. It is not required to discriminate the runoffs to the side and downwards from the surface aquifer in such a range of tanks.

Rainfall infiltrates into the ground and first reaches the surface unconfined aquifer. Therefore we need an observation record of the surface aquifer to estimate the groundwater recharge with the tank model. However, because observation was not carried out for the aquifer as shown in Figure 3-4-1-2, it is assumed, as shown in Figure 3-4-1-3, that the groundwater head fluctuation in the uppermost confined aquifer is the same as that in the surface unconfined aquifer. In reality, the fluctuation of the surface aquifer may be more or less larger and the response to rainfall may be slightly faster than the uppermost confined aquifer. This means that the estimated recharge may be more or less smaller than the real.

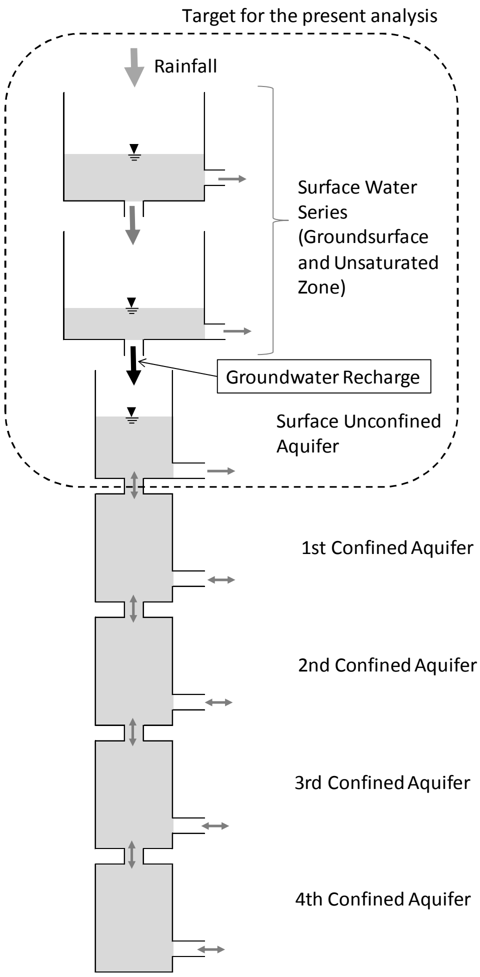


Figure 3-4-1-1 Tank Model Expression of Aquifers and Target Tanks for the Present Analysis

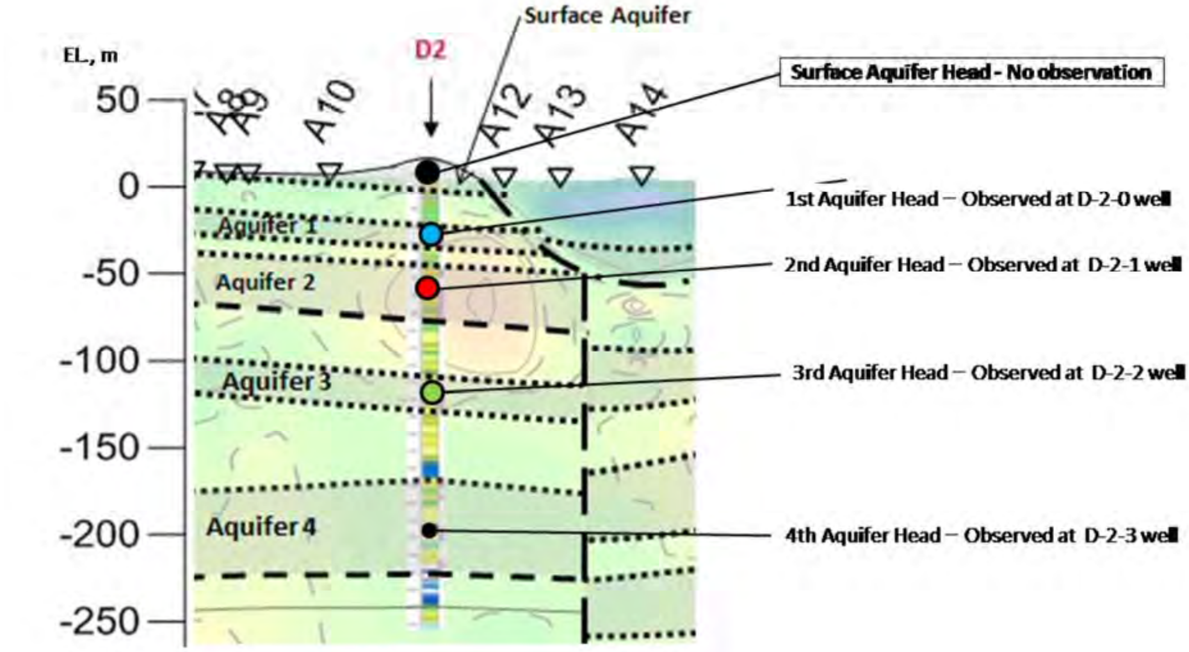


Figure 3-4-1-2 GW Head Observation Status of Aquifers (showing an example at the D2 site)

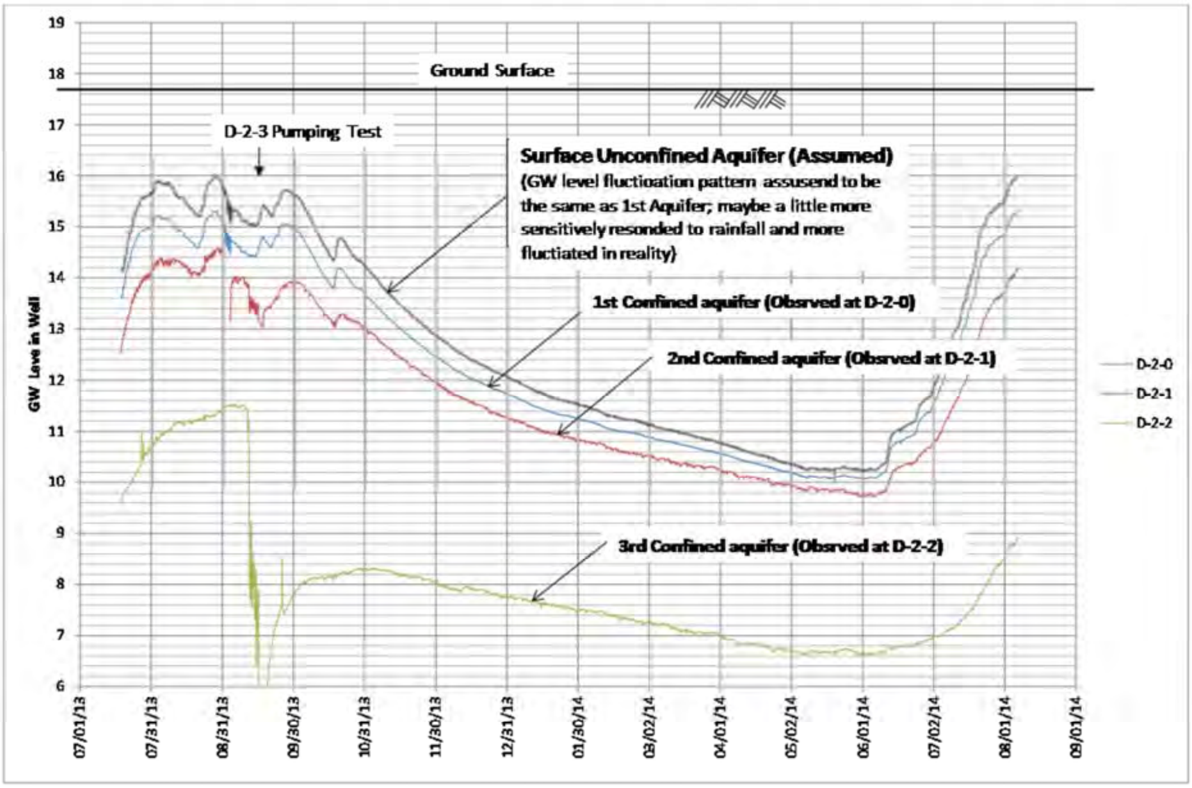


Figure 3-4-1-3 Assumption of GW Head Fluctuation for the Surface Aquifer

3-4-1-2 Parameters

(1) Rainfall and Potential Evapotranspiration Rate

The daily rainfall data in 2013 at the Yangon metrological station was used for the simulation. Concerning the potential evapotranspiration, the monthly values shown below are applied, which are used by Irrigation Department, MOIA, for the irrigation planning in the Yangon District

Monthly Evapotranspiration Rate (mm/day)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
5.82	6.11	7.65	8.01	5.88	4.43	4.45	4.38	4.89	4.92	5.27	5.43

(2) Groundwater Extraction Rate

Around the D5 site located in the Thanlyin town, groundwater use is very intensive and is not ignored in simulation. According to the well inventory survey, the extraction rate is estimated to be 1.3 mm/day as shown in Figure 3-4-1-4. According to observed groundwater level at the D-5-2 well, the daily fluctuation which is made by the extraction around the site is about 1.0 m in the wet season and 1.3 m in the dry season as shown in Figure 3-4-1-5. Considering these, the ground extraction rate for the simulation at the D-5 site is assumed to be 1.0 mm/day in the wet season and 1.3 mm/day in the dry season. For the other sites, no extraction was considered.

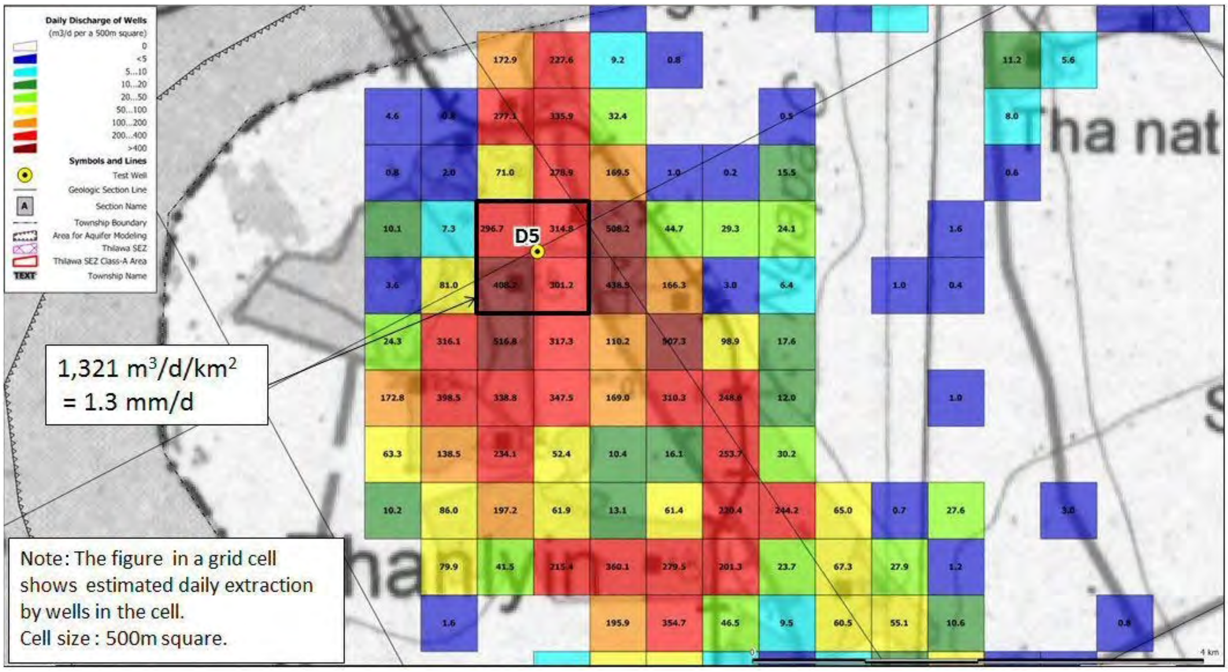


Figure 3-4-1-4 Groundwater Extraction Rate around D5 Site

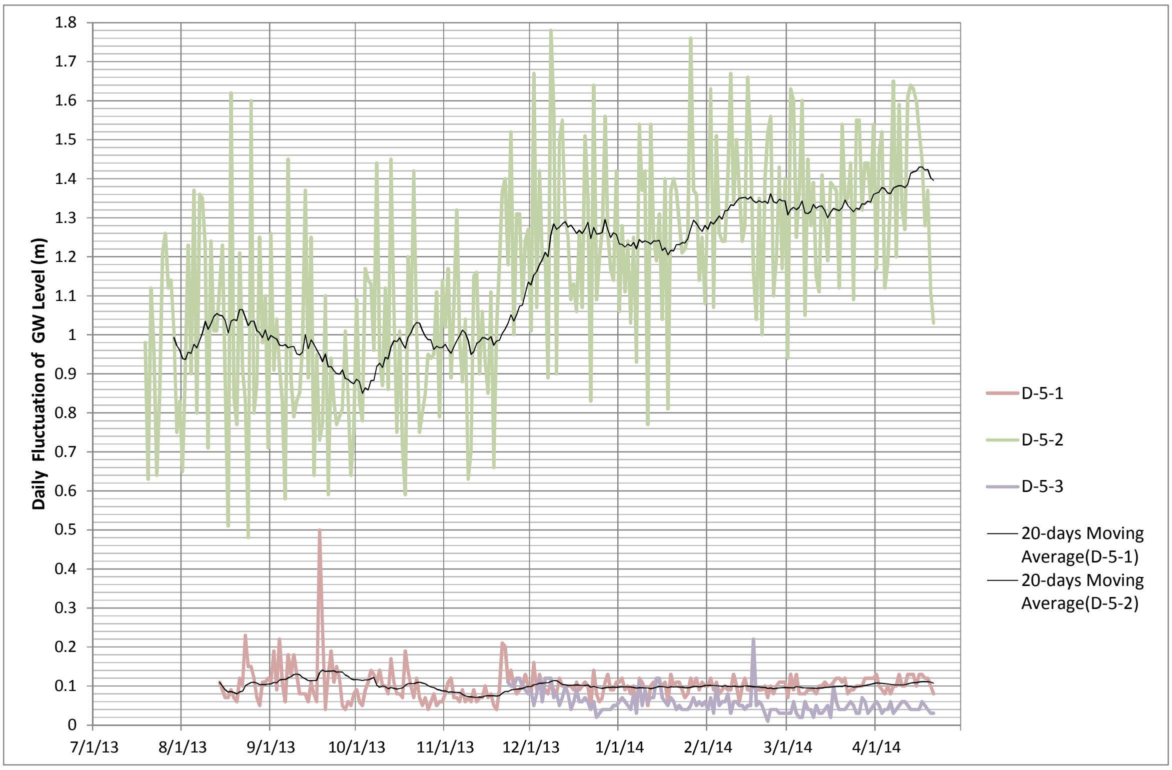


Figure 3-4-1-5 Daily Fluctuation of Groundwater Level at Observation Wells of D5 site

(3) Effective Porosity

The effective porosity is assumed 0.04 for the D5 site where sandstone of the Irrawaddy Formation mainly covers and 0.03 for the D-2 site where mudstone of the Pegu Formation mainly distributes. For the other sites, 0.03 is also assumed. The value 0.04 for the D5 site is considered to be reliable, because the observed level data was well simulated with the extraction rate in the dry season when no recharge occurs.

3-4-1-3 Result

Figure 3-4-1-6 to Figure 3-4-1-10 show the result of the tank model simulation for the five sites. The calculated groundwater head mostly simulated the observed one. The calculated water budget and groundwater recharge for 2013 is shown in Table 3-4-1-1.

Table 3-4-1-1 Water Budget of Tank Model Simulation

Item	Unit	D1	D2	D3	D4	D5
Rainfall	mm/yr	2774.0	2774.0	2774.0	2774.0	2774.0
Evapotranspiration	mm/yr	477.6	472.9	477.6	477.6	463.5
Surface Runoff	mm/yr	2235.7	1964.9	2232.7	2232.7	1686.3
Groundwater Runoff	mm/yr	61.2	325.5	65.3	64.1	187.4
Extraction	mm/yr	0.0	0.0	0.0	0.0	413.3
Sorage Change	mm/yr	-0.5	10.8	-1.5	-0.3	23.5
Groundwater Recharge	mm/yr	**60.7**	**326.2**	**63.8**	**63.8**	**624.2**
Annual Average GW Recharge	mm/day	**0.17**	**0.89**	**0.17**	**0.17**	**1.71**
Rainy Season Average GW Recharge (May~ Oct.;184 days)	mm/day	0.3	1.8	0.3	0.3	3.4

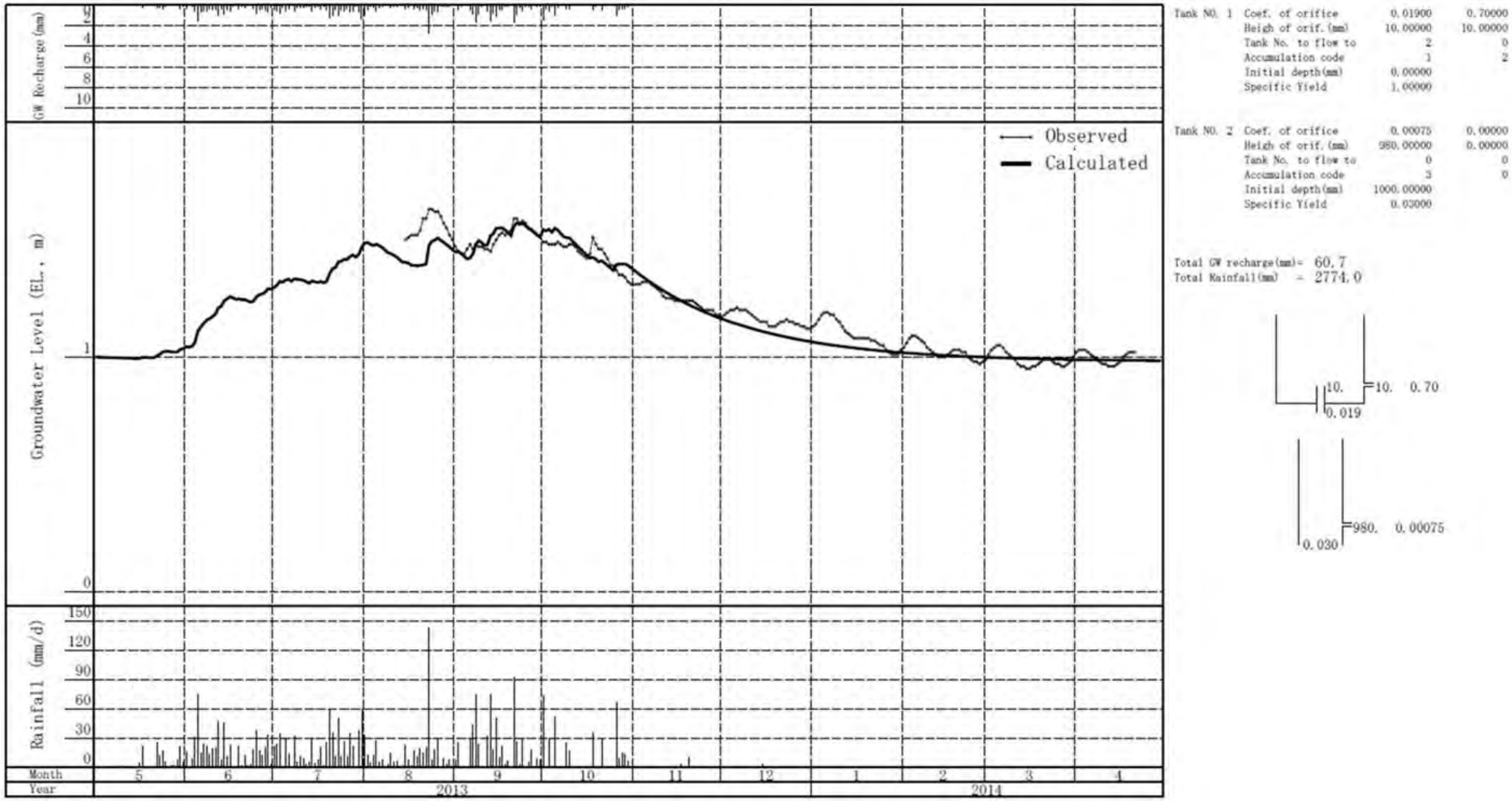


Figure 3-4-1-6 Tank Model Simulation Result of D-1 Site

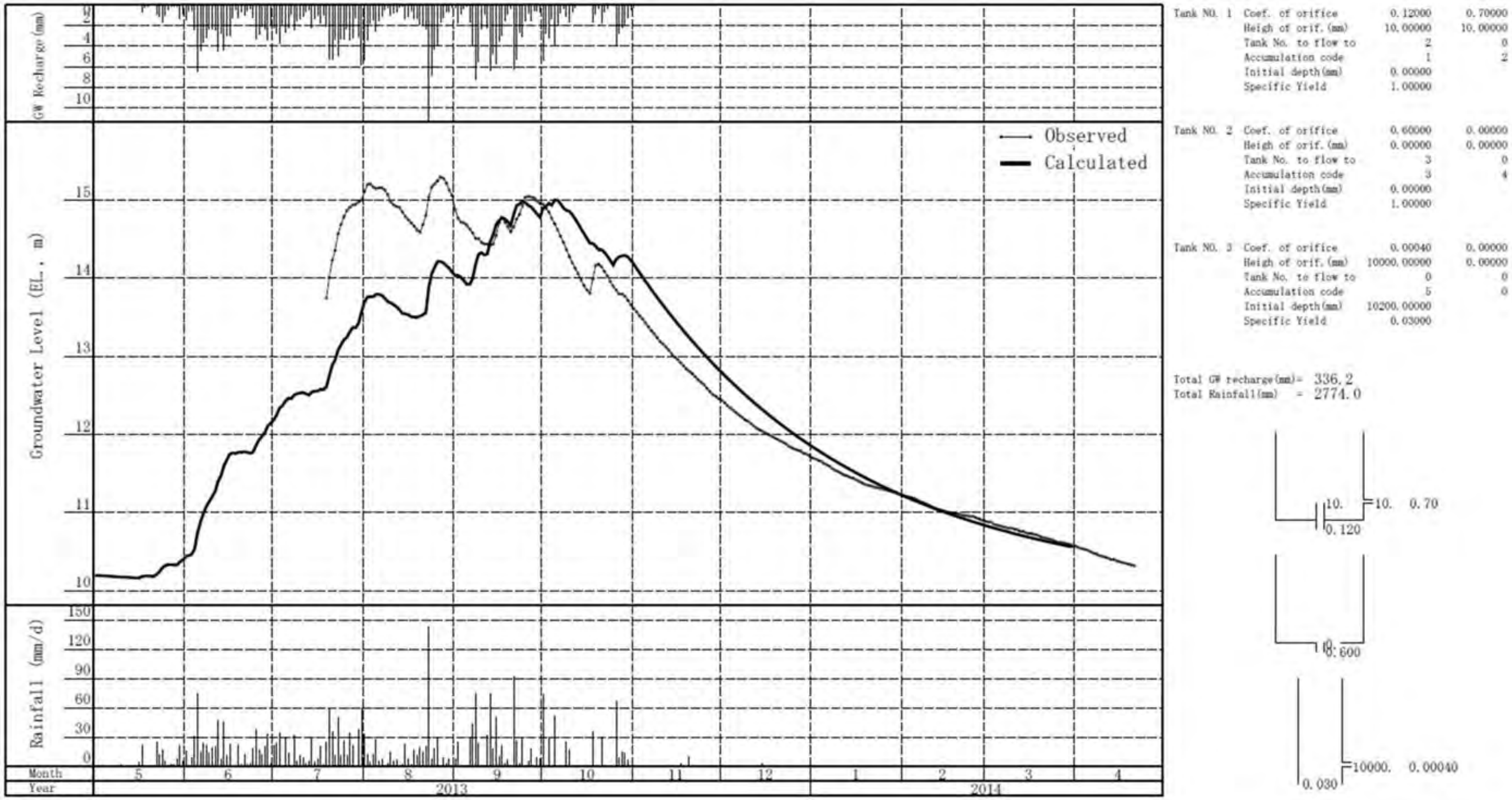


Figure 3-4-1-7 Tank Model Simulation Result of D-2 Site

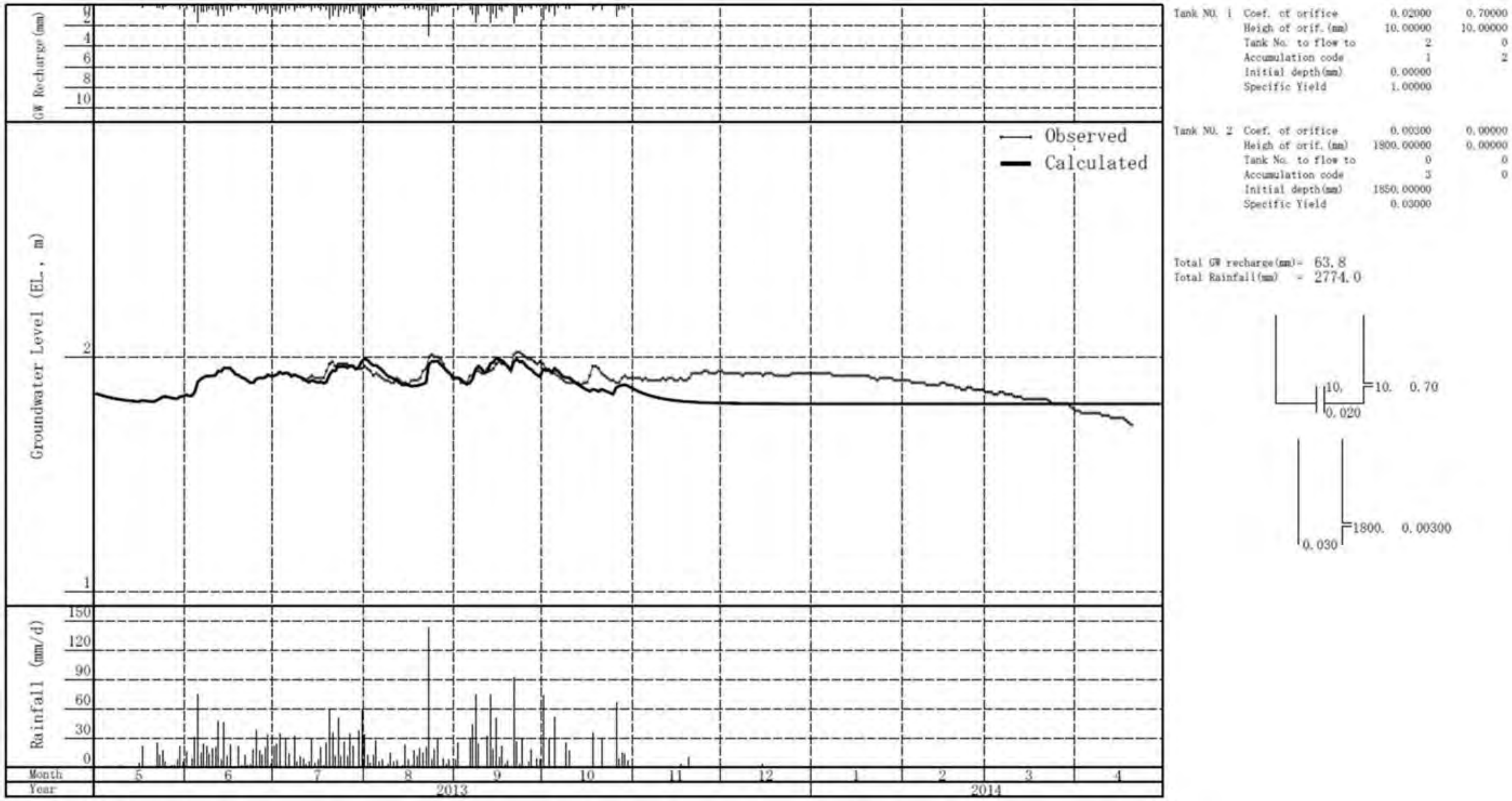


Figure 3-4-1-8 Tank Model Simulation Result of D-3 Site

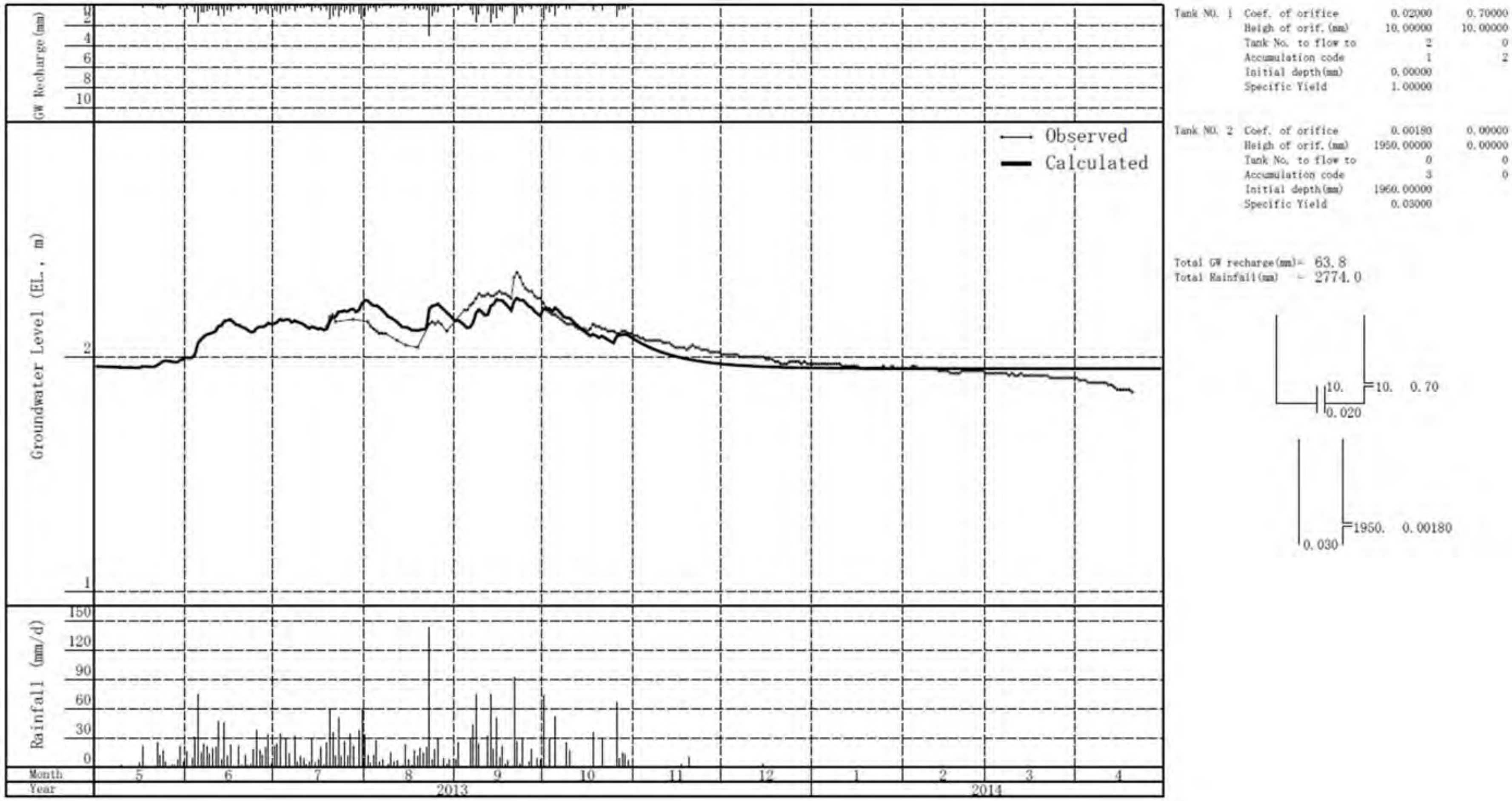


Figure 3-4-1-9 Tank Model Simulation Result of D-4 Site

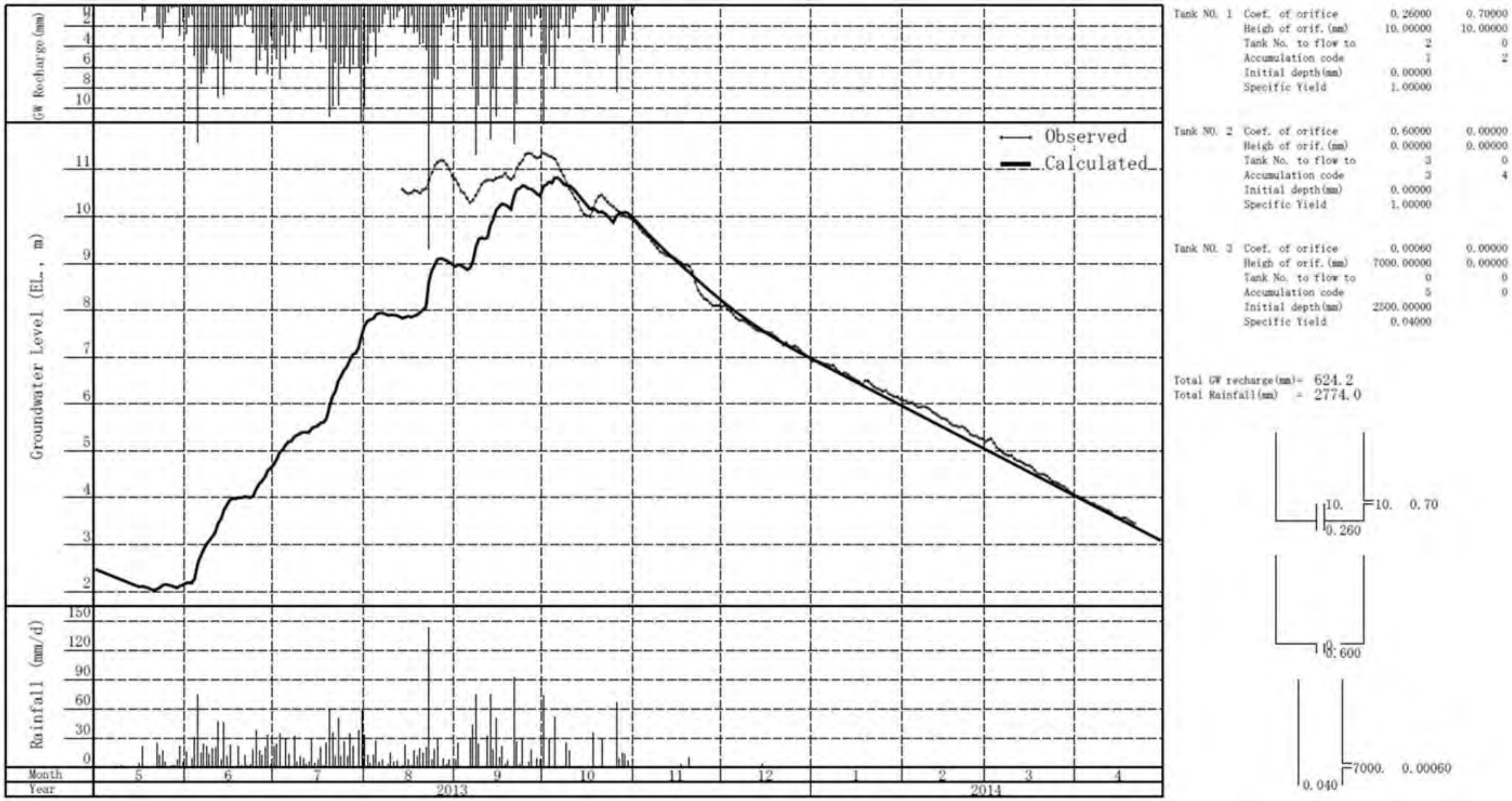


Figure 3-4-1-10 Tank Model Simulation Result of D-5 Site

3-4-2 Estimation of Groundwater Recharge Amount and Exploitation Rate

If the commanding area of the observation site is assumed as Figure 3-4-2-1 considering the land cover, the annual and average daily groundwater recharge from rainfall are roughly estimated as shown in Figure 3-4-2-1 and Table 3-4-2-1. The recharge rate is high on the hill and very small on the plain/lowland. The total recharge amount looks very large in the plain, but, in reality, most infiltrated water is probably drained out to a densely-developed waterway network of creeks, canals and ditches. In addition, the plain is mostly covered with a thick Quaternary layer containing salty water. This means that the infiltrated water cannot be used even if enforced groundwater movement would occur by pumping in the lower aquifers. Therefore only the recharge on the hill can be counted as an effective source for exploitation. The amount averages about 47,000m^3/day and about 30% is already developed. The exploitation rate is about 50% on the northern hill where the overdraft condition is found.

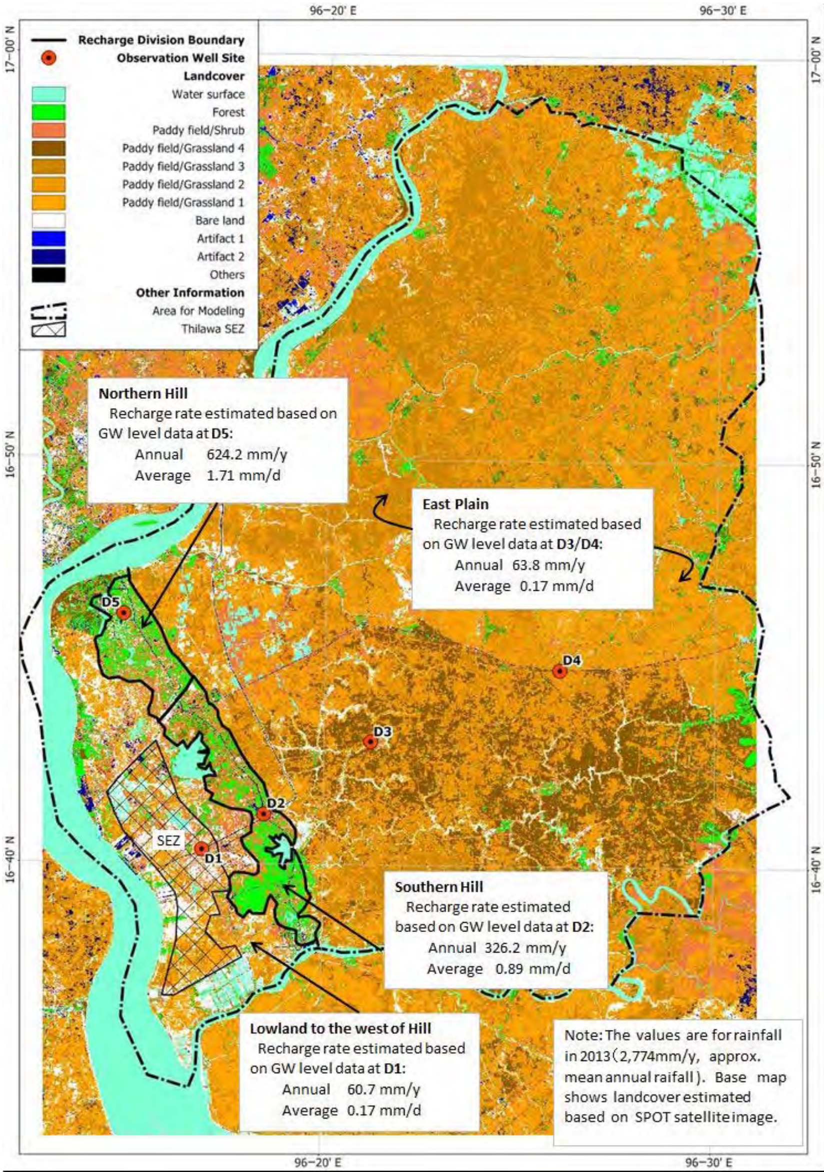


Figure 3-4-2-1 Estimated Groundwater Recharge and Areal Division

Table 3-4-2-1 Groundwater Recharge and Exploitation Rate

Region	Area	Annulal rainfall	Annul Recharge estimated by Tnak Model	Avearge daily recharge		Effective Recharge for GW Exploitation	GW extraction through well in Thanlyin & Kyauktan	Exploitation Ratio	
	(km^2)	(mm)	(mm)	(mm)	(m^3/day)	(m^3/day)	(m^3/day)		
Northern Hill	14.4	2,780	624.2	1.71	24,625	24,625	11,489	47%	31%
Southern Hill	24.7		326.2	0.89	22,077	22,077	3,005	14%	
West Lowland	92.0		60.7	0.17	15,292	Mostly discharged out to the nearby ground	942	-	-
East Plain	796.8		63.8	0.17	139,281		1,851	-	-
Total	927.9					46,702	17,287		

3-5. Estimation of Groundwater Development Potential

3-5-1 Assessment of Key Items on Groundwater Development Potential

Considering the survey results explained above, the key items on the groundwater development potential are accessed as follows:

(1) Water Budget

The effective groundwater recharge is produced on the hill from rainfall. It is estimated to average about 47,000 m^3/day and already about 30% is used. On the northern hill (around Thanlyin town), about 50% is used and in overdraft condition. On the southern hill, the exploitation rate is about 14% and may have a little space to develop in and around the area.

(2) Water Quality

Fresh water distributes mostly in the hill and nearby area. It generally contains much iron ion. Zinc ion also is found much in the deep aquifer (4th aquifer). Treatment is required to reduce these ions for drinking and other specific purposes.

(3) Hydraulic Ability

The hydraulic ability of the aquifer is not so large. Expectable well capacity is a few hundreds m^3/day (average of 300 m^3/day).

(4) Environmental Impact

The following three things must be considered for every development site:

1) Impact on water use at existing wells, because there are many wells in the area,
2) Induction of salty water intrusion, because salty water already distributes under the plain and nearby rivers, and
3) Land subsidence in the plain, because thick unconsolidated clayey layers cover the area.

3-5-2 Basic Figure of Groundwater Development Potential

The estimated effective groundwater recharge for development is averagely about 47,000 m^3/day and some proportion of it could be developed. Considering 17,000 m^3/day is already used and about 50% exploitation has brought overdraft in the northern hill, a further developable amount would be about a few thousands m^3/day in the whole area. This amount is apparently small for the mid-term demand of the Thilawa SEZ, 42,000 m^3/day. Therefore groundwater development is possible only for the short-term demand or for emergency use. Considering that groundwater is an essential water resource for the region and wells are increasing year by year, groundwater should not be used for the Thilawa SEZ whenever possible.