

INTERNATIONAL ORGANIZATION FOR THE PROMOTION OF ECONOMIC CO-OPERATION

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JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

THE MINISTRY OF AGRICULTURE AND RURAL DEVELOPMENT
THE SOCIALIST REPUBLIC OF VIET NAM

THE STUDY
ON GROUNDWATER DEVELOPMENT
IN THE RURAL PROVINCES
OF NORTHERN PART
IN THE SOCIALIST REPUBLIC
OF VIET NAM
FINAL REPORT
SUPPORTING REPORT VOLUME A

JANUARY 2000

KOKUSAI KOGYO CO., LTD.
OYO CORPORATION



1156007 (5)

Composition of the Final Report

The final reports are composed of the following 7 volumes.

1. Summary Report (Japanese)
2. Summary Report (English)
3. Summary Report (Vietnamese)
4. Main Report (English)
5. Supporting Report A (English)
6. Supporting Report B (English)
7. Data report (English)

**The Study on Groundwater Development in the Rural Provinces of Northern Part of
the Socialist Republic of Viet Nam
Final Report**

**Supporting Report
Volume A**

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CHAPTER 1

***HYDROGEOLOGICAL CONDITIONS
BY COMMUNE***

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CHAPTER 1 HYDROGEOLOGICAL CONDITIONS BY COMMUNE

For all the 20 target communes, groundwater quantity and quality have been evaluated based on the results of field measurement, sampling and laboratory analyses (groundwater quality evaluation), drilling and pumping test (groundwater quantity).

1.1 Thai Nguyen Province

1.1.1 Hoa Thuong Commune

(1) Hydrogeology

The topography of the commune is characterized by low hills. There are some hills in the east, whereas there are some limestone mountains in the south. The distance from the western part to the Cau River is about 2 km.

There are three (3) aquifers in Hoa Thuong Commune as follows:

- Quaternary unconsolidated deposits (Q) widely exposed on the surface, consisting of mixed clay, sand, gravel, pebble, etc. with various geneses. Thickness ranges from a few meters to 20 m.
- Triassic terrigenous sediments (T) building up the eastern side of the hill, composed of sandstone, siltstone, claystone with bedded structure.
- Carboniferous-Permian carbonate rocks (C-P), which are unconformably overlain by the Quaternary deposits, consisting of thick-bedded, massive, strongly fractured limestone. The aquifer has high capacity of yielding groundwater.

(2) Groundwater level

Groundwater levels of 10 existing wells were measured in September 1998. The measured 10 wells show the depth to groundwater level ranges between 1.63 and 6.80 m. Shallow groundwater levels within 3.0 m from the ground surface were detected at 8 wells.

The static groundwater level of the test well was 3.10 m from the ground surface in June 1999.

(3) Groundwater quantity

The pumping tests carried out at JICA-2 well having 92 m of well depth. The screens were installed in the depths from 24 to 32 m, 56 to 64 m and 76 to 88 m in limestone aquifers.

The pumping test shows that the yields and drawdowns in 4 steps are as follows:

$Q_1 = 250 \text{ l/min}$ $s_1 50.55 \text{ m}$

$Q_2 = 500 \text{ l/min}$ $s_2 51.32 \text{ m}$

$Q_3 = 750 \text{ l/min}$ $s_3 52.21 \text{ m}$

$Q_4 = 1,000 \text{ l/min}$ $s_4 53.76 \text{ m}$

The discharge of well is 1,000 l/min in accordance with the final drawdown of 5.55 m.

The discharge of the test well shows that the limestone in Hoa Thuong Commune has very high productivity. The limestone aquifers in Hoa Thuong is prospective for water supply. The optimal yield of the test well is evaluated as 1,000 m³/day with a permissible dynamic groundwater level of 10 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.1 to 1.3)

EC values are lower than 50 mS/m in north of the commune, but in the southern part EC values show more than 50 mS/m. The pH values of groundwater vary from 6.29 to 7.18. The groundwater having more than 7.0 in pH was found from the northeastern part of the commune. The DO content is low, ranging from 1.6 to 3.9 mg/l. The ORP values are also low, ranging from 48 to 87 mV.

The Stiff diagrams show that the groundwater in the central to northwestern part is Ca-HCO₃ type, but in the eastern part it shows Ca-HCO₃-SO₄ type.

According to the results of chemical analyses, only one hand-dug well has higher TDS value more than the standard (investigated well HT-9, TDS 51,181 mg/l).

2) Test well

The result of chemical analyses of groundwater from the test well (JICA-2) show that only the contents of total iron and manganese are higher than the Vietnamese and the WHO standards for drinking water.

Total Fe \approx 5.15 mg/l (Vietnamese standard Σ Fe 50.5 mg/l)
Mn²⁺ 50.392 mg/l (Vietnamese and WHO standard Mn²⁺ 50.100 mg/l).

(5) Evaluation

It is better to drill production wells in the Carboniferous-Permian carbonate rocks (C-P), because the Carboniferous-Permian carbonate rocks have higher groundwater productivity than the Triassic terrigenous sediments.

The groundwater quality in Hoa Thuong Commune is generally good for water supply, but the treatment for iron and manganese reduction will be necessary to use the test well water for drinking water supply.

1.1.2 Dong Bam Commune

(1) Hydrogeology

The topography of the commune is rather flat. There are some low hills in the north with elevation difference of about some tens meters. The distance from the western part of the commune to the Cau River is 300 m.

There are the following three (3) aquifers in Dong Bam Commune:

- Quaternary unconsolidated deposits (Q) distributed in the flat terrain and along the Cau River, consisting of mixed clay, sand, gravel, cobble, with poor sorting. There are various geneses such as alluvial, eluvial and diluvial. Their thickness varies from few meters to 20 m.
- Triassic terrigenous sediments (T) building up the low hills in the north. The hill located north of the drilling site is composed of brownish gray to yellowish gray sandstone and siltstone with bedded structures. The Triassic terrigenous sediment has low groundwater potential.
- Carboniferous- Permian carbonate rocks (C-P) are underling with unconformity below the Quaternary deposits. They consist of light gray to blackish gray limestone. The rock is massive and has thick-bedded structures. In the rocks there are calcite veins showing various direction. The rock is strongly fractured. The fractured are stained with brownish oxidized iron. Karst cavities are met at various depths. The groundwater potential in the limestone is fairly good.

The JICA-1 test well was drilled in the Carboniferous-Permian carbonate rocks. During the well development, the loose materials filling with the opening spaces of limestone

were pumped out, then the activity caused ground collapse, cracks in the cement foundation and walls of surrounding residential houses. The JICA study team decided to stop the pumping.

(2) Groundwater level

Groundwater level of 11 existing dug wells and two (2) tube wells were measured in September 1998. The measured 13 wells show the depth to groundwater level ranges between 0.30 and 5.66 m. Shallow groundwater levels within 3.0 m from the ground surface were detected at 7 wells.

(3) Groundwater quantity

The test well in Dong Bam Commune had a depth of 100 m in limestone aquifer. The screens have been installed in depths from 40 to 72 m. In the time of well development, the pumping rate was 900 ℓ/min , but the well development was stopped because it caused the said damages in the surrounding area of the well.

Therefore, pumping tests could not be performed, however, it can be said that the limestone in Dong Bam Commune has high productivity and is prospective for water supply.

(4) Groundwater quality

1) Existing wells (see Figures 1.1 to 1.3)

The results of the field survey show that the water of all hand dug wells and one tube well (DB-9) has high quantity of coliforms. Coliform is not detected from DB-11 tube well. The pH values range from 4.94 to 6.83. Other characteristics of groundwater quality are:

EC from 11.42 to 112.8 mS/m

ORP from 48 to 87 mV

DO from 2.6 to 8.5 mg/ℓ

The results of chemical analyses of groundwater from 10 existing wells shows that the groundwater of 4 hand dug wells has lower pH values than the Vietnamese standard. The wells having lower pH values are:

DB-1 (pH55.24), DB-2 (pH55.62), DB-4 (pH56.27), and DB-5 (pH56.37)

Water of one hand dug well has TDS value higher the Vietnamese standard (DB-8: TDS

51,234 mg/l). The Stiff patterns are large in the southern part of the commune, showing Ca-HCO₃ type and Ca-SO₄ type.

2) Test well

Due to the impossible to carry out pumping test, the groundwater sample from Dong Bam test well was not taken. But groundwater quality have been evaluated on the result of chemical analyses of groundwater sample taking in the field survey. It is presumed that the groundwater quality of the limestone aquifer is good for drinking water supply.

(5) Evaluation

The Carboniferous-Permian carbonate rocks in Dong Bam Commune has high groundwater potential. In future it is possible to obtain large amount of groundwater when the well is drilled at suitable place not near from houses. The quality of groundwater in Dong Bam Commune is good and can be used for centralized water supply system. For selecting new well site, more attention must be paid to the problem of karst limestone to prevent ground surface collapse.

1.1.3 Tinh Duc Commune

(1) Hydrogeology

The topography of the commune is characterized by low hills dissected by small streams. There are the following two (2) aquifers in Tinh Duc Commune.

- Quaternary unconsolidated deposits (Q) widely exposed surface, consisting of clay, gravel sand of various geneses and a thickness varying from few meters to 20 m.
- Triassic terrigenous sediments (T) underlying with unconformity the Quaternary deposits consisting of sandstone, siltstone, claystone, with bedded structure. Those rocks usually alternate with each other. Volcanic rocks are also met in some place.

The test well in Tinh Duc was drilled in Triassic terrigenous sediment. The thickness of Quaternary sediments was 16.5 m. Triassic terrigenous sediments has very low groundwater-bearing capacity. That is the reason why the test well has low productivity.

The result of chemical analyses of groundwater from test well shows that, groundwater quality is good for drinking water and water supply.

(2) Groundwater level

Groundwater levels of 14 existing wells were measured in September 1998. The measured 14 wells shows the depth to groundwater level ranges between 1.53 and 5.90 m. Shallow groundwater levels within 4.0 m from the ground surface were detected at 12 wells.

The static groundwater level of the test well was 2.00 m from the ground surface in June 1999.

(3) Groundwater quantity

In Thinh Duc Commune, the drilled test well has the depth 88 m. The screens were installed in depth from 8 to 16 m, 52 to 60 m, and 68 to 84m in Quaternary gravel layer and sandstone aquifer. The result of pumping test shows that the yields and drawdowns in 4 steps are as follows:

Q ₁ 530.0 l/min	s ₁ 54.37 m
Q ₂ 565.4 l/min	s ₂ 59.50 m
Q ₃ 5102.0 l/min	s ₃ 514.72 m
Q ₄ 5130.8 l/min	s ₄ 518.80 m.

The discharge of the well shows that the sandstone in Thinh Duc Commune has low groundwater productivity. The optimal yield of the test well is evaluated as 150 m³/day when the permissible dynamic groundwater levels is set at 20 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.4 to 1.6)

The field survey shows that EC values in the existing wells are generally, ranging from 3 to 70 mS/m. The EC values are low in the southern to eastern parts of the commune, whereas higher values were detected in the northwestern part. All the samples from existing wells have very low pH values, ranging from 4.47 to 5.88. Particularly lower pH values were found from the central to western parts of the commune. Among 17 investigated hand dug wells, groundwater in 13 wells is highly polluted by coliforms. Other parameters are:

DO from 1.9 to 6.1 mg/l

ORP from 70 to 117 mg/l.

Results of chemical analyses of groundwater taken from the hand-dug wells shows that the groundwater has very low pH values than the standard as follows:

TD-1 (pH55.62), TD-2 (pH55.49), TD-3 (pH55.63), TD-4 (pH55.39), TD-5 (H55.64), TD-6 (pH55.28), TD-7 (pH55.28), TD-8 (pH54.97), TD-9 (pH56.20), TD-10 (pH54.50), TD-11 (pH55.34), TD-1 (pH54.50).

Two exiting dug wells have higher Fe concentrations than the Vietnamese drinking standard: TD-3 (Fe50.505 mg/l) and TD-9 (Fe50.502 mg/l). One existing dug well is contaminated by Manganese (TD-12, Mn50.642).

The Stiff patterns of the existing wells are small in size, but some samples show (Na1K)-SO₄ type.

2) Test well

The result of chemical analyses of groundwater from the test well (JICA-4) show that no chemical parameter exceeds the Vietnamese and the WHO standards for drinking water.

3) Evaluation

According to the hydrogeological conditions, quality and quantity of existing wells and test well are generally good. But the shallow groundwater has very low values of pH, that cannot satisfy the Vietnamese drinking water standard. The groundwater yield of the test well is limited for piped water supply systems. In future it will be necessary to drill many production wells for satisfying the estimated groundwater demand. For locating new well sites, it should be noted that the areas near the disposal site of Thai Nguyen City, which is located in the northern part of the commune, should be avoided. Because it seems that there have been no measures to prevent seepage of dirty polluted water from the site. Testing the groundwater quality of new production wells will be necessary.

1.1.4 Nam Tien Commune

(1) Hydrogeology

The topography of the site is relatively flat. There are the following aquifers in Nam Tien Commune:

- Quaternary unconsolidated deposits (Q) widely exposed on the surface, consisting

of clay, sand and gravel of various geneses and a thickness varying from few meters to 20 m.

- Triassic terrigenous sediments (T), underlying with unconformity the Quaternary deposits composed of sandstone, siltstone, claystone. Those rocks usually alternate with each other.

The Triassic terrigenous sediments has very low groundwater potential.

It is better for Nam Tien commune to explore groundwater from the Quaternary aquifer than from the basement rock from the viewpoints of quantity. According to the local well company, it is said that there is a relatively higher groundwater productive zone in the northeastern part of the commune having NW-SE direction, crossing the National Road No.3. However, the geophysical prospecting by the Study did not detect such structures in the basement rocks.

(2) Groundwater level

Groundwater levels of 13 existing wells were measured in September 1998. The measured 13 wells showed the depth to groundwater level ranged between 1.20 and 6.69 m from the surface. Shallow groundwater levels within 3.0 m from the ground surface were detected at 9 wells.

The static groundwater level of the test well was 1.50 m from the surface in June 1999.

(3) Groundwater quantity

The test well in Nam Tien (JICA-3) was drilled up to 100 m in depth, but the well depth was determined as 21.5 m due to the low groundwater productivity of basement sandstone. The screens have been installed in the depth from 5.5 to 17.5 m in the Quaternary sediments and the upper part the weathered sandstone. The result of step-drawdown pumping test shows the yields and drawdowns in 2 steps as follows:

$Q_1 548 \text{ l/min}$	$s_1 51.75 \text{ m}$
$Q_2 596 \text{ l/min}$	$s_2 53.66 \text{ m}$

The discharge of wells shows that the Quaternary sediments in Nam Tien Commune have also low groundwater potential. The optimal yield of the test well was evaluated as $100 \text{ m}^3/\text{day}$ when the permissible dynamic groundwater level was set at 10 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.7 to 1.9)

The groundwater investigation was carried out at 13 wells in the commune. The characteristics of the groundwater quality are as follows:

pH from 4.39 to 7.19

EC from 7.21 to 70.2 mS/m

ORP from 55 to 115 mV

DO from 3.0 to 6.10 mg/l

The EC values are low in the western to the southern parts of the commune, showing lower than 20 mS/m. The eastern part of the commune along the Road No.3 has higher EC values, ranging from 40 to 70 mS/m. The pH values are generally low in the commune except one tube well in the northeast of the commune. Among 13 investigated wells, there are 3 wells (NT-8, NT-10 and NT-11) having small quantity (from 2 to 4 pcs./ml) of coliform. The other wells except wells NT-12 and NT-13, which were not tested, have many coliforms.

The results of chemical analyses shows that the groundwater of all existing hand-dug wells has low pH values lower than the standard. One tube well (NT-11) has laboratory analysis pH value of 6.50 (the field measured value is 7.19). The pH values of the dug wells are:

NT-1 (pH55.05), NT-2 (pH55.90), NT-3 (pH55.62), NT-4 (pH56.30), NT-5 (pH55.38), NT-6 (pH55.58), NT-7 (pH56.20), NT-8 (pH55.90), NT-10 (pH55.00), NT-12 (pH54.60), NT-13 (pH54.80).

Fe concentration was higher than the Vietnamese standard at NT-9 dug well (Fe50.830 mg/l). The values of the rest of the chemical parameters are lower than the standard values.

The Stiff patterns of shallow groundwater show Na-Cl-SO₄ type

2) Test well

The result of chemical analyses of groundwater from the test well (JICA-3) show that no chemical parameter exceeds the Vietnamese and the WHO standards for drinking water.

(5) Evaluation

In Nam Tien Commune, the Quaternary unconsolidated deposits (Q) and Triassic terrigenous sediments (T) have low groundwater potential. For future water supply, several production well will be necessary, but their yield may be limited like the test well. If new wells pump groundwater from shallow zone, the water may have lower value in pH. One of the target areas for additional production wells will be in the northeastern part of the commune. To obtain groundwater from the Quaternary sediments, the western to the southwestern parts of the commune may be better considering the thickness of the Quaternary sediments and the quality of shallow groundwater.

1.2 Ha Noi

1.2.1 Dong Ngac Commune

(1) Hydrogeology

The topography of the site is flat alluvial plain of the Red River Delta. There are following aquifers in Dong Ngac Commune:

Aquifer is in Holocene sediments (Q_{IV}) (First Aquifer)

Aquifer is in Middle- Upper Pleistocene (Q_{II-III}) (Second Aquifer)

Between the above mentioned two (2) aquifers, there is upper Pleistocene aquitard (Q_{III}). The upper part of the Holocene deposits consist of clayey layers.

According to the existing data, the elevation of the top of the First Aquifer ranges from 25 to 215 masl. The top surface of the First Aquifer becomes deeper towards northeast. The bottom elevation of the First Aquifer ranges from 215 to 225 masl. The top elevations of the Second Aquifer range from 230 to 235 masl, while the bottom elevations range from 255 to 265 masl.

Although the available existing data of the aquifer characteristics are limited in the commune, the values of transmissivity in the Second Aquifer ranges from 800 to 1,000 m²/day.

(2) Groundwater level

Groundwater levels of 2 existing dug wells were measured in October 1998. The levels

of the rest could not be measured because they were tube wells. The measured two (2) wells showed the depth to groundwater level is about 0.8 m from the surface.

(3) Groundwater quantity

No test well was drilled by the study. However, the quantity of groundwater can be estimated from the existing data. If the transmissivity of production well site is assumed to be 800 m²/day and the specific capacity is assumed to be 656 m²/day from the T51.22 Sc relation by Logan (1964), the computed drawdown is 2.0 m in Dong Ngac well. Considering the present piezometric head in the target communes, the dynamic groundwater level of 25 masl (15 m depth from ground surface) can allow the yield to meet the groundwater production. However, the permissible groundwater level of the wells should be determined by considering an optimal groundwater basin management plan of Hanoi area.

(4) Groundwater quality

1) Existing wells (see Figures 1.10 to 1.12)

The groundwater investigation was carried out at 10 wells in the commune. The characteristics of the groundwater quality are as follows:

pH from 6.42 to 7.15

EC from 31.9 to 170.1 mS/m

ORP from 218 to 276 mV

DO from 5.5 to 7.0 mg/ℓ

The EC values are low in the eastern part but high in the western part. The pH values are more than 7.0 in the western and central parts, but the values tend to decrease towards south. Coliform bacteria was detected from the two (2) dug wells and two (2) tube wells. Rest of the tube wells have coliform free water.

The results of chemical analyses shows that three (3) existing wells have TDS values more than the standard value. The followings are wells having higher TDS values:

DN-5 (EC51,730 mg/ℓ), DN-6 (EC51,360 mg/ℓ), and DN-7 (EC51,287 mg/ℓ)

Seven (7) wells among the investigated 10 wells have higher Manganese concentration above the standard, ranging from 0.429 mg/ℓ at DN-3 well to 19.374 mg/ℓ at DN-7 well. Five (5) existing wells have higher iron concentration above the standard, ranging from 0.588 to 1.875 mg/ℓ. The values of the rest of chemical parameters are below the

standard values.

The most samples of existing wells show Ca-HCO_3 type of water from the Stiff diagrams.

2) Test well

Exact groundwater quality of the Second Aquifer in the commune is not known because test well was not drilled in the commune, however, it is presumed that Fe and Mn concentrations are higher than the standard values.

(5) Evaluation

In Dong Ngac Commune, a large amount of groundwater can be pumped from the Second Aquifer. At present, the piezometric heads are above 0 masl. However, it is planned that production wells of the Cao Dinh well field will be constructed in the commune near future. If the pumping operations are started, the piezometric heads and quality of the Second Aquifer will be significantly affected. It is necessary to consider the yields of those production wells as well as the designed well of the study to prevent land subsidence and worsening of groundwater quality.

1.2.2 Xuan Dinh Commune

(1) Hydrogeology

The topography of the site is flat alluvial plain of the Red River Delta. There are following aquifers in Xuan Dinh commune:

Aquifer is in Holocene sediments (Q_{IV}) (First Aquifer)

Aquifer is in Middle-Upper Pleistocene (Q_{II-III}) (Second Aquifer)

Between the above mentioned two (2) aquifers, there is upper Pleistocene aquitard (Q_{II}). The upper part of the Holocene deposits consist of clayey layers.

According to the existing data, the elevation of the top of the First Aquifer ranges from 25 to 220 masl. The top surface of the First Aquifer becomes deeper towards northeast. The bottom elevation of the First Aquifer ranges from 210 to 225 masl. The top elevations of the Second Aquifer range from 225 to 235 masl, while the bottom elevations range from 250 to 270 masl.

Although the available existing data of the aquifer characteristics are limited in the

commune, the values of transmissivity in the Second Aquifer ranges from 800 to 1,200 m^2/day .

(2) Groundwater level

Groundwater levels of three (3) existing dug wells were measured in October 1998. The levels of the rest could not be measured because they were tube wells. The measured three (3) wells showed the depth to groundwater level is about 0.55 to 9.21 m from the surface. It is found that the shallow groundwater levels have already declined by the lowering of the piezometric heads of the deep aquifer.

(3) Groundwater quantity

No test well was drilled by the study. However, the quantity of groundwater can be estimated from the existing data. If the transmissivity of production well site is assumed to be 800 m^2/day and the specific capacity is assumed to be 656 m^2/day from the $T51.22 Sc$ relation by Logan (1964), the computed drawdown is 4.7 m in Xuan Dinh. Considering the present piezometric head in the target communes, the dynamic groundwater level of 25 masl (15 m depth from ground surface) can allow the yield to meet the groundwater production. However, the permissible groundwater level of the wells should be determined by considering an optimal groundwater basin management plan of Hanoi area.

(4) Groundwater quality

1) Existing wells (see Figures 1.10 to 1.12)

The groundwater investigation was carried out at 10 wells in the commune. The characteristics of the groundwater quality are as follows:

pH from 5.05 to 6.55

EC from 6.61 to 123.8 mS/m

ORP from 141 to 178 mV

DO from 3.7 to 6.3 mg/l

The EC values are low in the eastern part but high in the central part. The pH values are generally lower than 6.0 and tend to decrease towards south. Coliform bacteria was found from the two (2) dug wells and even from four (4) tube wells.

The results of chemical analyses shows that only one well satisfy the pH standard value. A higher TDS value of 1,271 mS/m was found at XD-5 well. The following two (2) wells have higher Mn concentrations than the standard values:

XD-2 (Mn50.124 mg/ℓ), XD-3 (Mn51.882 mg/ℓ)

Five (5) tube wells have higher Fe concentrations above the standard, ranging from 0.7 to 1.26 mg/ℓ.

The Stiff diagrams show that some wells have Na-Cl type of water, and the rest shows Ca-HCO₃ type.

2) Test well

Exact groundwater quality of the Second Aquifer in the commune is not known because test well was not drilled in the commune, however, it is presumed that Fe and Mn concentrations are higher than the standard values.

(5) Evaluation

In Xuan Dinh Commune, a large amount of groundwater can be pumped from the Second Aquifer. At present, the piezometric heads are 0 to 210 masl. However, it is planned that production wells of the Cao Dinh well field will be constructed along the right side bank of the Red River near future. If the pumping operations are started, the piezometric heads and quality of the Second Aquifer will be significantly affected. Also the pumping operation of existing Ngoc Ha and Mai Dich well fields, those are located 2 to 3 km from the commune, will give some impacts to the designed new well in the commune. It is necessary to consider the yields of those production wells as well as the designed well of the study to prevent land subsidence and worsening of groundwater quality.

1.3 Ninh Binh Province

1.3.1 Yen Thang Commune

(1) Hydrogeology

The topography of the commune is mainly alluvial plain. There are several isolated small hills in the plain. The southeastern part of the commune is situated on hilly area. There are two aquifers in Yen Thang Commune:

- Quaternary aquifer is represented by alluvial (river and marine) sediments. They are widely exposed on the surface. The groundwater quality of Quaternary deposits

is not good: saline or brackish, and can not be used for water supply. Quaternary aquifer has low groundwater capacity.

- Middle Triassic carbonate aquifer is exposed on the west of the commune and underlying Quaternary sediments. Carbonate rock in Yen Thang Commune has high groundwater capacity, but quality of the water is not good for water supply. But in the southeastern part of Yen Thang Commune, where the Yen Thang lake is located, there are two deep wells and two springs from limestone (well-LK 12, LK42, spring No 51, No 55) with groundwater of good quality.

The groundwater of wells has TDS from 0.21 to 0.23 g/l. The discharge of well No 12 (Yen Thang Lake) is 27.65 l/s in correspondence with drawdown of 1.25 m. The discharge of well No 42 in the northeast of Yen Thang Lake is 7.7 l/s in correspondence with drawdown of 1.8 m. The spring No 51 in the south of Yen Thang Lake has the discharge of 5.49 l/s and the spring No 55 (west of Yen Thang Lake) has the discharge of 95.35 l/s.

In the central part of Yen Thang Commune, the Middle Triassic limestone has poor groundwater quality and can not be used for groundwater supply.

But in the southeastern part of Yen Thang Commune, the Middle Triassic limestone has good groundwater quality.

(2) Groundwater level

Groundwater levels of 18 existing hand-dug wells were measured in September 1998. The measured 18 wells show that the depth to the groundwater level ranges between 0.53 and 2.48 m. Shallow groundwater levels within 2.0 m from the ground surface were detected at 17 wells.

The static groundwater level in the test well was 1.23 m below the ground surface in March 1999.

(3) Groundwater quantity

The test well has a depth of 136 m. The screens have been installed in the depth from 76 to 84 m, 92 to 104 m and 124 to 132 m in limestone aquifer.

The step-drawdown pumping test shows that the yields and drawdowns in the 4 steps are as follows:

Q ₁ 5120 ℓ/min,	s ₁ 510.83 m
Q ₂ 5240 ℓ/min,	s ₂ 522.89 m
Q ₃ 5360 ℓ/min,	s ₃ 535.77 m
Q ₄ 5480 ℓ/min,	s ₄ 554.97 m.

The discharge of test well is 480 ℓ/min in correspondence with the final drawdown of 54.79 m in the continuous pumping test. This discharge of well shows that limestone aquifer in Yen Thang Commune has high productivity. The optimal yield of the test well is evaluated as 120 m³/day when the permissible dynamic groundwater levels is set at 30 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.13 to 1.15)

13 hand dug wells and 1 natural spring were investigated in Yen Thang Commune. The results of field measurement are as follows:

pH from 5.93 to 7.47

EC from 6.13 to 213 mS/m

ORP from 13 to 216 mV

DO from 1.8 to 6.2 mg/ℓ

There are some wells having good quality of water; quantity of coliform ranges from 0 (YT-12, YT-13) to 41 pcs./ml (YT-18). Permanent spring has a discharge rate about 20 ℓ/sec with 8 pcs./ℓ of coliform. Other hand dug wells have many coliforms from about 100 to 400~500 pcs./ml. Groundwater of some wells shows a very brown color. People use water from some hand dug wells only for washing and bathing but not for drinking.

The results of chemical analyses of groundwater shows that the following 9 wells have iron content higher than the standard value:

YT-2 (ΣFe 51.01 mg/ℓ), YT-3 (ΣFe 50.56 mg/ℓ), YT-6 (ΣFe 50.615 mg/ℓ), YT-7 (ΣFe 51.8 mg/ℓ), YT-9 (ΣFe 50.95 mg/ℓ), YT-10 (ΣFe 50.615 mg/ℓ), YT-15 (ΣFe 51.175 mg/ℓ), YT-18 (ΣFe 50.615 mg/ℓ) and YT-19 (ΣFe 50.612 mg/ℓ)

Two hand-dug wells has sulfate content higher than standard: YT-3 (SO_4 5486.37 mg/ℓ), YT-18 (SO_4 5415.88 mg/ℓ).

Among 10 hand dug wells, 6 hand dug wells have total dissolved solid (TDS) higher

than the standard: TDS varies from 1,025 mg/ℓ (YT-6) to 2,372 mg/ℓ (YT-2):

Water of the hand-dug wells such as: YT-1 (TDS51,259 mg/ℓ), YT2 (TDS52,372 mg/ℓ), YT-4 (TDS52,342 mg/ℓ), YT-5 (TDS51,463 mg/ℓ), YT-11 (TDS51,482 mg/ℓ), YT-12 (TDS51,357 mg/ℓ), YT-13 (TDS51,786 mg/ℓ) are brackish.

2) Test well

The results of chemical analysis of groundwater from the test well (JICA-) shows that the groundwater of Yen Thang Commune has much higher values of TDS, Mn^{2+} , ΣFe , Cl^{-} and Na^{+} exceeding the Vietnamese and WHO standards for drinking water:

TDS52,372 mg/ℓ (Vietnamese and WHO standard TDS51,000 mg/ℓ)

Mn^{2+} 50.420 mg/ℓ (Vietnamese and WHO standard Mn^{2+} 50.100 mg/ℓ)

ΣFe 51.80 mg/ℓ (Vietnamese standard ΣFe 50.5 mg/ℓ)

Cl^{-} 52,343 mg/ℓ (Vietnamese and WHO standard Cl^{-} 5200,00 mg/ℓ)

Na^{+} 5882,50 mg/ℓ (Vietnamese and WHO standard Na^{+} 5200,00 mg/ℓ)

The groundwater quality of Yen Thang Commune is not satisfied by the Vietnamese and WHO standard for drinking water and for water supply.

(5) Evaluation

In general, the quantity of groundwater of limestone aquifer in Yen Thang is high, but quality of groundwater is not good and can not be used for drinking water. But, in Yen Thang there are two existing wells situated not far from Yen Thang Lake and two springs from limestone aquifer has high yield and good quality. In the southwestern area on the commune, it is possible to find some good locations to obtain groundwater in good quality. To confirm the hydrogeological conditions, it is necessary to investigate groundwater quality and quantity of the existing groundwater source in detail. It is also recommended to drill one more test well in the area.

1.3.2 Quang Son Commune

(1) Hydrogeology

There are two aquifers in Quang Son Commune:

- Quaternary aquifer is exposed on the surface, which is represented by diluvial deposits. The sediments are composed of clay and pebble. The thickness ranges from several meters to 12 m. The Quaternary sediments has low groundwater

potential, not prospective for groundwater supply.

- Middle Triassic carbonate aquifer (T₂adg) overlain by Quaternary sediments is composed of limestone. In deeper portions, the limestone is strongly fractured where the groundwater potential is very high. In Quang Son Commune, Middle Triassic limestone has high groundwater productivity and prospective for water supply. Groundwater quality is good and can be used for drinking water.

(2) Groundwater level

Groundwater level of 17 existing wells and one cave were measured in September 1998. The measured 17 wells shows the depth to the groundwater level ranges between 1.19 and 13.00 m. Shallow groundwater levels within 5.0 m from the ground surface were detected at 11 wells. The groundwater levels are deep in the hilly areas of the western part of the commune.

The static groundwater level of the test well was 10.80 m in March 1999.

(3) Groundwater quantity

The pumping tests were performed at the test well (JICA-5) with the depth of 120 m. The screens have been installed in the depth from 72 to 116 m in limestone aquifer.

The step-drawdown pumping test shows that the yields and drawdowns in the 4 steps are as follows:

Q ₁ 560 ℓ/min,	s ₁ 58.0 m
Q ₂ 5120 ℓ/min,	s ₂ 515.2 m
Q ₃ 5180 ℓ/min,	s ₃ 521.9 m
Q ₄ 5240 ℓ/min,	s ₄ 543.0 m

The discharge of well is 240 ℓ/min in correspondence with the final drawdown of 42.6 m by the continuous pumping test. This discharge of well shows that limestone in Quang Son Commune has medium productivity and it can be used as one of the production well in the commune. The optimal pumpage of the test well is evaluated as 250 m³/day when the permissible dynamic groundwater level is set at 30 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.16 to 1.18)

There are 17 hand dug well and one cave which were investigated in Quang Son

Commune. EC values are relatively high in the central part of the commune, ranging from 50 to 90 mS/m. The western part and the eastern part have lower EC values below 30 mS/m. From the pH measurements, slightly acidic water occurs in the central to southern parts in the commune. The western and eastern parts show that the groundwater is slightly alkaline.

The quality of groundwater in this commune is not good; all hand dug wells are polluted by coliforms about 100 to 400~500 pcs./ml. The results of field measurement are:

pH from 6.14 to 7.89

EC from 11.03 to 122 mS/m

DO from 2.7 to 6.2 mg/l

ORP from 177 to 266 mV

Result of Laboratory chemical analysis of groundwater that samples from one hand-dug well has a TDS value higher than standard: QS-5 (TDS-1,164 mg/l). And another has iron content higher than standard: QS-11 (Fe50.61 mg/l). The shallow groundwater quality of almost hand-dug wells in Quang Son Commune is not good for drinking without boiling the water.

The Stiff diagram shows that the groundwater in the central area is Ca-HCO₃ type, however, (Na+K) is dominant in cations in the northwestern part of the commune.

2) Test well

The result of chemical analysis of groundwater from the test well (JICA-5) shows that only the concentrations of Fe and Mn are higher than the WHO standard for drinking water, but the Fe concentration can clear the Vietnamese standard.

The total Fe content is 0.420 mg/l (Vietnamese standard is 0.5 mg/l and WHO standard is 0.3 mg/l).

Mn content is 0.250 mg/l (Vietnamese and WHO standard content of Mn is 0.100 mg/l).

For drinking water supply, the treatment of iron reduction will be needed.

(5) Evaluation

Quang Son Commune has high groundwater potential in the basement limestone

aquifer, but the yield from the test well was not enough due to the fractures in the limestone are filled with clayey materials. It is possible to encounter more productive zones in other areas in the commune.

The groundwater of new production wells may also have high content of iron and manganese. To meet the Vietnamese drinking water standard, iron removal is required. It is noted that there is a pig-farming plant in the upper stream area in the commune. And in the cultivated area the farmers using much agricultural chemicals such as fertilizer. The groundwater quality must be tested when new production wells are constructed.

1.3.3 Dong Phong Commune

(1) Hydrogeology

Dong Phong Commune is located in the intermountain flat basin surrounded by limestone mountains. There are two aquifers in Dong Phong Commune:

- Quaternary aquifer exposed on the surface, which is represented by diluvial deposits. They are composed of clay and pebble. The thickness ranges from several meters to 12 m. Quaternary sediments have low groundwater potential and not perspective for water supply.
- Middle Triassic carbonate aquifer (T₂adg) underlying the Quaternary sediments is composed of limestone. In deeper portions the limestone is strongly fractured. The groundwater potential in the fractured limestone is very high.

(2) Groundwater level

Groundwater levels of 18 existing wells were measured in September 1998. The measured 18 wells shows the depth to the groundwater level ranges between 0.63 and 2.70 m. Shallow groundwater levels within 2.0 m from the ground surface were detected at the 16 wells.

The static groundwater level in the test well was 0.60 m below the ground surface in May 1999.

(3) Groundwater quantity

The test well (JICA-7) in Dong Phong Commune has the depth of 130 m. The screens were installed in depths from 92 to 126 m in the fractured limestone aquifer.

The step-drawdown pumping test shows that the yields and drawdowns in the 4 steps are as follows:

Q ₁ 5300 ℓ/min,	s ₁ 52.07 m
Q ₂ 5600 ℓ/min,	s ₂ 54.56 m
Q ₃ 5900 ℓ/min,	s ₃ 56.48 m
Q ₄ 51200 ℓ/min,	s ₄ 58.54 m

The discharge of test well is 1,200 ℓ/min in correspondence with the final drawdown of 8.77 m by the continuous pumping test.

This discharge of the test well shows that limestone in Dong Phong Commune has very high productivity and prospective for water supply. The optimal yield of the test well is evaluated as 1,500 m³/day when the permissible dynamic groundwater level is set at 10 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.19 to 1.21)

There are 18 existing hand-dug wells investigated in Dong Phong Commune. The EC values are relatively high in the southwestern and southeastern parts of the commune, exceeding 100 mS/m. The EC values are low in the central to the northern part of the commune, having the values below 50 mS/m.

Among the investigated wells, some wells have small quantity of coliform such as DP-1, DP-2, DP-4 (coliform50 pcs./ml), DP-3, DP-10 (coliform51 pcs./ml), DP-8 (coliform53 pcs./ml), DP-9 (coliform514 pcs./ml), DP-13 (coliform515 pcs./ml), DP-12 (coliform530 pcs./ml), DP-17 (coliform532 pcs./ml), DP-18 (coliform550 pcs./ml). Another wells have many coliforms, from about 100 to 300~400 pcs./ml.

Other groundwater quality characteristics by the field measurement are as follows:

pH from 6.22 to 7.21

EC from 33.5 to 105.9 mS/m

ORP from 52 to 219mV

DO from 2.1 to 4.8 mg/ℓ

The result of Laboratory chemical analysis of groundwater samples from existing hand-dug wells shows that four (4) hand-dug wells have Iron content higher than the

standard: DP-7 (Fe50.785 mg/ℓ), DP-8 (Fe50.700 mg/ℓ), DP-10 (Fe50.610 mg/ℓ), DP-16 (Fe50.610 mg/ℓ).

The Stiff diagrams show that the most shallow groundwater samples are Ca-HCO₃ type water.

The results of chemical analysis of groundwater shows that the groundwater quality of Dong Phong Commune is generally good except higher Fe concentration is some areas.

2) Test well

The results of chemical analysis of groundwater from the test well shows that the groundwater quality in Dong Phong Commune is very good, satisfied for water supply.

(5) Evaluation

Dong Phong Commune has high groundwater potential and good quality, perspective for feasibility study in future.

1.4 Thanh Hoa

1.4.1 Vinh Thanh Commune

(1) Hydrogeology

The topography of the area is rather flat. There is a low-elevated hill of Lower Triassic claystone in the southeast of the commune. The Ma River is located on the western perimeter of the commune.

There are two following aquifers in Vinh Thanh Commune:

- Quaternary unconsolidated deposits (Q) distributed in the flat terrain and along the Ma River consisting of mixed clay, silt clay, below with mixed with quartz sand and gravel.
- Low Triassic carbonate rocks (T₁dg₁) occur in the southern part of the commune and underlying the Quaternary deposits. They consist of gray, brown gray, blue gray, in some places pinkish, massive, solid limestone with moderate fracture level. The claystone forming the hill in the southeast may exists as an interbedded layer. In the boring logging section there are empty karst cavities between 33.5 to 36.8 m and 45.3 to 45.4m. From 50.0 to 54.8 m karst caves are filled with reddish brown

clay and silt.

In Vinh Thanh Commune Low Triassic carbonate rocks have very high groundwater potential.

(2) Groundwater level

Groundwater levels of 10 existing hand-dug wells were measured in October 1998. The measured 10 wells shows the depth to the groundwater level ranges between 0.36 m and 6.07 m. Shallow groundwater levels within 4.0 m from the ground surface were detected at 8 wells. Deeper groundwater levels were measured near the Ma River.

The static groundwater level in the test well was 7.55 m below the ground surface in April 1999.

(3) Groundwater quantity

The test well (JICA-11) in Vinh Thanh Commune has the well depth of 80 m. The screens were installed in depths from 32 to 48 m, and from 60 to 76 m in limestone aquifer.

The step-drawdown pumping test shows that the yields and drawdowns in the 4 steps are as follows:

Q ₁ 5252 ℓ/min,	s ₁ 51.86 m
Q ₂ 5510 ℓ/min,	s ₂ 54.90 m
Q ₃ 5780 ℓ/min,	s ₃ 59.80 m
Q ₄ 51,050 ℓ/min,	s ₄ 14.27 m

The discharge of well is 1,050 ℓ/min in correspondence with the final drawdown of 16.29 m by the continuous pumping test. The optimal yield of the test well is evaluated as 1,500 m³/day with the permissible dynamic water level of 20 m from the ground surface.

(4) Groundwater quality

1) Existing wells (see Figures 1.22 to 1.24)

There are 10 investigated hand-dug wells investigated by the study in the commune. The well depth ranges from 3.6 m to 10.22 m (VT-4). The results of field measurement are as follows:

pH from 6.36 to 7.36

EC from 53.6 to 187.5 mS/m

ORP from 367 to 454 mV

DO from 3.5 to 4.6 mg/l

The distribution of EC values shows that higher EC values more than 80 mS/m were found along the Ma River, whereas lower EC values less than 40 mS/m were found from northeastern part of the commune, that is located far from the Ma River. The pH values were high, showing slightly alkaline water along the Ma River. On the other hand, lower pH values below 6.0 were found in the northeastern part of the commune. The coliform content varies from 4 to 100 pcs./ml. Only one hand-dug well (VT-7) had no coliform. Water of most hand-dug wells is used for everything including washing, cooking and drinking purposes.

The results of laboratory analyses show that the groundwater quality of the commune is generally good and satisfies the Vietnamese standard and the WHO standard. However, three (3) hand-dug wells have higher TDS values than the standard. Those wells are:

VT-1 (TDS51,893 mg/l), VT-4 (TDS51,101 mg/l), VT-5 (TDS51,181 mg/l)

One hand-dug well has pH lower than standard: VT-9 (pH56.48).

Two hand-dug wells have manganese concentrations higher than the standard: VT-8 (Mn50.374 mg/l), VT-9 (Mn50.338 mg/l). Two hand-dug wells have Fe concentration higher than the Vietnamese standard: VT-5 (Fe50.560 mg/l), VT-8 (Fe50.700 mg/l).

The Stiff diagrams of the shallow groundwater show that the groundwater is mostly Ca-HCO₃ type. The size of stiff diagrams is large in the area along the Ma River.

2) Test well

The result of chemical analysis of groundwater from the test well (JICA-11) shows that only iron (ΣFe) exceeds the Vietnamese and WHO standard for drinking water.

ΣFe 1.82 mg/l (the Vietnamese standard; ΣFe 0.5 mg/l, the WHO standard ΣFe 0.3 mg/l)

For using the test well water for water supply, it is necessary to treat the water to reduce the iron concentration.