Executive Summary

Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC)

Present to

Bureau of Groundwater Resources Region 9 (Rayong)

Department of Groundwater Resources

Ministry of Natural Resources and Environment

By

Center for Applied Economics Research

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Preface

This report is an executive summary of a Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC). The research team conducted the study on potential of the large-scale groundwater resources for more detailed and accurate information of groundwater potential in EEC, in both quantity and quality. The research team also conducted an economic viability and analysed the real cost of groundwater utilisation in EEC for effective water allocation. Furthermore, the research team constructed an area integrated water resources planning and development in EEC which includes public participation regarding consumption, agriculture, industry, and tourism (in short, medium, and long term).

The study results will greatly contribute to future studies on exploration and economic viability of the large-scale groundwater development in other areas. In addition, the project will give the benefit to all sectors, including government, private sector, and society.

In this regard, the research team would like to express our gratitude to people who supported us on this project. We truly appreciate your generosity.

Research Team

February 2021

Acknowledgement

The Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC) could not be successful without helps from Department of Groundwater Resources and relevant government officials, private sector, and all types of groundwater operators (consumption, commercial, and agriculture) in 3 Provinces (Rayong, Chonburi, and Chachoengsao). Their valuable comments and suggestions helped the Project to complete successfully. We are totally grateful for that.

Additionally, we hope that this study could give you some benefits and we would like to contribute the benefit to all stakeholders who helped providing us the useful information. We are solely responsible for any errors found. Any comments and suggestions are welcome in order to further improve our research.

Research Team

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Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC)

1. Rationale

Thai Government places importance on Eastern Economic Corridor Project in Chachoengsao, Chonburi, and Rayong Province, where manufacturing industry has been rapidly and continually expanding, resulting in an influx of investment in various related business, such as accommodation, restaurants, wholesales and retails, and other services. Labour from other regions also migrated into the EEC area. Such development therefore increases demand for water. If water scarcity happens even only for a short period, it could severely affect investment climate in Thailand.

Moreover, industrial expansion and increasing population in the region has caused the rapid rise of water uses for both households and industries. Currently, surface water is insufficient for demand, especially during the dry season, and sometimes the water quality is non-consumable. Therefore, new water resource is needed to serve the development of EEC area. In this regard, groundwater is an important reserved source which could be developed for EEC development use. In order to use the groundwater effectively, we need detailed, precise, and updated information of groundwater in the EEC area. Unfortunately, the current information is not enough for study as the existing groundwater map was conducted during 1987-1992 when information related to groundwater extraction for evaluation was limited. Nevertheless, after almost 20 years, the information has become much more available. Since the groundwater sources in some areas have changed significantly, in terms of both quantity and quality, and the groundwater from shallow aquifers in Chachoengsao Province is often saline. Therefore, groundwater extraction from deeper aquifers is needed. Nonetheless, the lack of information about potential groundwater sources causes difficulty and inefficiency in groundwater resource management.

For more accurate, reliable, detailed, and updated information and economical and efficient groundwater allocation, it is essential to have a study on groundwater resource evaluation in terms of quantity and quality and an integrated plan of groundwater management and development which includes public participation (households, industrial, and agricultural sector) to reduce water conflicts and create a fair and effective allocation.

Therefore, Department of Groundwater Resources has launched the Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC) to be a guideline for an effective water management in EEC to prevent water scarcity, increasing input security which directly affect investor confidence, economic climate, and quality of life of people.

2. Objectives

2.1 To get more detailed and accurate information of groundwater potential in EEC, in both quantity and quality.

2.2 To conduct an economic viability and analyse the real cost analysis of groundwater utilisation in EEC for effective water allocation.

2.3 To construct an area integrated groundwater resources planning and development in EEC which includes public participation regarding consumption, agriculture, industry, and tourism (in short, medium, and long term)

3. Research methodology

The Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC) has research methodology and approaches as follows.

3.1 Groundwater Exploration and Evaluation

1) Collecting and analysing data obtained from secondary sources, including geology setting, structural geology, surface water data, meteorological and hydrological data, land use data, groundwater well and groundwater usage, water demand, water supply, and other social factor that impact the conditions. All collected data were decided and plan to field investigation.

2) Exploring groundwater sources, water usage, and groundwater demand to understand current water resource problems and estimation of future demand of water. Information could be obtained from questionnaires or from relevant authorities.

3) Conducting surface-geophysical survey in areas where soil and rock data are not available to determine the boundary of hydrogeological units, soil layers, bed rocks, and

aquifer types. The research team used Resistivity survey method, Vertical Electrical Sounding or VES, using Schlumberger configuration with minimum current electrode spacing (AB/2) at 200 metres and at least 4,500 stations.

4) Selecting at least 150 existing groundwater wells for jetting and preparing for pumping test. Well jetting by air leaching is required to ensure adequate water and optimum water quality.

5) To determine groundwater yield and hydraulic properties of aquifers, including transmissivity (T), hydraulic conductivity (K) and storativity (S), constant-rate pumping tests were conducted at least 12 hours or until the drawdown became steady for at least 4 hours. After that, the research team measured recovery test value until the drawdown returned to its pre-pumping level. Water samplings were collected in pre-pumping and before the end of pumping to measure physical and chemical properties. If there are nearby groundwater wells which were developed in the same aquifer with the testing wells, the research team had to measure the water level and recovery test value of those wells during the pumping test of the testing wells too. The pumping test is operated following the Department of Groundwater Resources' standards and minimum 250 groundwater wells were tested.

6) Analysing, interpreting, and processing data as follows.

(1) Analysing the available data of soil layers and bed rocks, geophysics surveys, and well log data by generating hydrogeologic cross section display, and distribution boundary, thickness, and depth of aquifers.

(2) Analysing the hydraulic properties of the aquifers using pumping test data from previous studies and from this study.

(3) Analysing groundwater system and flow direction using contour map to show surface of the aquifers (using data from both existing wells and newly drilled wells).

(4) Processing data to evaluate groundwater quality and groundwater potential.

(5) Assessing groundwater potential areas in terms of quality and quantity. Then selecting areas that have potential for economic growth or have high groundwater potential to evaluate the water balance and groundwater properties by using mathematical models at local scale.

7) Mapping

(1) Updating hydrologic map at 1:50,000 scale as well as illustrated maps, in both digital and hard copy format, each for 10 copies.

(2) Generating maps of suitable areas for groundwater development for each purpose in digital format.

3.2 Economic Evaluation and Analysis

1) Field survey to collect information regarding water use, water allocation, and cost of water usage in EEC to update and improve the current secondary database.

2) Organising focus groups, at least twice with minimum 35 participants each, with stakeholders and relevant parties, e.g. representatives of business, industrial, agricultural sector, households, government agencies, and other organisations to gather insightful comments and suggestions, and to better engage with relevant government agencies.

3) Analysing and conducting economic viability of groundwater utilisation, using information gathered from field survey and focus group, along with secondary data from Department of Groundwater Resources. Also conducting the economic viability of the large-scale groundwater development and analysing the real cost of groundwater utilisation in EEC.

4) Organising public hearings, at least 15 with minimum total 1,200 participants, to collect comments and suggestions from all stakeholders, including local people, to make the groundwater development project acceptable and beneficial to all sectors.

5) Organising meetings between relevant organisations, at least 12 with minimum 20 participants each or 240 in total, for discussion and suggestions.

6) Developing an area integrated groundwater resources planning and development in EEC which includes public participation regarding consumption, agriculture, industry, and tourism (in short, medium, and long term)

3.3 Project Launch and Dissemination

1) Organising a project launch seminar with minimum 100 participants.

2) Organising a seminar to disseminate the findings and to be open for comments and suggestions from all stakeholders, including representatives from business, industrial, agricultural sector and households in EEC with minimum 100 participants.

4. Results

The study results comprise 4 parts as follows.

4.1 Groundwater exploration and evaluation, groundwater mapping, hydrogeological mapping, and potential groundwater zones.

4.2 Water usage and water demand.

4.3 Economic viability and real cost analysis of groundwater utilisation in EEC.

4.4 Water resources planning and development in EEC

4.1 Groundwater Exploration and Evaluation, Groundwater Mapping, Hydrogeological Mapping, and Potential Groundwater Zones

4.1.1 Location and Area

The study area is Eastern Economic Corridor (EEC) located in Rayong, Chonburi, and Chachoengsao Province, covering 24 map sheets namely 5134I, 5134II, 5135I, 5135II, 5136I, 5136II, 5234I, 5234II, 5234III, 5234IV, 5235I, 5235II, 5235III, 5235IV, 5236I, 5236II, 5236III, 5236IV, 5334I, 5334II, 5334III, 5334IV, 5335II and 5335III. All study areas are located in 3 Eastern Provinces of Thailand as shown in Figure 1.

(1) Rayong Province

In Pluak Daeng District, Wang Chan District, Nikhom Phatthana District, Ban Chang District, Ban Khai District, Klaeng District, and parts of Mueang Rayong District and Khao Chamao District.

(2) Chonburi Province

In Phan Thong District, Bang Lamung District, Phanat Nikhom District, Sattahip District, and parts of Mueang Chonburi District, Ban Bueng District, Bo Thong District, Si Racha District, Ko Chan District, and Nong Yai District.

(3) Chachoengsao Province

In Bang Nam Priao District, Mueang Chachoengsao District, Khlong Khuean District, Ratchasan District, Bang Khla District, Ban Pho District, Bang Pakong District, Plaeng Yao District, and parts of Phanom Sarakham District, Sanam Chai Khet District, and Tha Takiap District.

The research area connects with other areas as follows.

North	connects with	Ongkharak District, Nakhon Nayok Province and Part of Prachinburi Province
East	connects with	Parts of Chachoengsao and Chanthaburi Province

West	connects with	Gulf of Thailand, Nong Chok District, Bangkok, and Lamlukka District, Pathum Thani Province
		Bang Bo District, Samut Prakan Province
South	connects with	Gulf of Thailand

4.1.2 Geological and Hydrogeological Work Results

4.1.2.1 Hydrogeological Survey

1) Boreholes Survey Result

The research team conducted a survey to measure water level and groundwater quality for 3 times. First was in June 2020, 250 boreholes data were collected (125 boreholes in upper parts and 125 in lower part of the study area). The second survey was in July 2020 and the third was in December 2020. For the second and the third survey, only the boreholes located in the areas set for modelling were examined. The location of the examined boreholes are shown in Figure 2.

The data collected in field survey were proceeded further for hydrogeology setting by combining hydraulic properties of groundwater and aquifer unit represented in hydrogeological map and hydrogeologic cross section, illustrating aquifer distribution unit, equipotential line, groundwater flow direction and flow system. These data led to conceptual model simulation and modelling. Besides, the data are necessary to be assessed before transforming into 3 – dimensional mathematical model.

2) Well Jetting Result

The research team chose 150 groundwater wells based on local groundwater demand and coverages of the wells that must cover aquifers in the study area. Afterwards, the chosen groundwater wells got air leaching (well jetting) to clean up their bottom to ensure adequate water flow and optimum water quality. All the leached wells also got the pumping test. Location of the jetted wells are presented in Figure 3.

3) Pumping Test Result

The pumping test were conducted in various sites as shown in Figure 4. The 250 groundwater wells were examined using the constant-rate pumping test for 12 hours or until the drawdown reached steady stage. The data analysis is operated on Aquifer Test Pro 2016.1 program (University of Waterloo, Canada), using Jacob's method and Theis's method (drawdown curve and recovery curve).

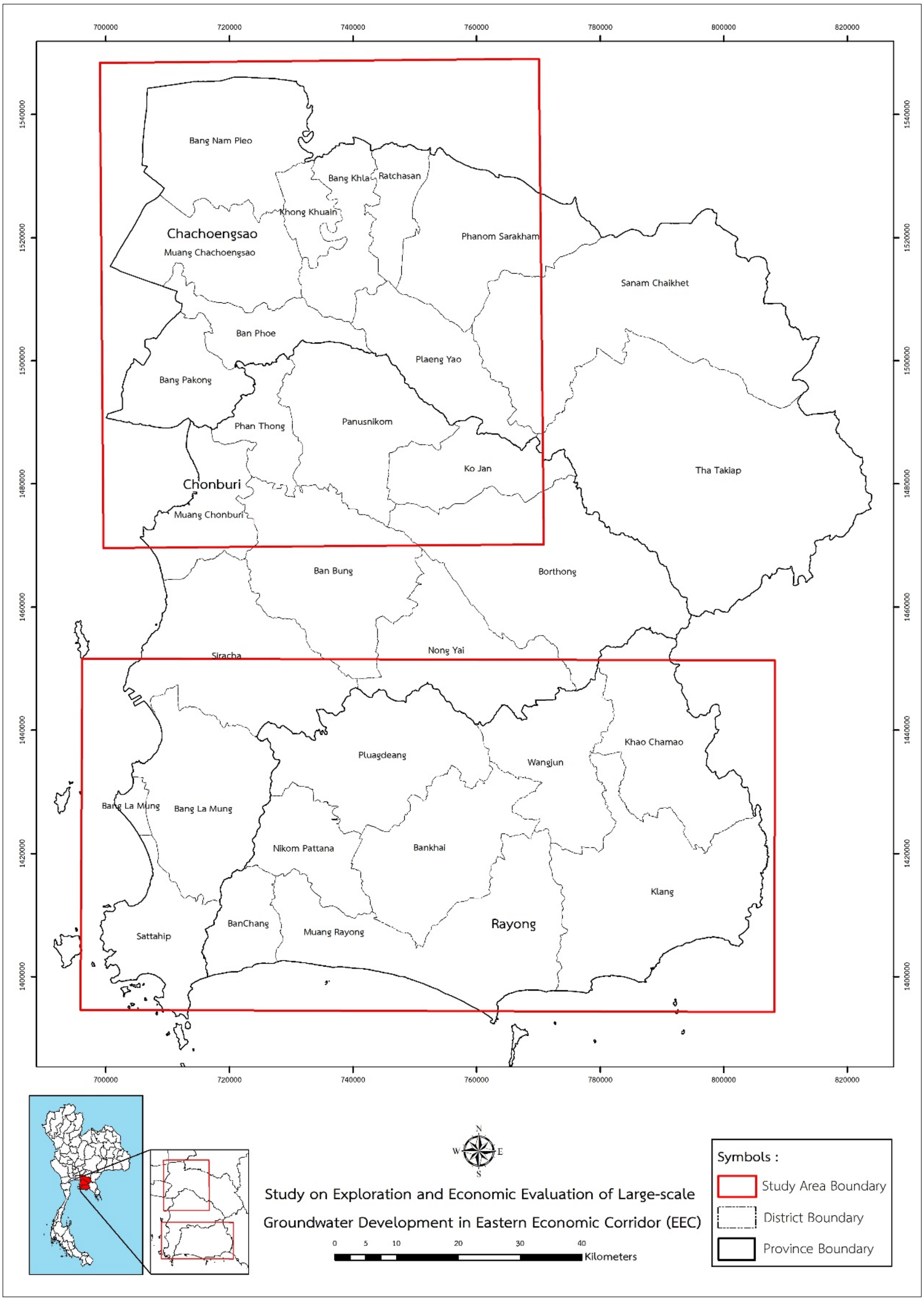


Figure 1 Study on Exploration and Economic Evaluation of Large-scale Groundwater Development in Eastern Economic Corridor (EEC)

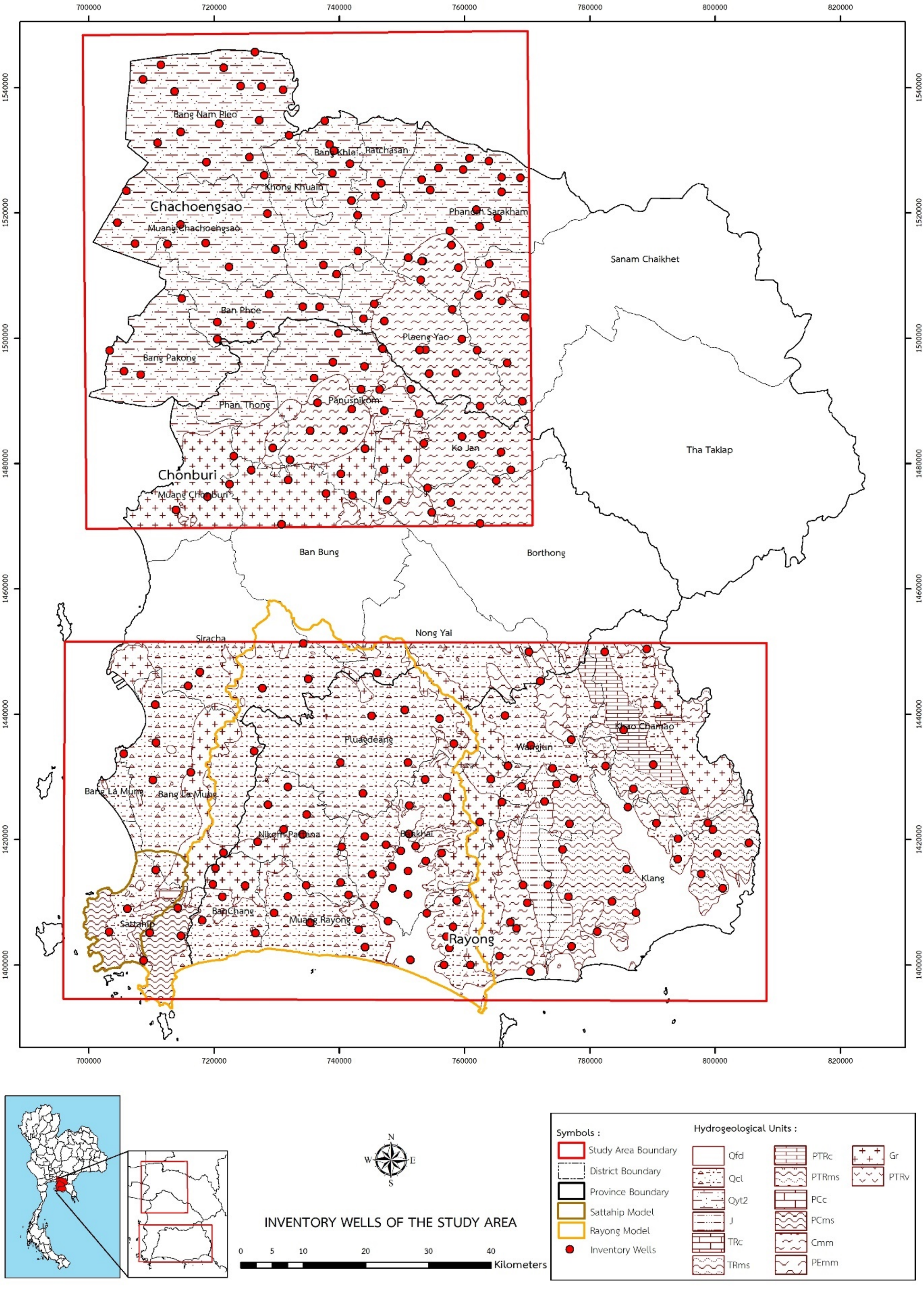


Figure 2 Location of Examined Boreholes

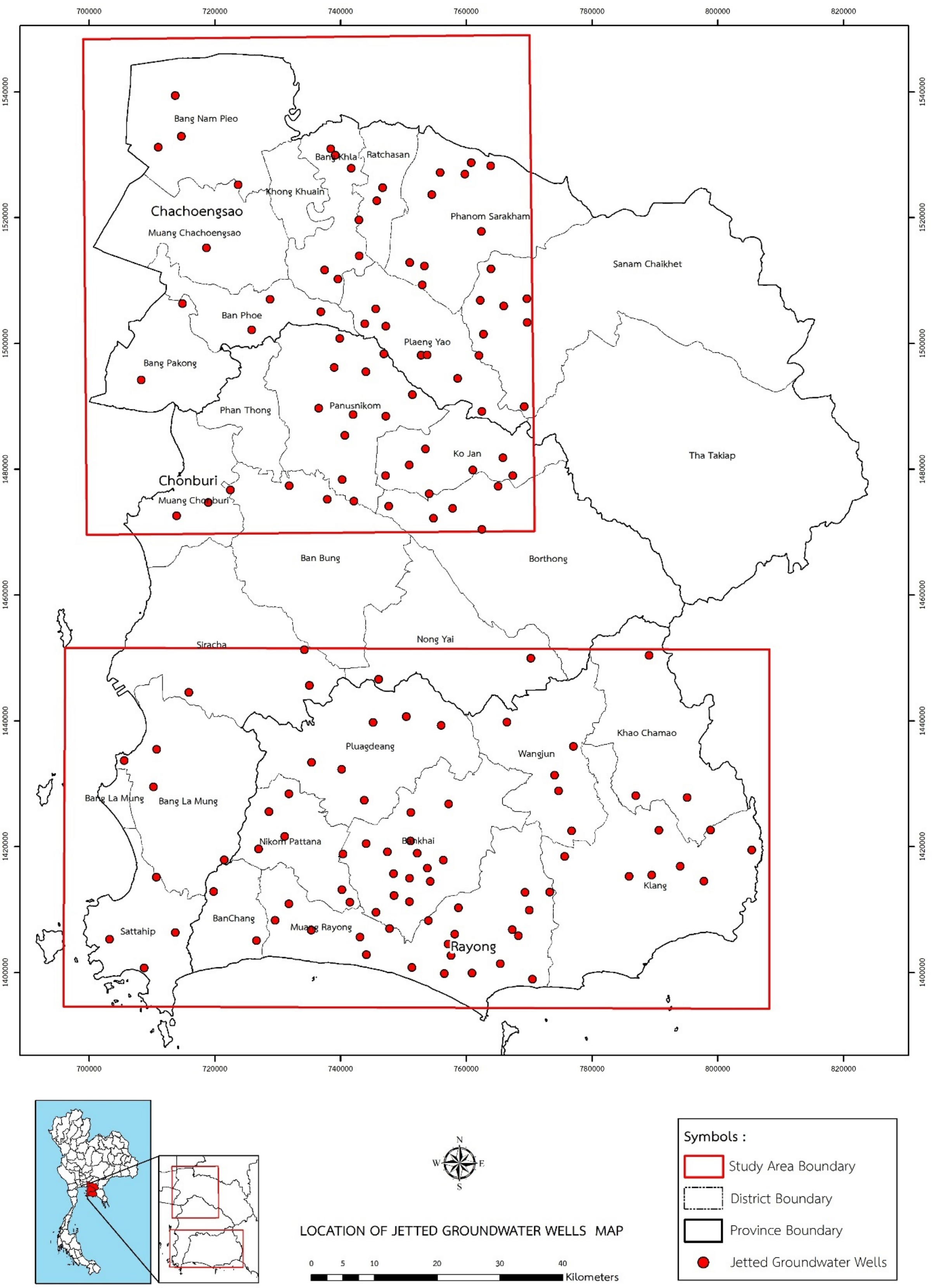


Figure 3 Location of Jetted Groundwater Wells

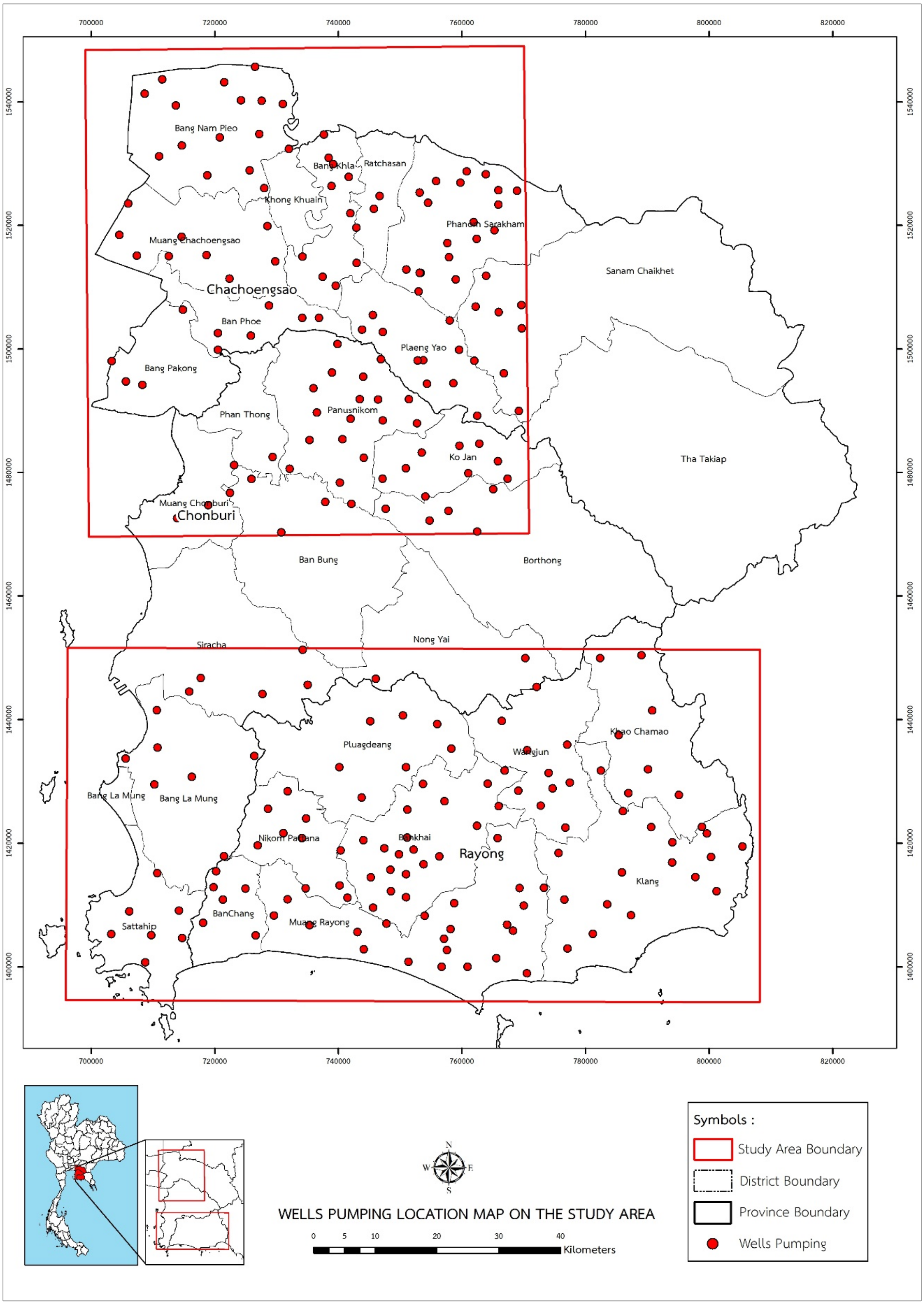


Figure 4 Location of the Pumping Test Sites

4) Geophysical Survey Results

The vertical electrical sounding (VES) data collected from geophysical surveys are shown as a dot for each single survey point. To identify soil layer from bed rocks, the VES data from 4,517 survey points were processed before groundwater modelling simulation as can be seen in Figure 29.

The results found the potential aquifers in 772 survey points out of total 1,879 survey points (41.1%) in the upper part of the study area. In addition, 166 survey points out of total 450 survey points (36.8%) were potential aquifers related to Phanom Sarakham fault zone and 91 survey points out of total 188 survey points (48.4%) were potential aquifers near Phanat Nikhom fault zone in the west of the study area. In the lower part of the study area, 940 survey points out of total 2,638 survey points were expected to be the potential aquifers. Meanwhile, none of the survey points were found aquifers that could be related to Klaeng fault zone (Figure 5 and 6).

From analysis and interpretation of geophysical data covering major fault zone in Phanom Sarakham area using structural geologic map (at 1:250,000 scale) from Department of Mineral Resources in shape file format, the result shows strong fracture zones or weak zones in the cross-section profile. (Electrical) Resistivity coefficients in hard rock bed (shown in blue colour) is lower than ones in adjacent area, possibly resulting from fracture or weak zones in their bed. These are related to groundwater well data from Department of Groundwater Resources that gave low resistivity coefficients comparing to vicinity area, with flow rate at 1.14 cubic metre per hour.

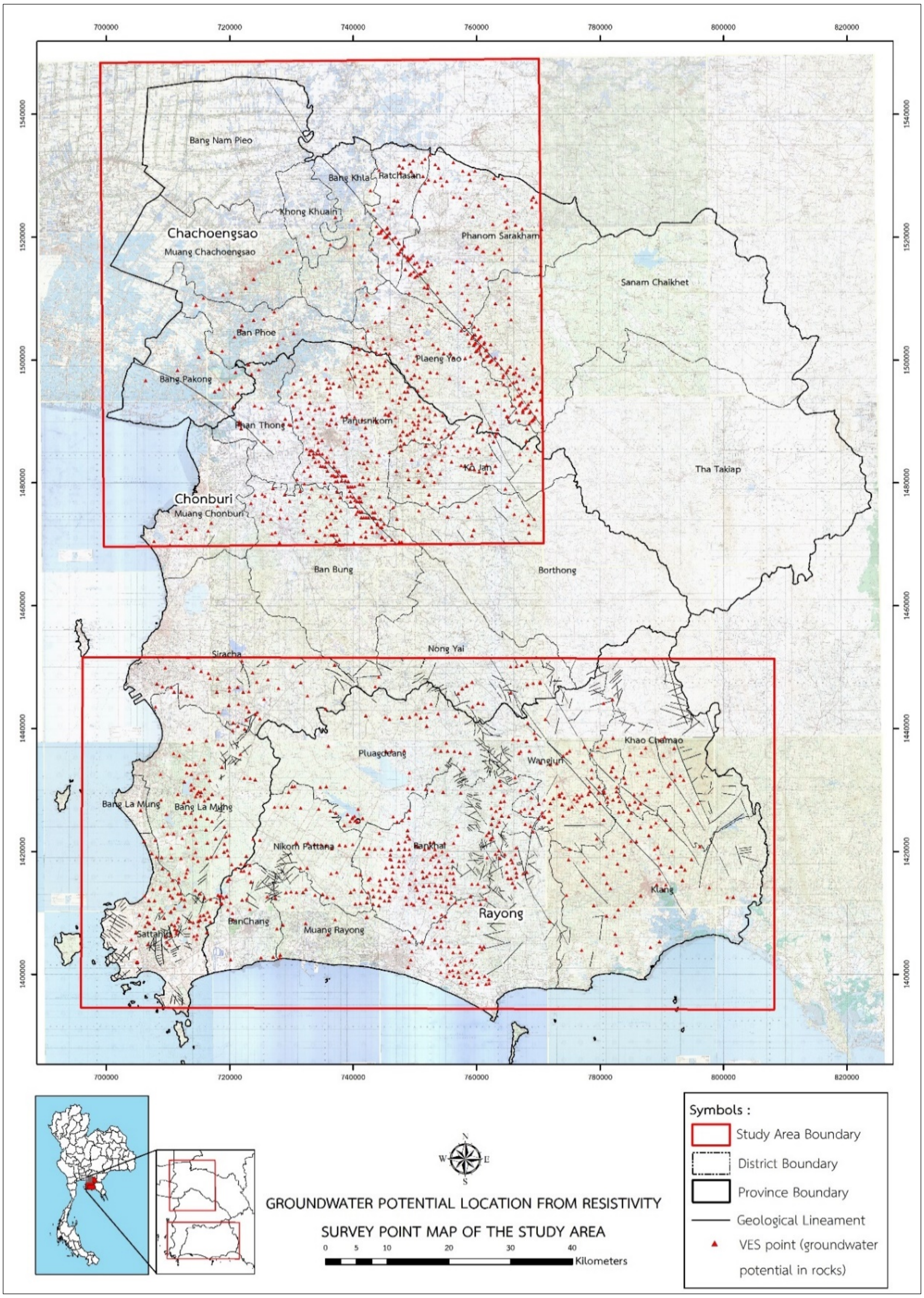


Figure 5 Geophysical Survey Points

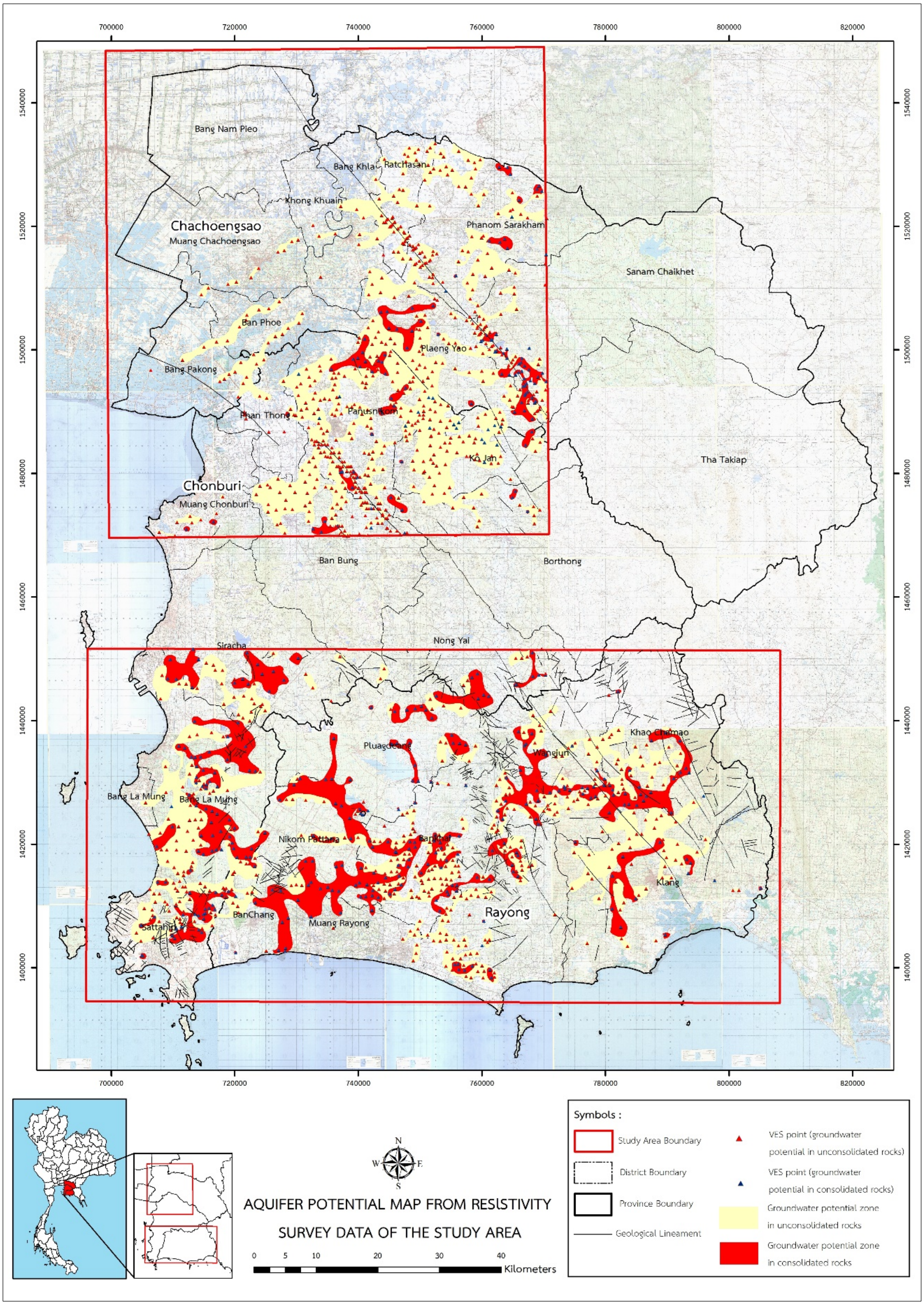


Figure 6 Areas of Potential Aquifers Based on Geophysical Survey

5) Groundwater Sampling

The research team collected 250 groundwater samples from existing wells twice (pre-pumping and prior to end of pumping) for laboratory test, measuring physical and chemical properties including Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K), Iron (Fe), Manganese (Mn), Copper (Cu), Zinc (Zn), Sulfate, Chlorine, Carbonate, Bicarbonate, Fluoride, Nitrate, total hardness, permanent hardness, and total dissolved solids (TDS). Afterwards, the research team sent all samples to The Bureau of Groundwater Resources Region 9 (Rayong) for further analysis.

4.1.2.2 Geology Setting Analysis

To analyse geology setting of the study area, the research team used the geological data including rock units, rock formations, geological structure, and geomorphology for mapping which became a basis for soil layer and bed rocks procedures analysis as follows.

Geological Units

Geological data were obtained from both digital files and hard copies of geological maps at 1:50,000 scale from Department of Mineral Resources. The research team used the data to examine rock units and rock formations in the study area. However, the study area covers 24 sheets of Royal Thai Survey Department's topographic map at 1:50,000 scale, but only 11 map sheets were available in Department of Mineral Resources' geological map at the same scale. The unavailable 13 map sheets were 5136I, 5136II, 5234I, 5234II, 5234II, 5236I, 5236I, 5334I, 5334II, 5334III, 5334IV, 5335II and 5335III which the research team decided to use the geological map at 1:250,000. See Figure 7.

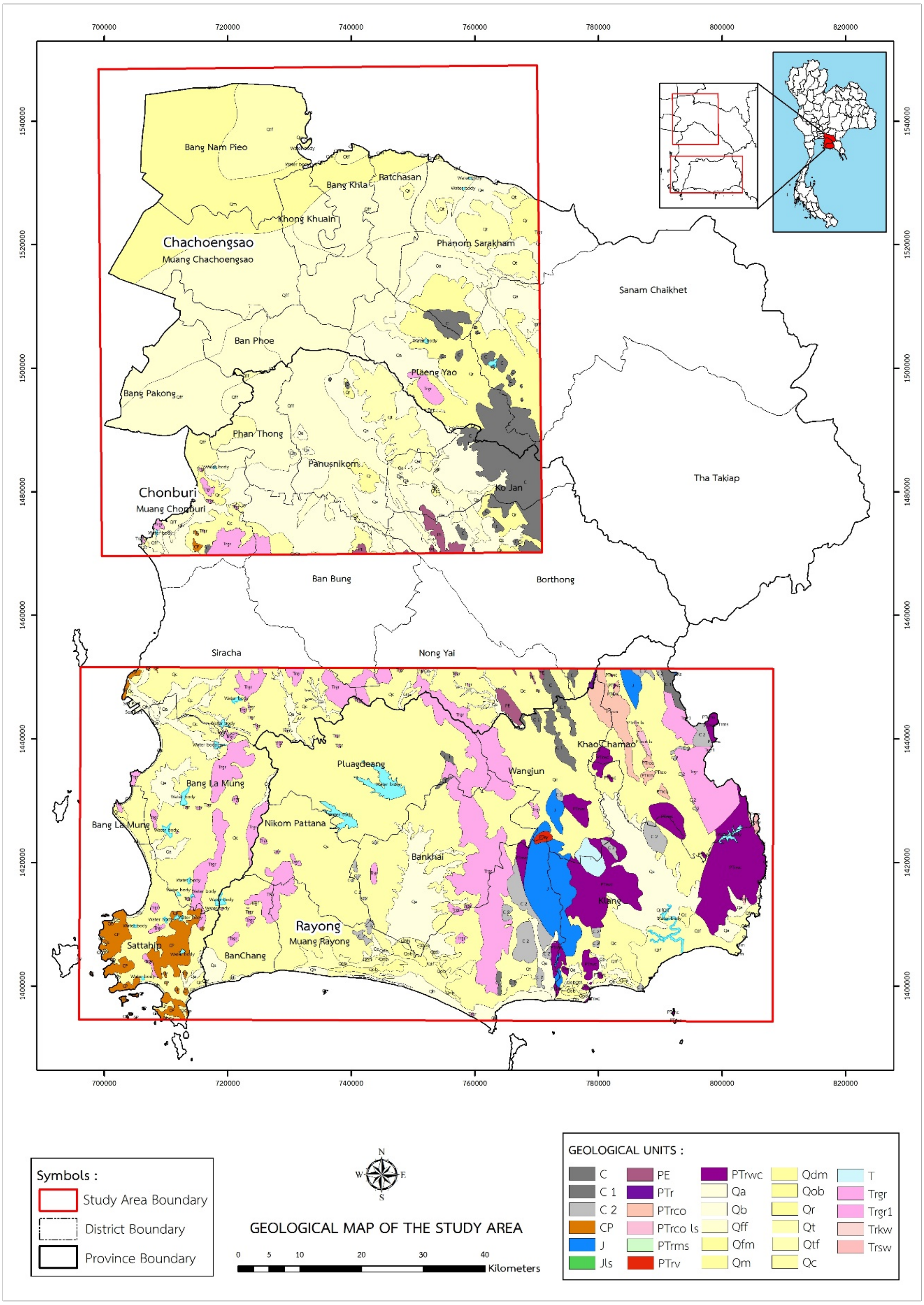


Figure 7 Geology Setting Map

Geological Structure

Geological structure data are obtained from Department of Mineral Resources' geologic maps at 1:50,000 and 1:250,000 scale which are available in digital file-vector system. The preliminary fault analysis found that the geologic map at 1:250,000 scale classified faults into 4 categories based on hydrogeological properties as follows.

- Category 1 Unclassified Faults: faults that are not related with any streams
- Category 2 Water Barrier Faults: faults that lie along 2 streams or vicinity area, blocking the streams
- Category 3 Water Flow Through Faults: faults that let several streams run through
- Category 4 Water Conduit Faults, faults that have fault lines parallel to water stream

Nonetheless, structural geology orientation (Strike and dip direction) data were used to confirm the preliminary fault analysis. Figure 8 shows mapping and structural geologic data layers.

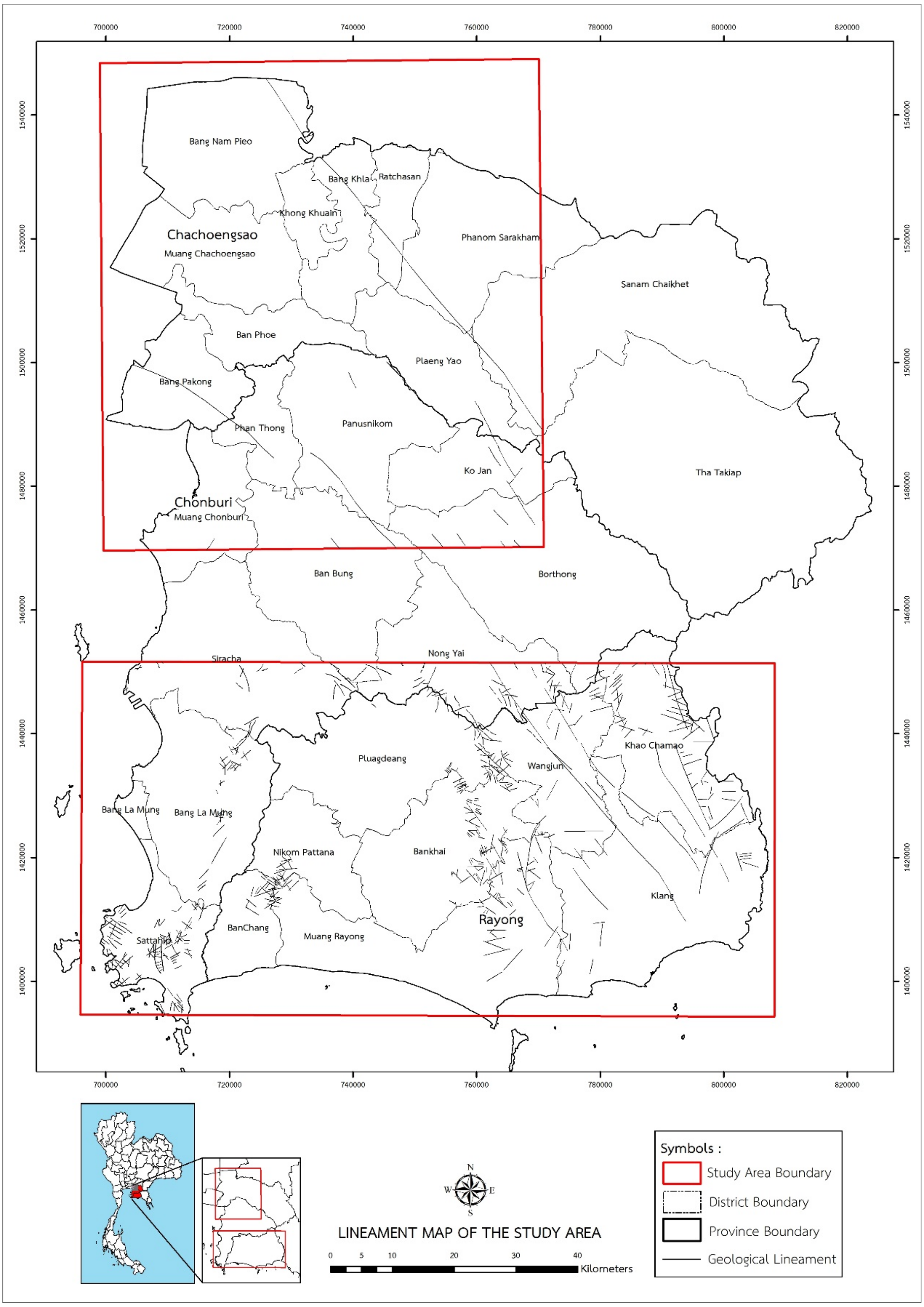


Figure 8 Geological Structure Map

4.1.2.3 Hydrological Analysis

For hydrological data analysis, the processed geological data and data collected from fieldworks were analysed together, then the result were illustrated in map or data layer, showing aquifer's distribution and aquifer's depth and thickness. In this regard, the definition of hydrogeological units and aquifer are as follows.

1) Hydrogeological Units

The research team generated the preliminary hydrogeological map which were used for planning the further fieldworks. Then data collected from the further fieldworks, including well condition survey, surface geophysical survey, borehole logging, drilling, and well developments, would be used to improve the hydrogeological map.

The completed hydrogeological map (Figure 9) shows hydrogeological data of the study area which is comprised of 25 hydrogeological units as indicated in Table 1. The aquifers could be classified into 2 groups as unconsolidated aquifers and consolidated aquifers. The unconsolidated aquifers were found in the upper study area covering 2,707 square kilometres, and also in the lower area of the study covering Sattahip District and Bang Lamung District of Chonburi Province, and Ban Khai District and Mueang Rayong District of Rayong Province covering 3,070 square kilometres. The consolidated aquifers covered 1,929 square kilometres. The remaining areas were surface water or reservoirs.

2) Aquifer Identification

Besides the analysis of aquifer distribution in terms of area and depth/thickness, primary and secondary data, especially the test results of rock cutting samples from boreholes, were examined to clarify lithology and hydrogeological properties of aquifers.

3) Aquifer's Depth

To determine aquifer's depth, it is required interpretation of surface resistivity data, ground penetrating radar data, and geophysics cross-section data. The data were rechecked for accuracy by overlaying the data set with structure geologic map, topographic map, drainage pattern, and depth of aquifers. The results are shown in Figure 10.

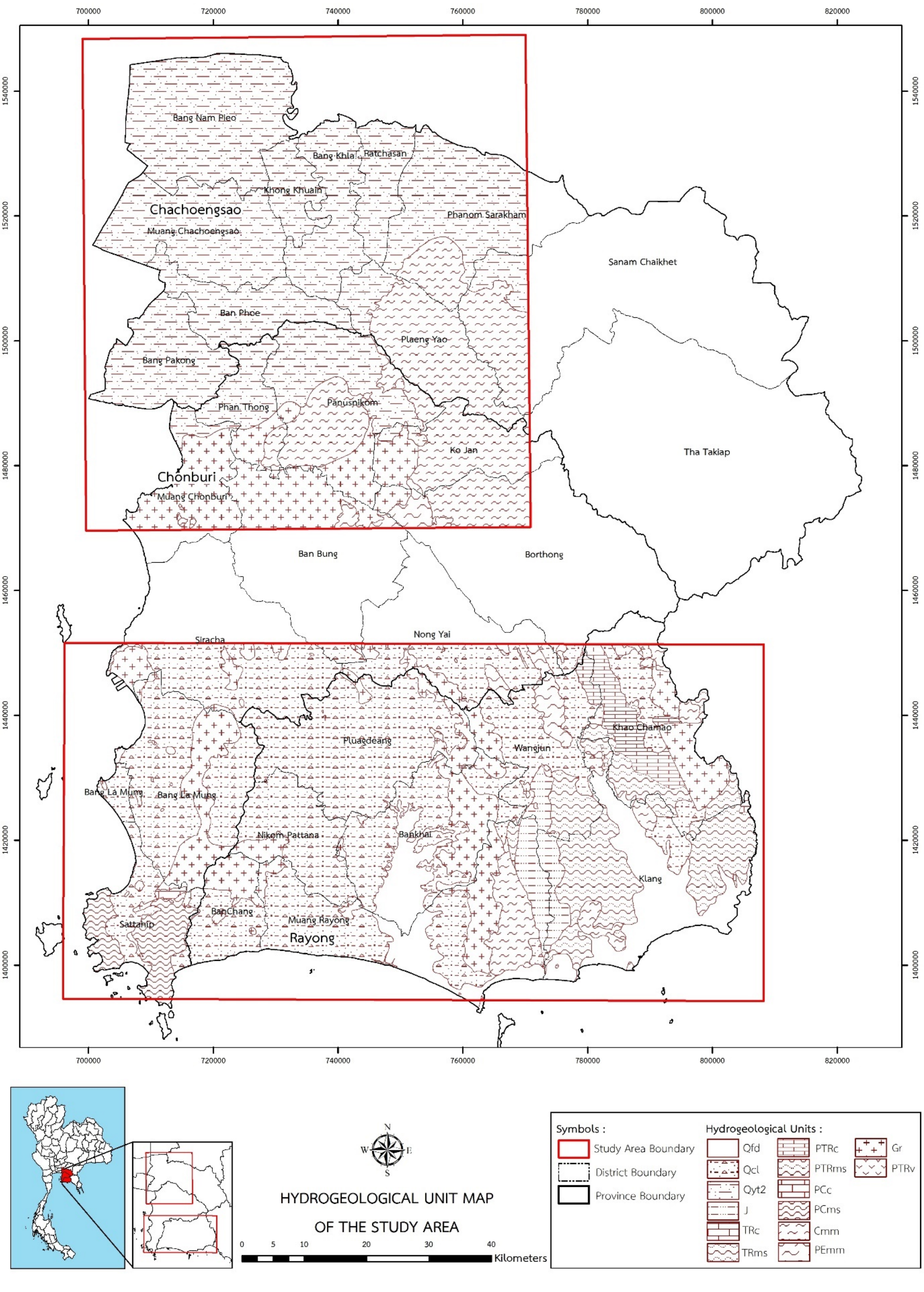


Figure 9 Hydrogeological Units Map

Table 1 Aquifers in Study Area

No.	Hydrogeological units	Description	Type of aquifer
1.	Qfd	Floodplain deposit aquifer	Unconsolidated aquifers
2.	Qt	Terrace deposit aquifer	
3.	Qyt2	Upper young terrace deposit aquifer	
4.	Qyt1	Lower young terrace deposit aquifer	
5.	Qot8	8th Old terrace deposit aquifer	
6.	Qot7	7th Old terrace deposit aquifer	
7.	Qot6	6th Old terrace deposit aquifer	
8.	Qot5	5th Old terrace deposit aquifer	
9.	Qot4	4th Old terrace deposit aquifer	
10.	Qot3	3rd Old terrace deposit aquifer	
11.	Qot2	2nd Old terrace deposit aquifer	
12.	Qot1	1st Old terrace deposit aquifer	
13.	Qcl	Colluvial deposit aquifer	
14.	J	Jurassic sediment aquifer	Consolidated aquifers
15.	TRc	Triassic limestone aquifer	
16.	TRms	Triassic metasediment aquifer	
17.	PTRc	Permo – Triassic limestone aquifer	
18.	PTRms	Permo – Carboniferous metasediment aquifer	
19.	PCc	Permo – Carboniferous limestone aquifer	
20.	PCms	Permo- Carboniferous metasediment aquifer	
21.	Cmm	Carboniferous sediment aquifer	
22.	PEmm	Pre-Cambrian metamorphic aquifer	
23.	Gr	Granitic aquifer	
24.	PTRv	Permo – Triassic volcanic aquifer	

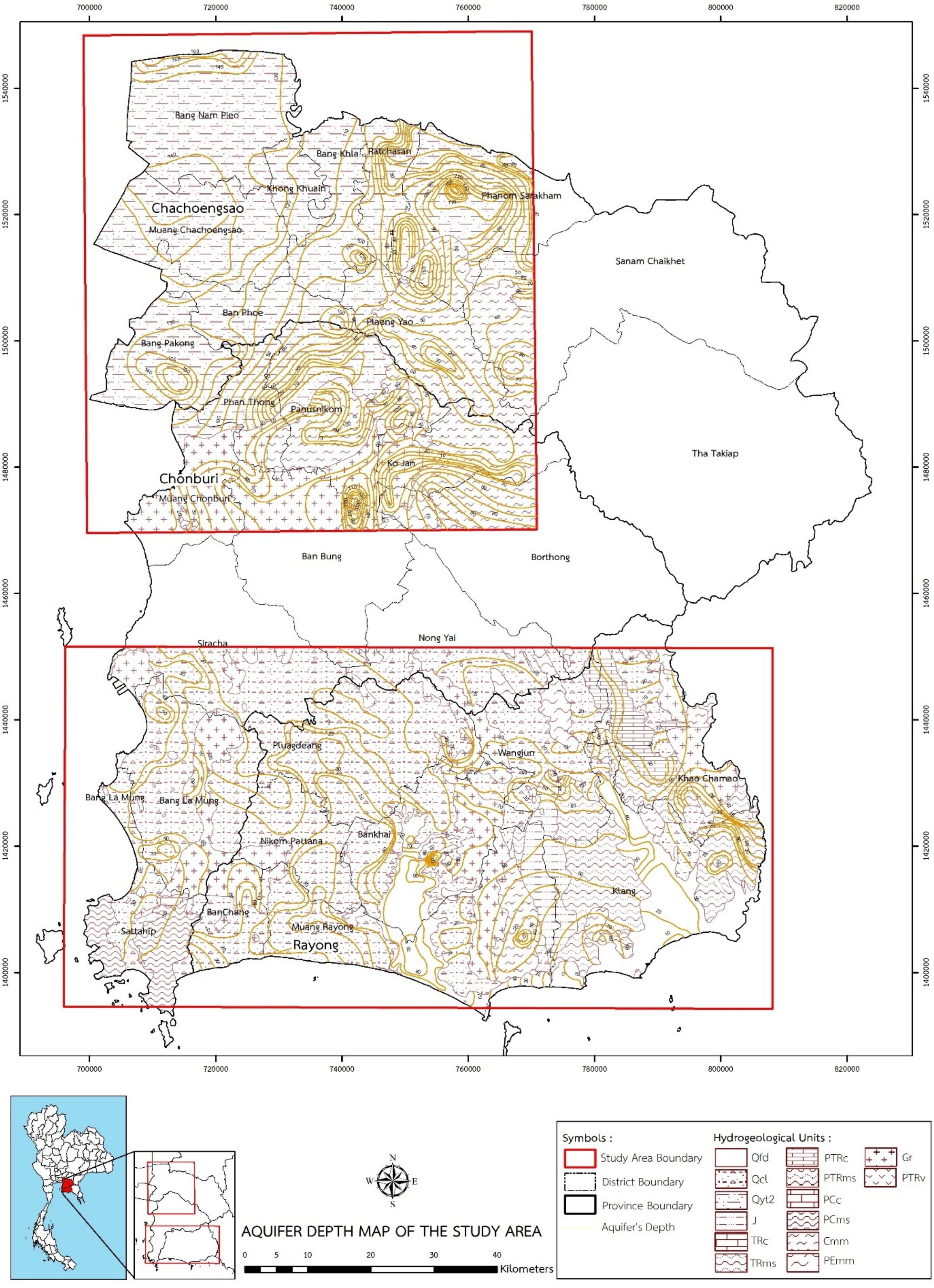


Figure 10 Aquifer’s Depth in Study Area

4) Saline Groundwater Sources and Deep Aquifers

Deep aquifers mapping and saline groundwater sources mapping were conducted by the research team using analysed data from deep borehole drilling in this study (drilled in the upper and lower part of the study area).

4.1) Upper Study Area

Based on geomorphology, the upper study areas were categorised into 2 landforms as follows.

(1) Rolling hills and mountainous areas in lower part, covering several Districts of Chonburi Province and some parts of Chachoengsao Province, have basement rocks that are overlaid by sediments at shallow depth, hence the groundwater wells developed in this area are shallow with average depth at 20-60 metres. An exception can be found in the wide and large basin that deposits thick sediments, for examples, the west of Phanat Nikhom District and the south of Phanom Sarakham District. However, Department of Groundwater Resources has never reported any saline water problem in this area.

(2) The lowland basin near the seacoast in the north, covering most Districts in west of Chachoengsao Province and upper part of Pan Thong District and Phanat Nikhom District of Chonburi Province, is mostly overlaid by very thick sediments bedding/layers which could be separated into many layers. An exception can be found in the east and south (part of Mueang Chachoengsao District and upper part of Pan Thong District and Phanat Nikhom District of Chonburi Province (basin margin) which are overlaid by hard rock at shallow depth.

In summary, the saline aquifers overlays sediment deposits in the upper study area. Furthermore, the data from geophysical borehole logging (Figure 11) obtained from the new testing wells in several areas showed that the saline aquifers lying from surface to 90 metres depth excepted in some areas in Mueang Chachoengsao District (Bang Ka Hi SAO and Ban Teen Ped SAO) clearly indicated that the saline aquifers lying from surface to 250 metres depth. According to these data, it could be assumed that the upward area in the north and west (Mueang Chachoengsao District, Ban Pho District, Bang Pakong District, and Bang Nam Priao District, far away from basin margin) have the same aquifer condition as mentioned above.

Therefore, it could be concluded that the lowland in upper study area has freshwater aquifers overlying at 250 metres depth.

4.2) Lower Study Area

Based on geomorphology, the lower part of study area could be categorised into 3 landforms as follows.

(1) Undulatory plain/rolling plain which expand into a large area in Phanat Nikhom District, Ban Khai District, and Mueang Rayong District.

(2) High mountainous areas in the west and east of the study area, next to the undulatory plain

(3) Alluvial plain basin along rivers in Ban Khai District and Mueang Rayong District.

According to Department of Groundwater Resources' groundwater sources maps (scale 1:50,000) of Chonburi Province and Rayong Province during 1988-2011, saline groundwater problem was not found in the lower study area.

Data from Department of Groundwater Resources about existing wells in Chonburi and Rayong Province showed that most are shallow wells with average depth between 30-60 metres, except few groundwater wells located in alluvial plain basin as mentioned before which are 120 metres deep or more. These deeper wells were drilled to mitigate drought problem in 2005.

Nevertheless, deep test-well drilling was conducted for this study and we found the continued sediments deposits for over 400 meters depth which act as an aquifer. Hence, it could be concluded that, in the lower study area, there are fresh water aquifers overlaid under alluvial plain basin landform at 120-400 metres depth.

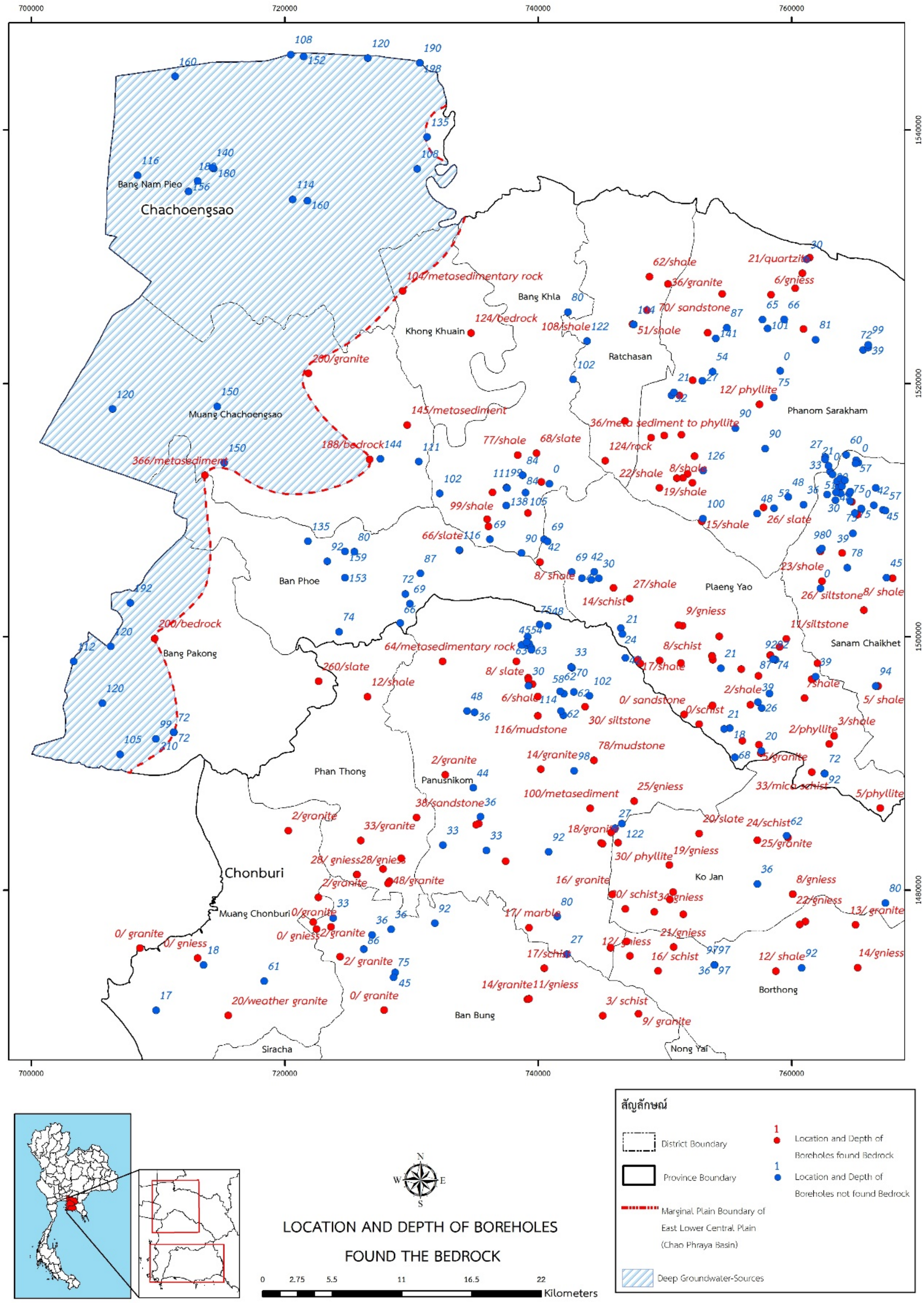


Figure 11 Location and Depth of Boreholes found the Bedrock

5) Hydraulic Properties of Aquifers

The upper and lower part of the study area are consisted of unconsolidated and consolidated aquifers that expanded differently. In other words, the unconsolidated aquifers expanded in a large area, while the consolidated aquifers have locally and discontinued expanded in fracture zone, rocks contact, or geological structures.

To analyse hydraulic factors for each aquifer in the study area precisely, the data of short period (12-hour) pumping test for 250 existing wells were analysed and evaluated for transmissivity (T), hydraulic conductivity (K), and storativity (S). However, the hydraulic conductivity (K) is calculated from equation T=Kb, but we do not have b value (thickness of aquifers) because this study did not operate geophysical borehole logging for the testing wells. Therefore, the K is not included in the analysis and not presented in the map. Additionally, water level from pumping test were not measured for storativity (S) calculation, so we estimated the S values from Aquitest program using Theis's Method Jecob's Method, and Recover Method. Transmissivity (T) and hydraulic conductivity (K) values of aquifers of the wells in upper and lower study area were successfully determined. The results are as follows.

A. Upper Study Area

1) 5 aquifer units were conducted pumping test. The maximum data was found in Cmm aquifer with 44 pumping test wells.

2) T values for the upper study area range from 0.0006 to 48.30 square metre/day for unconsolidated aquifers, and range from 0.006 to 21.80 square metre/day for consolidated aquifers. K values for unconsolidated aquifers range from 0.0006 to 6.67 metre/day and range from 0.0002 to 9.50 meter/day for consolidated aquifers. S values for unconsolidated aquifers vary from 1.15×10^{-6} to 8.54×10^{-2} while for consolidated aquifers range from 4.65×10^{-5} to 9.56×10^{-2}. In case of consolidated aquifers, the Qfd aquifer executed highest T value at approximately 48.30 square metre/day, and Gr aquifer performed highest K and S values at around 9.50 metre/day and 9.56×10^{-2}, respectively.

B. Lower study area

1) 14 aquifers units were operated pumping test. The maximum data is found in Gr aquifer with 45 pumping test wells.

2) T values for the lower study area range from 0.0006 to 94.80 square metre/day for unconsolidated aquifers, and range from 0.007 to 52.50 square metre/day for consolidated aquifers. K values for unconsolidated aquifers range from 0.0002 to 23.70 metre/day and range from 0.0002 to 25.50 meter/day for consolidated aquifers. S values for unconsolidated aquifers vary from 1.8×10^{-4} to 157.00, while for consolidated aquifers range from 3.42×10^{-5} to 2.21×10^{-2}. The Qfd aquifer executed highest T and S value at approximately 94.80 square metre/day and 157.00 respectively. Cmm aquifer performed highest K at around 25.50 metre/day.

By illustrating the pumping test well locations/points in the map or overlaying them with hydrogeological data layer, we could get hydraulic properties distribution as exhibited in Figure 12.

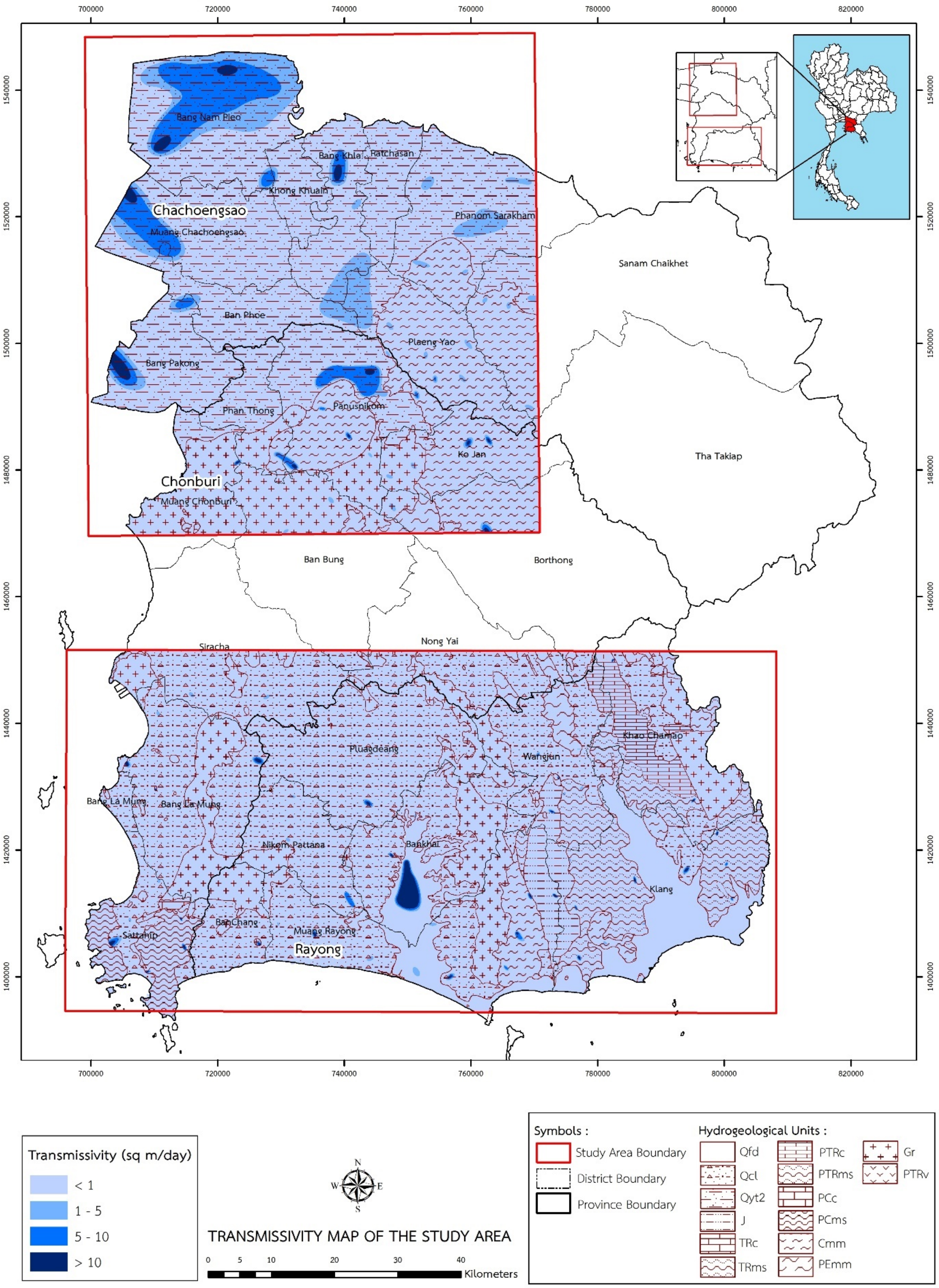


Figure 12 Hydraulic Properties of Aquifers

4.1.3 Mathematical Modelling

4.1.3.1 Model of Sattahip District, Chonburi Province

1) Hydrogeological Conceptual Model

The conceptual model of the study area (Figure 13) has groundwater divide in the east, surface water boundary in the north, and marine zone in the west and south. The main flow direction of groundwater is from the recharge area (with hydraulic head 30-80 m. MSL) to the discharge area which is the valley in the central and the upper-west side of the study area (with hydraulic head less than 30 m. MSL).

Therefore, it could conclude that the flow direction is controlled by topography and groundwater usage. The salinity of groundwater is also related to the characteristics of groundwater flow as total dissolved solids (TDS) in the recharge area is lower than in the discharge area, especially in the south seashore and the upper-west part of the study area which mainly are sand-gravel aquifers. The water in these areas is brackish to saline because of saltwater intrusion.

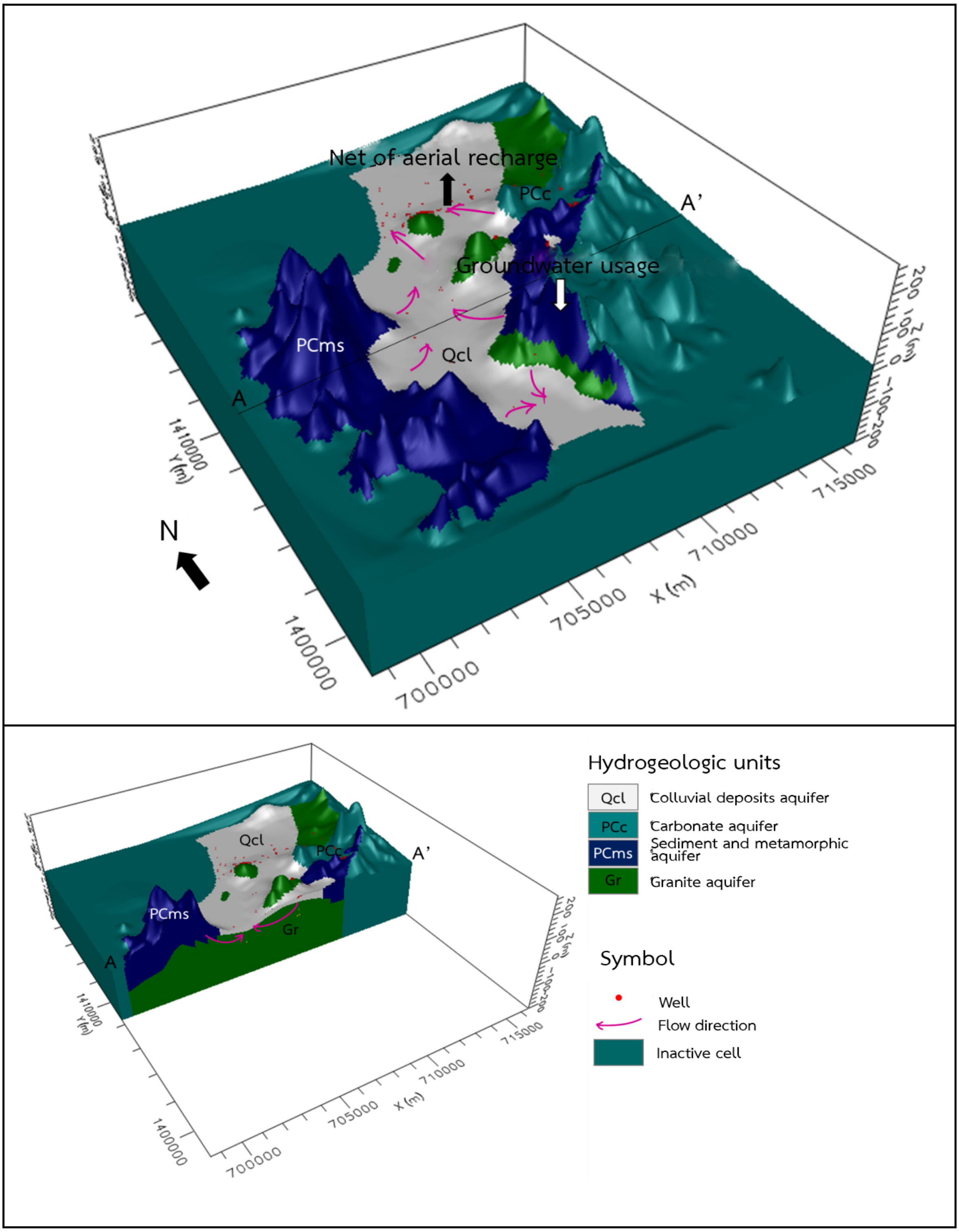


Figure 13 Hydrogeological Conceptual Model of Groundwater Sources, Sattahip District

2) Simulation of Current Groundwater Salinity Distribution

To simulate groundwater salinity distribution, after the data are imported and processed, we need to calibrate the Dispersivity values. The calibration continued adjusting until the calibrated Total Dissolved Solids (TDS) values are consistent, in the acceptable range, with the TDS values collected from the fieldworks. The research team used the TDS data collected from 33 observed groundwater wells during April-December 2020 and adjusted the data to be within their own possible range by increasing or decreasing the data, one batch at a time, using trial-and-error method until the TDS values from fieldworks and the calibrated TDS values are as close as possible. The simulation gave us Dispersivity values from calibration as presented in Figure 14. The mean error of the simulation was approximately 128.92 mg/l and a deviation of 12.19% (Figure 15).

From the simulation of groundwater salinity distribution using 3D mathematical modelling, the calibrated TDS values are consistent with the result from conceptual model because the areas with TDS higher than 1,000 mg/l distribute on the beach in the west, and the upper and south of Sattahip District.

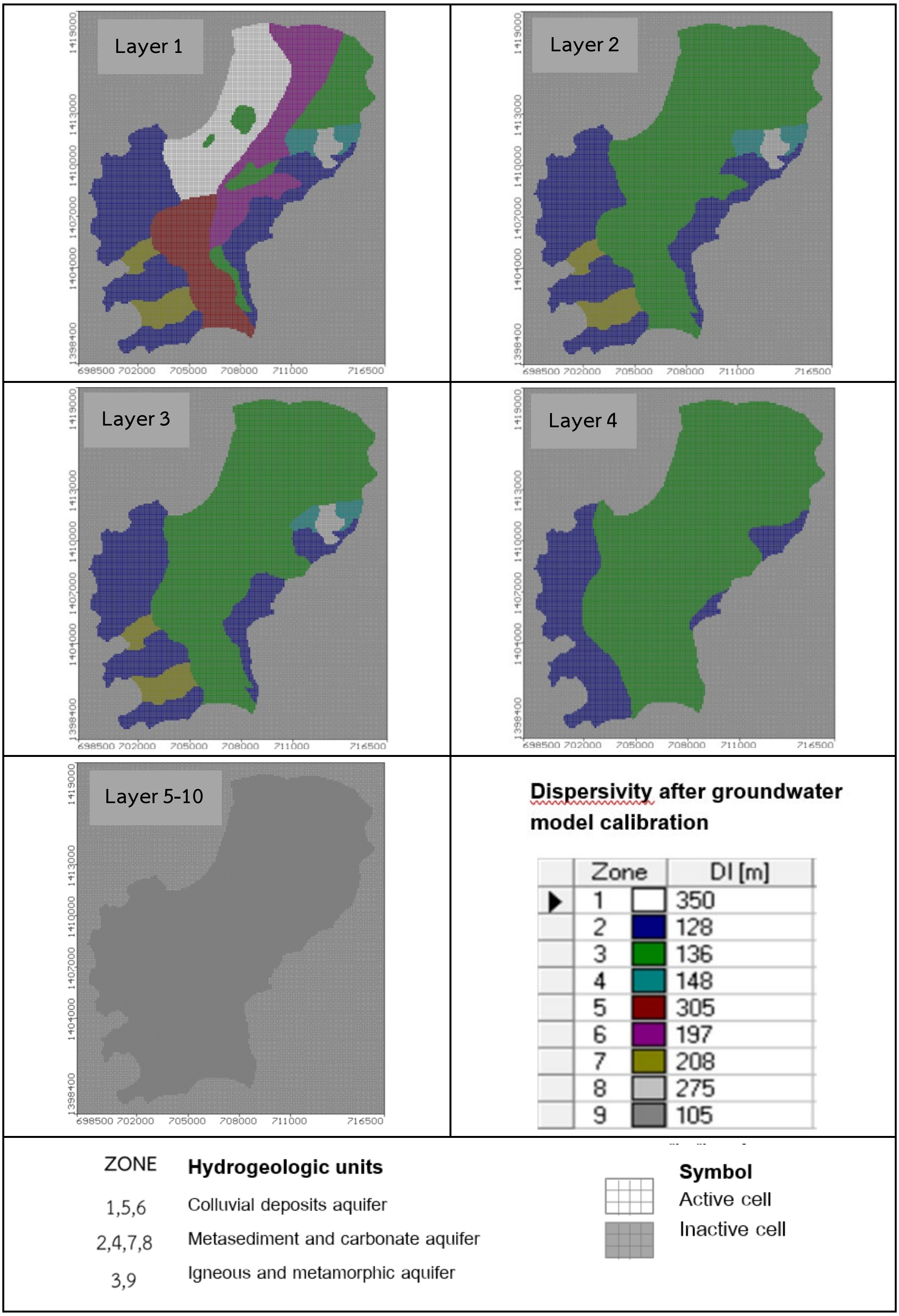


Figure 14 Dispersivity Values Using Model Calibration, Sattahip District

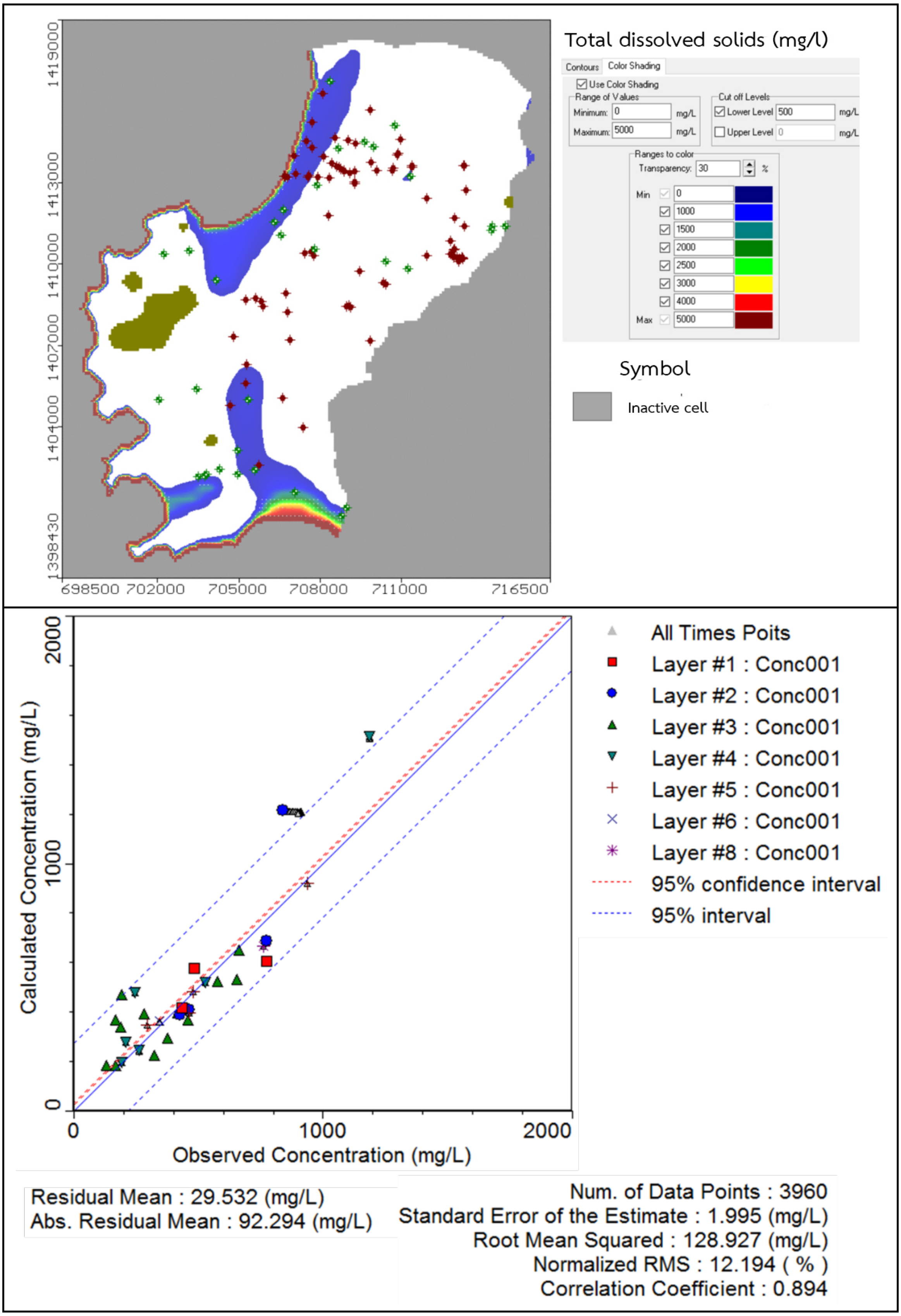


Figure 15 Total Dissolved Solids (TDS) Using Model Calibration, Sattahip District

3) Groundwater Potential Simulation, Sattahip District

Sustainable groundwater use concept was applied to groundwater management by using undesirable results from groundwater overuse, such as groundwater-level declines, water quality degradation, and land subsidence, as sustainability indicators regarding groundwater usage and hydrogeological properties of the area. For sustainable groundwater use, environmentally and economically, groundwater from unconsolidated and consolidated aquifers in Sattahip District were developed and managed for households, industrial, and agricultural use.

Therefore, this study has defined safe level of groundwater use (safe yield) under increasing groundwater demand. The definition of "safe yield" is the highest yield of existing wells that could be pumped in 10 years (2021-2031) with minimum drawdown at 20 metres and TSD not exceed 1,000 mg/l.

The estimation shows the areas with amount of developable groundwater at 1) higher than 20 cubic metre/hour, scattering in southeast of Na Chom Tian Sub-district; 2) 10-20 cubic metre/hour, scattering in central valley in Sattahip Sub-district; and 3) 2-10 cubic metre/hour, scattering in west of Huai Yai and Na Chom Tian Sub-district, and from central of Bang Sare Sub-district through central of Sattahip District as shown in Figure 16.

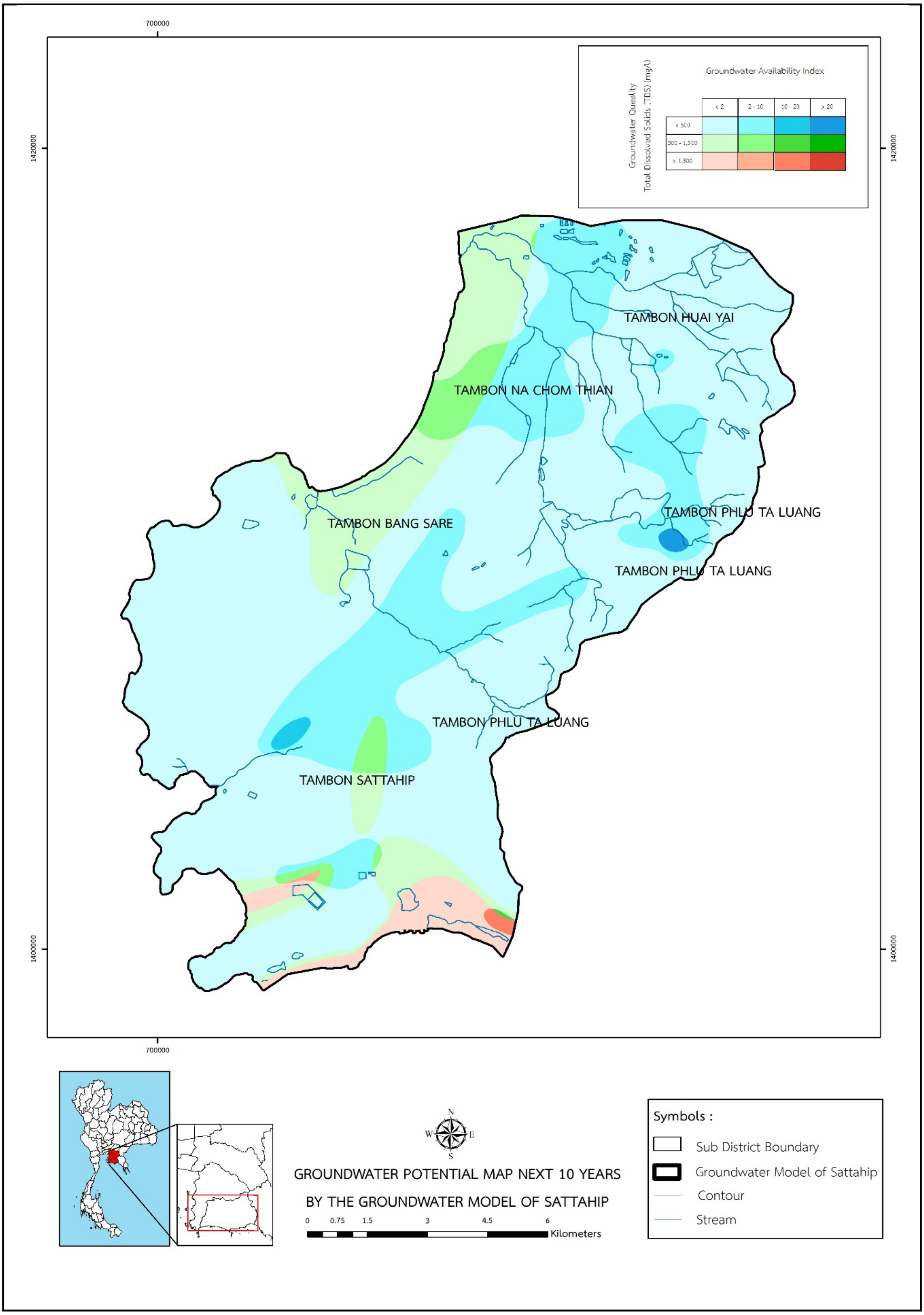


Figure 16 Groundwater Potential Map of Sattahip District, Using Groundwater Model

4.1.3.2 Model of Rayong Basin

1) Hydrogeological Conceptual Model

Hydrogeological characteristics of aquifers in the study area could be classified into 2 units as unconsolidated units and consolidated units. The unconsolidated units included alluvial deposits, young terrace deposits, and old terrace deposits, which are distributed along the north-south direction in central part of Ban Khai and Mueang Rayong District with 7 kilometres width, 21 kilometres length, and more than 400 metres thickness. These deposits were lying over colluvium deposits that are mainly found in Ban Chang District, Nikhom Pattana District, Pluak Daeng District, west of Mueang Rayong District, and north and west of Ban Khai District. These unconsolidated aquifers overlayed on igneous rocks, mostly granitic rocks (Figure 17). The shallow unconsolidated aquifers were unconfined aquifers while the deeper aquifers were both confined and semi-confined aquifers. This led to different hydraulic conductivity (K) values. Generally, groundwater flows easily through horizon high K value bed.

The conceptual model of the study area has groundwater divide in the north, east, and west, while the gulf of Thailand is located in the south. Groundwater mainly flows from the recharge area (with hydraulic head 40-120 m. MSL) to the discharge area which is the alluvial plain.

Thus, it could conclude that the flow direction is controlled by topography and groundwater usage. The salinity of groundwater is also related to the characteristics of groundwater flow as total dissolved solids (TDS) in the recharge area is lower than in the discharge area, especially in the south and southeast seashores where the water is brackish to saline because of saltwater intrusion.

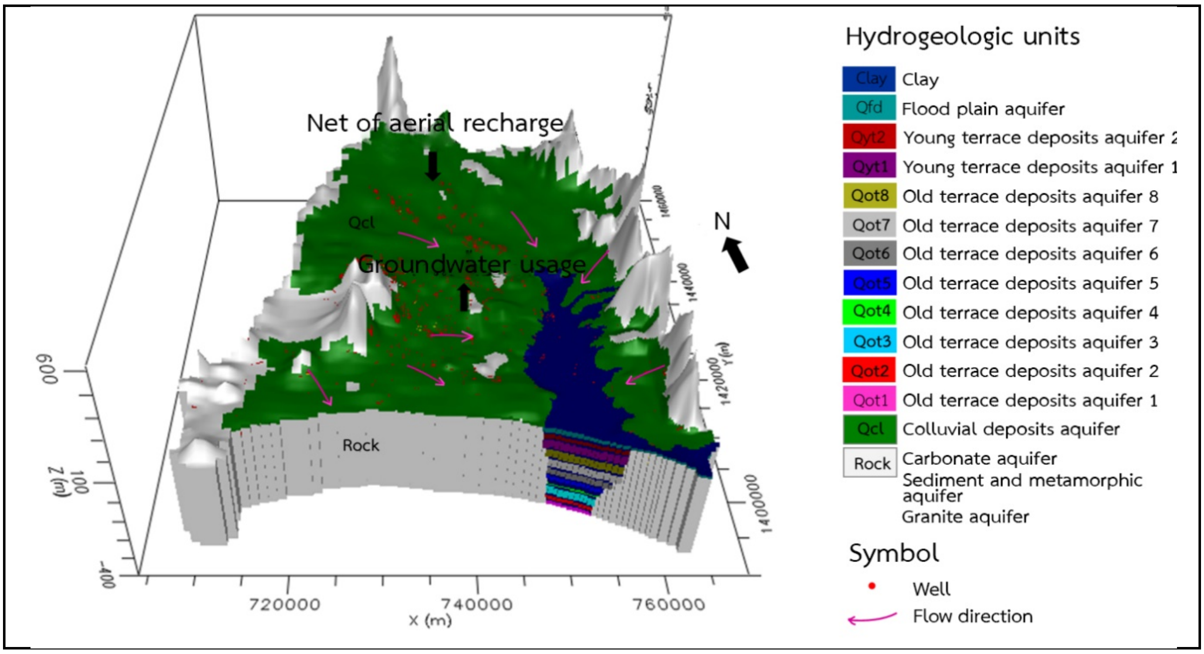


Figure 17 Hydrogeological Conceptual Model, Rayong Basin

2) Simulation of Current Groundwater Salinity Distribution

To simulate groundwater salinity distribution, after the data are imported and processed, we need to calibrate the Dispersivity values. The calibration continued adjusting until the calibrated Total Dissolved Solids (TDS) values are consistent, in the acceptable range, with the TDS values collected from the fieldworks. The research team used the TDS data collected from 33 observed groundwater wells during April-December 2020 and adjusted the data to be within their own possible range by increasing or decreasing the data, one batch at a time, using trial-and-error method until the TDS values from fieldworks and the calibrated TDS values are as close as possible. The simulation gave us Dispersivity values from calibration as presented in Figure 18. The mean error of the simulation was approximately 116.78 mg/l and a deviation of 8.85% (Figure 19).

From the simulation of groundwater salinity distribution using 3D mathematical modelling, the calibrated TDS values are consistent with the result from conceptual model because the areas with TDS higher than 1,000 mg/l distribute on the beach in the southeast of the study area.

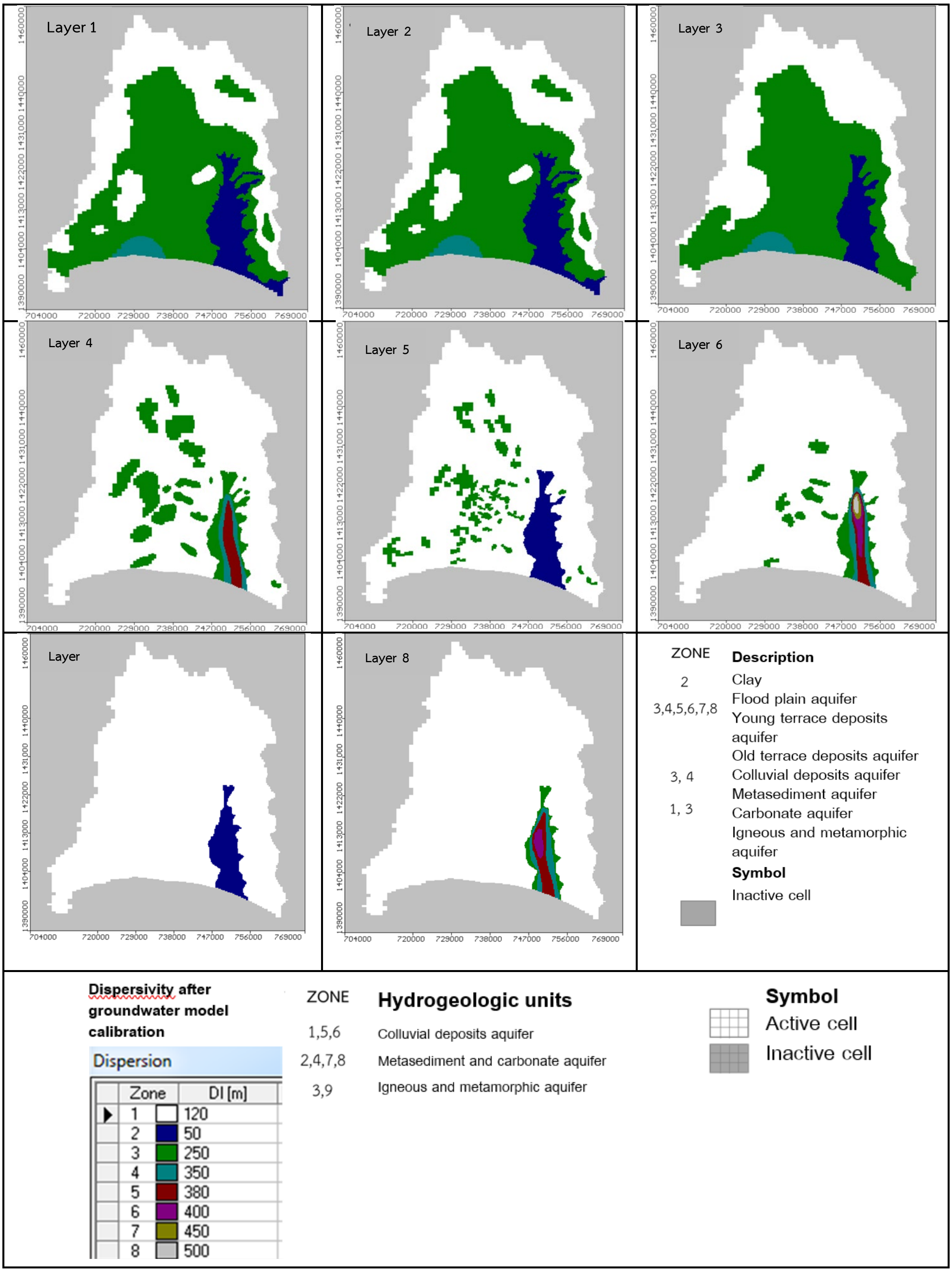


Figure 18 Dispersivity Values Using Model Calibration, Rayong Basin

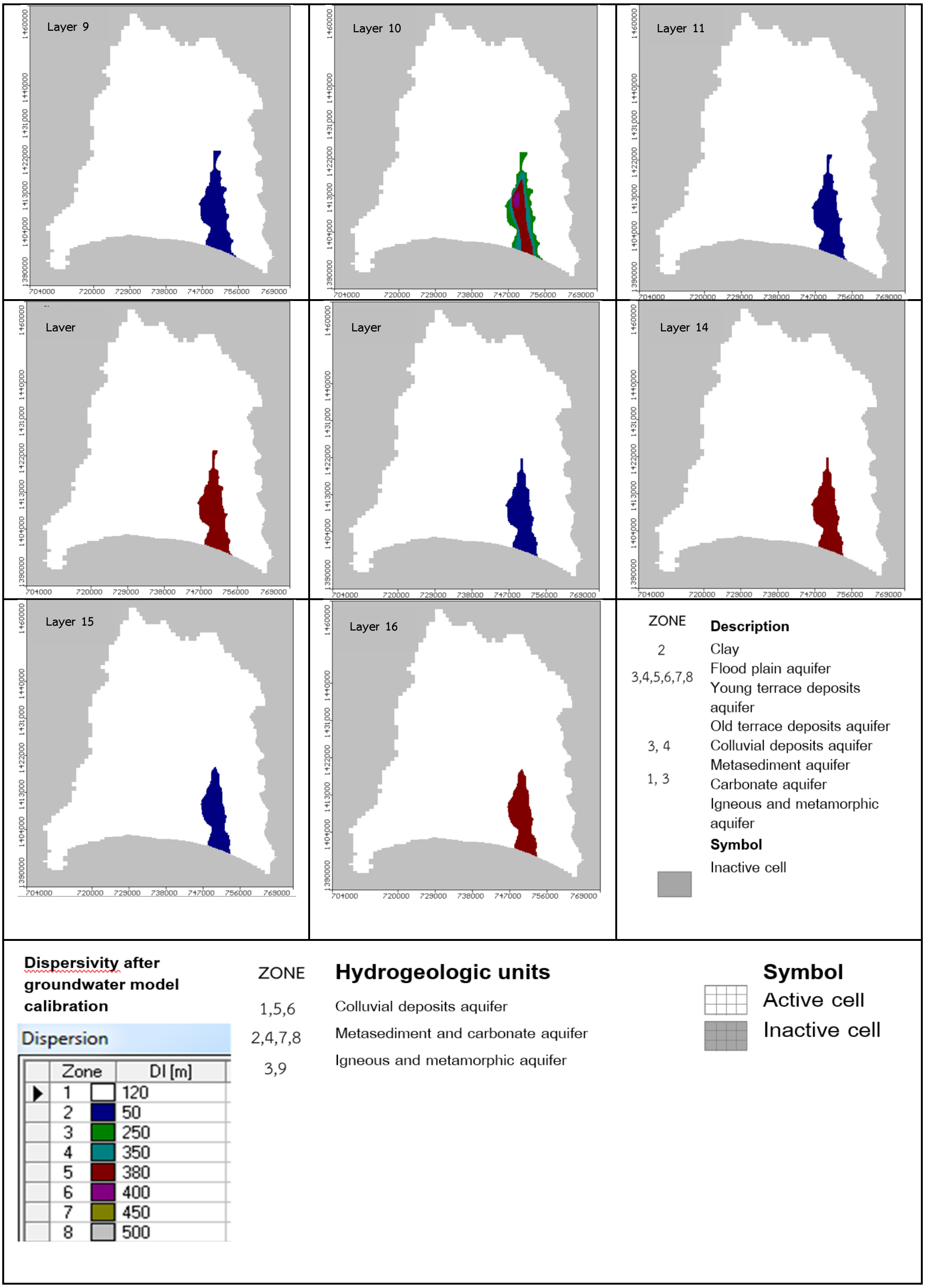
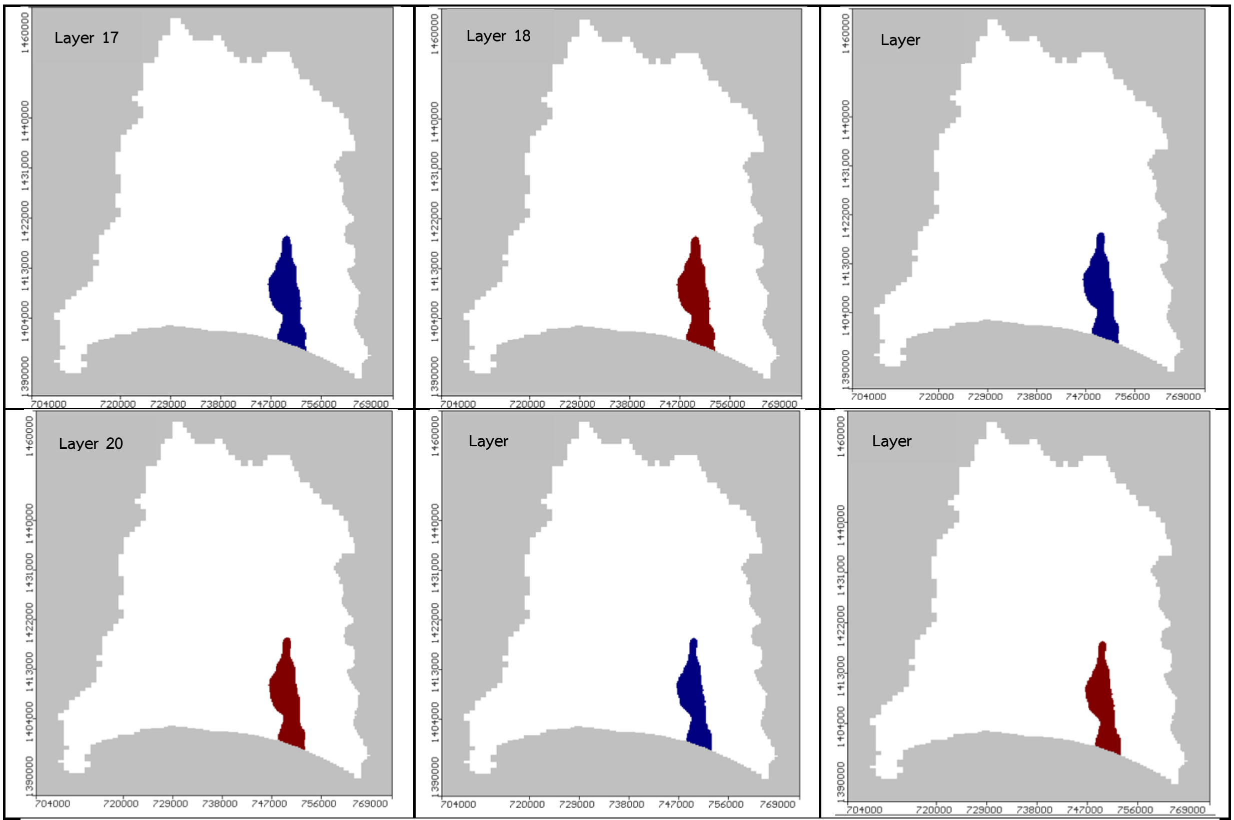


Figure 18 Dispersivity Values Using Model Calibration, Rayong Basin (Cont.)



Hydraulic conductivity (K) and Storativity (S) after groundwater model calibration

Zone	Kx [m/s]	Ky [m/s]	Kz [m/s]
1	1.16E-6	1.16E-6	1.16E-8
2	1E-10	1E-10	1E-11
3	2.79E-6	2.79E-6	2.79E-8
4	5.16E-6	5.16E-6	5.16E-7
5	1.31E-5	1.31E-5	1.31E-6
6	4.79E-5	4.79E-5	4.79E-6
7	5.32E-5	5.32E-5	5.32E-7
8	8.31E-5	8.31E-5	2.31E-6

Zone	Ss [1/m]	Sy []	Eff. Por. []	Tot. Por. []
1	5.05E-6	0.05	0.05	0.1
2	1E-7	1E-6	0.2	0.3
3	2.25E-5	0.1	0.15	0.2
4	0.0001	0.18	0.15	0.2
5	3.2E-5	0.19	0.15	0.2
6	4.1E-5	0.2	0.15	0.2
7	0.00015	0.22	0.15	0.2
8	0.00025	0.25	0.15	0.2

Dispersivity after groundwater model calibration

Dispersion

Zone	Dl [m]
1	120
2	50
3	250
4	350
5	380
6	400
7	450
8	500

ZONE	Hydrogeologic units
1,5,6	Colluvial deposits aquifer
2,4,7,8	Metasediment and carbonate aquifer
3,9	Igneous and metamorphic aquifer

Symbol

Active cell

Inactive cell

Figure 18 Dispersivity Values Using Model Calibration, Rayong Basin (Cont.)

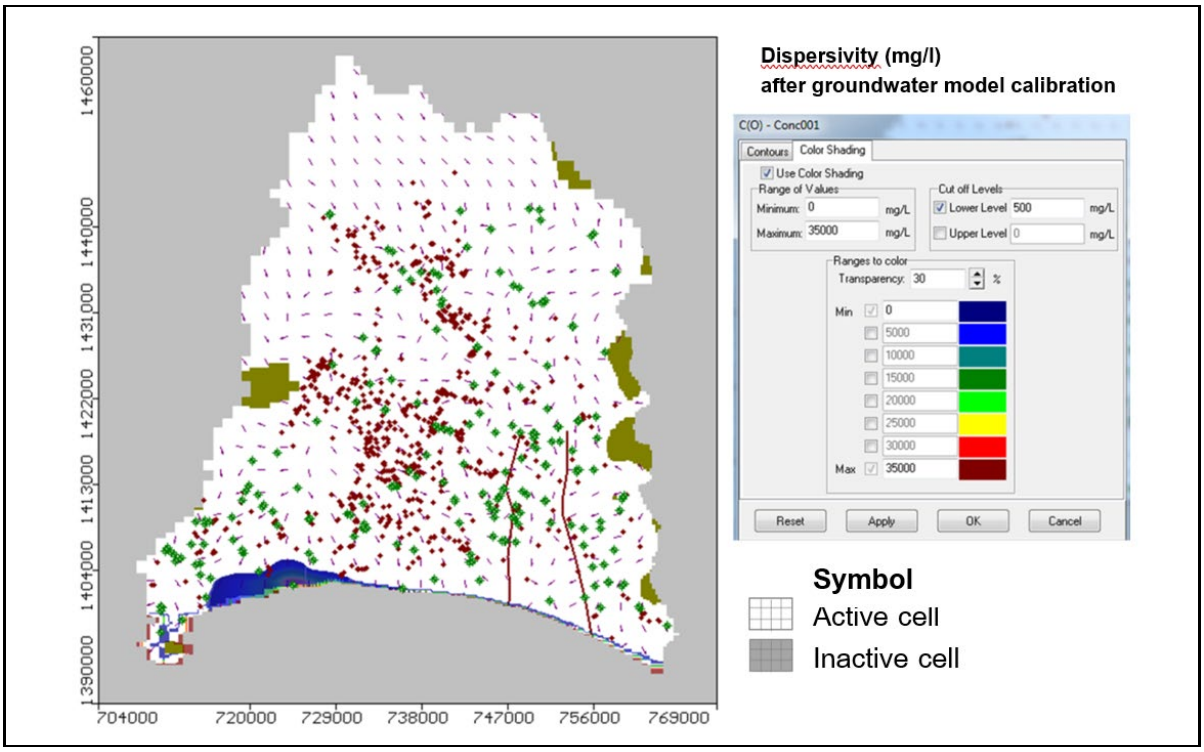


Figure 19 Hydraulic Properties Using Model Calibration, Rayong Basin

3) Assessment of Groundwater Potential of Rayong Basin, Using Groundwater Modelling

The assessment found that there are several potential areas with developable groundwater amount 1) higher than 20 cubic metre/hour dispersing in central part of Ban Khai District along Klong Yai river basin; 2) between 10-20 cubic metre/hour dispersing along Klong Yai river basin near central part of Ban Khai District and Mueang Rayong District; and 3) between 2-10 cubic metre/hour widely dispersing in some part of Mueang Rayong, Ban Khai, Pluak Daeng, Nikhom Pattana, and Ban Chang District as can be seen in Figure 20.

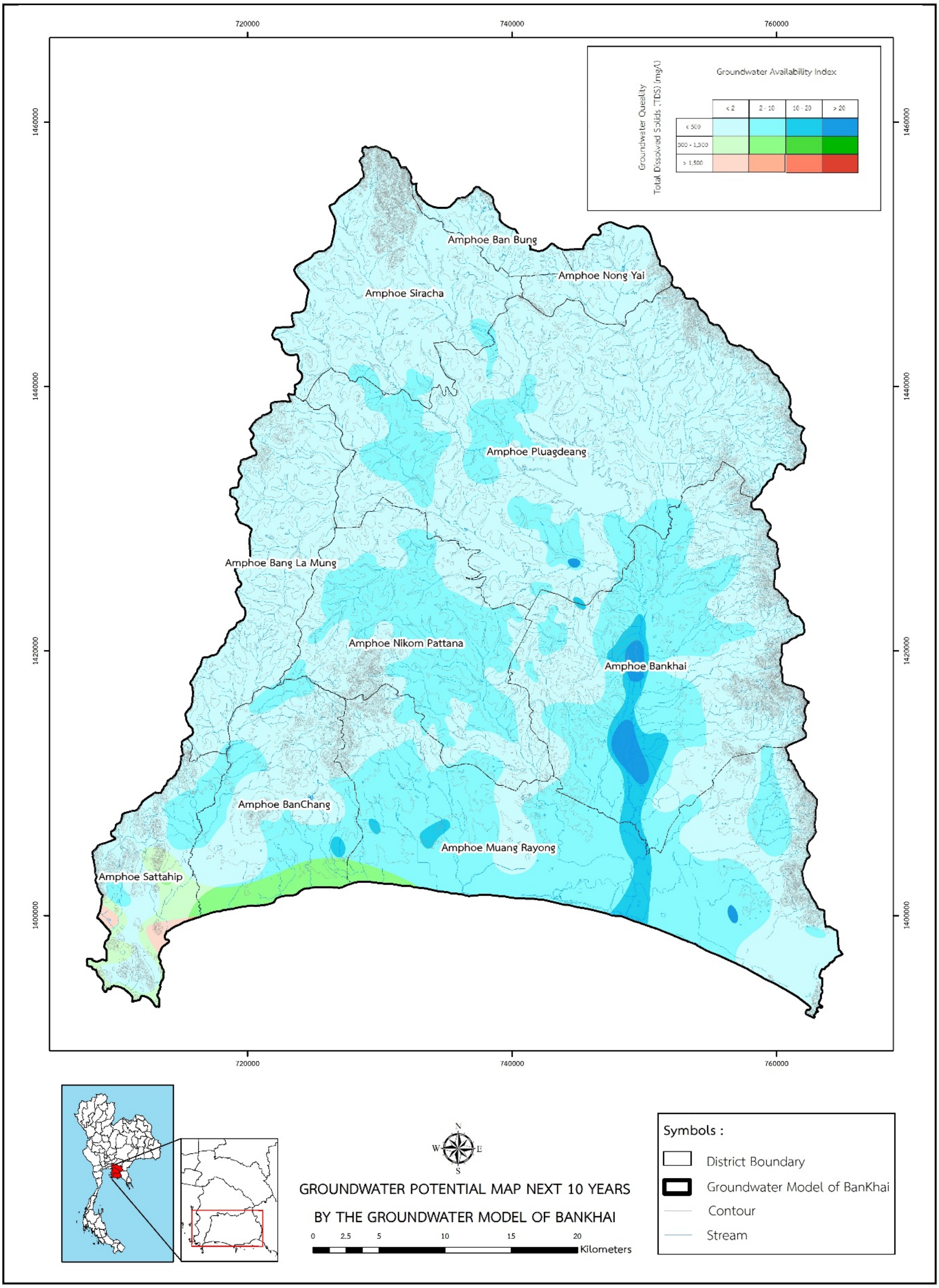


Figure 20 Groundwater Potential Map of Rayong Basin, Using Groundwater Model

4.1.4 Groundwater Data Generation

4.1.4.1 Groundwater level

Data layers of groundwater level of the study area are shown in Figure 21.

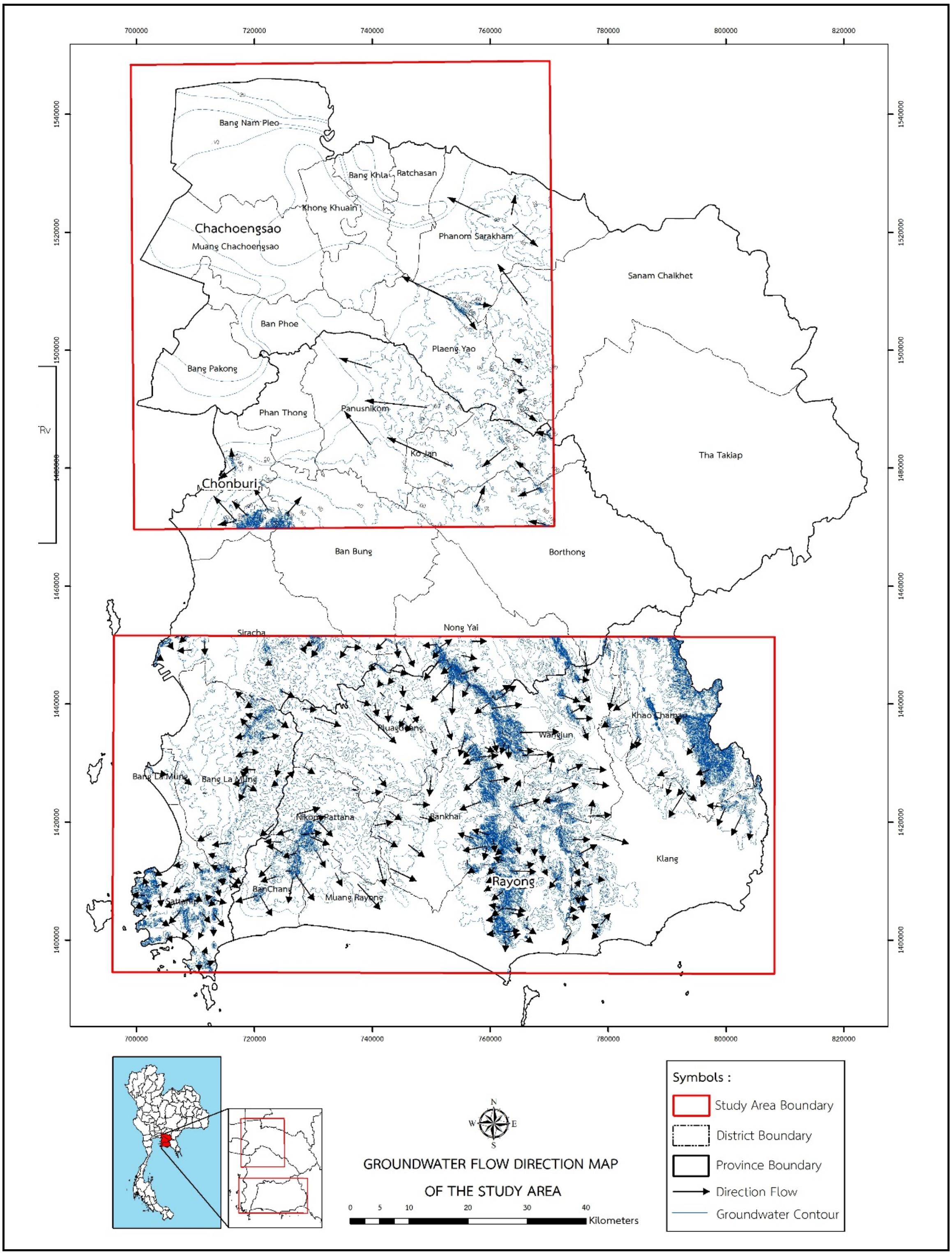


Figure 21 Groundwater Levels and Groundwater Flows

4.1.4.2 Groundwater Availability Data Set

Data layers of maximum yield in the study area are shown in Figure 22, while data layers of specific yield are shown in Figure 23.

4.1.4.3 Groundwater Quality Data Set

Groundwater quality data set consists of Total Dissolved Solids (TDS) Map, Total Hardness Map, Iron (Fe) Content Map, Chloride Content Map, and Nitrate (NO_3) Map, as can be seen in Figure 24 - 28 respectively.

4.1.4.4 Groundwater Availability Map (GWAV)

Groundwater Availability Map (GWAV) of the upper study area found that most of the west of Chachoengsao Province had Max Yield 2-10 / TDS > 1,500, the Central of Chachoengsao Province, in Bang Khla, Ratchasan, Plaeng Yao, Ban Pho, and Phanom Sarakam District, had Max Yield 2-10 / TDS 500 - 1,500. Some parts of Plaeng Yao, Sanam Chai Khet and Phanom Sarakam District, the west of Chachoengsao Province, had Max Yield < 2 / TDS < 500. For Chonburi Province, most areas had Max Yield < 2 / TDS < 500 and the Max Yield might be slightly different depends on the areas.

The lower study area generally had Max Yield < 2 / TDS < 500 which could be different in each District. The groundwater potential area in Rayong basin, identified from cross-section data and groundwater usage data, had Max Yield > 20 / TDS < 500 as shown in Figure 30.

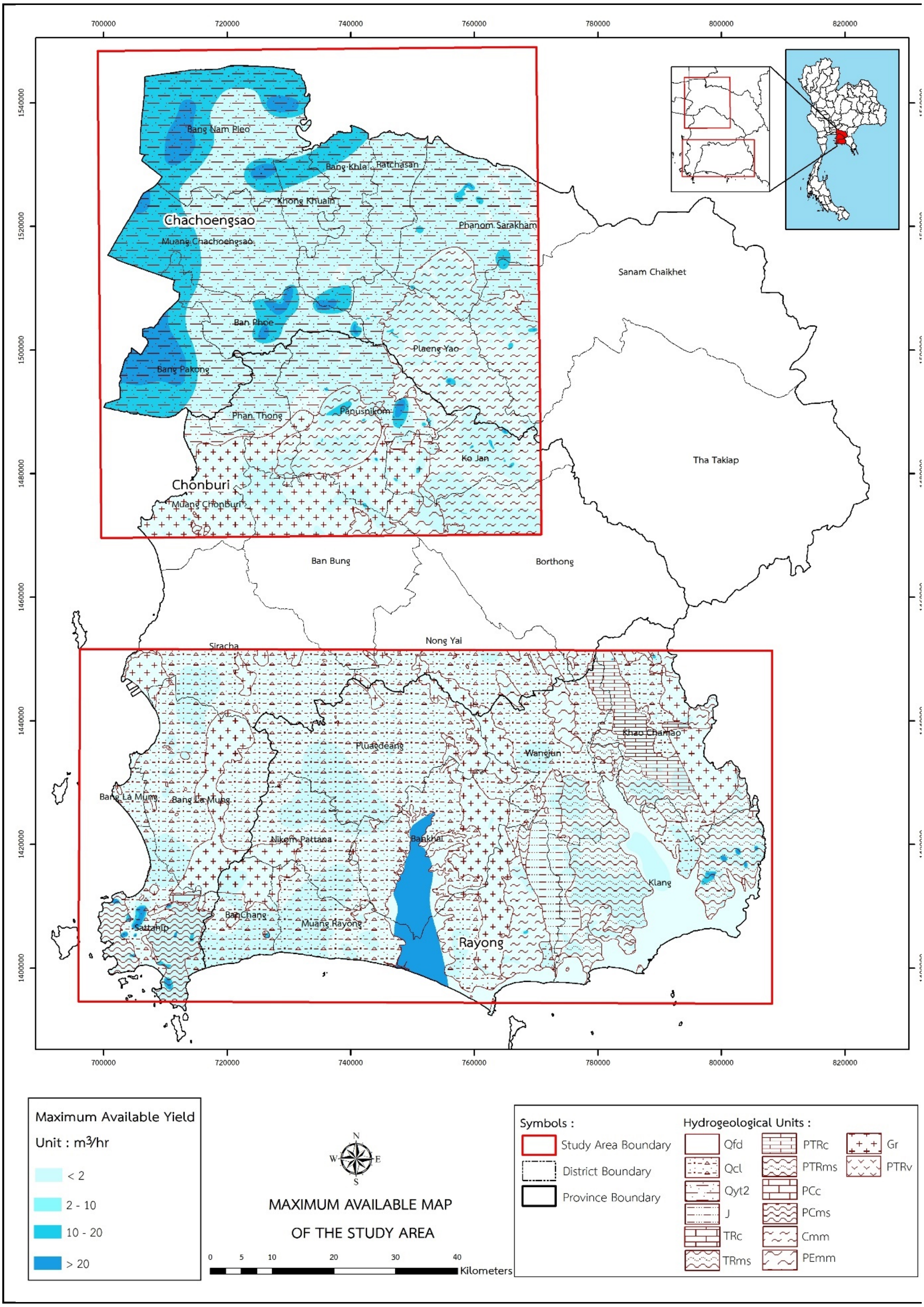


Figure 22 Maximum Yields Map

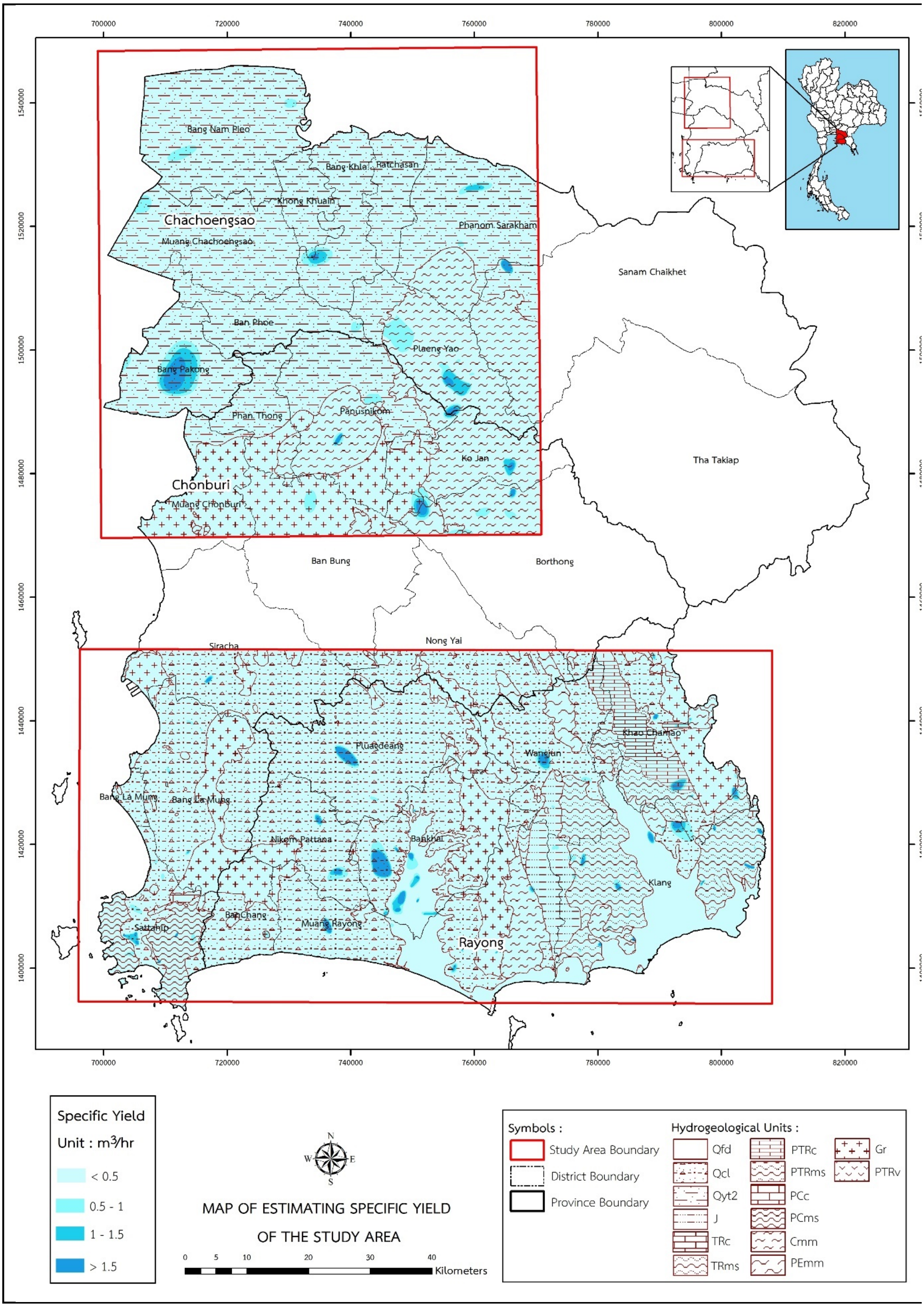


Figure 23 Specific Yields Map

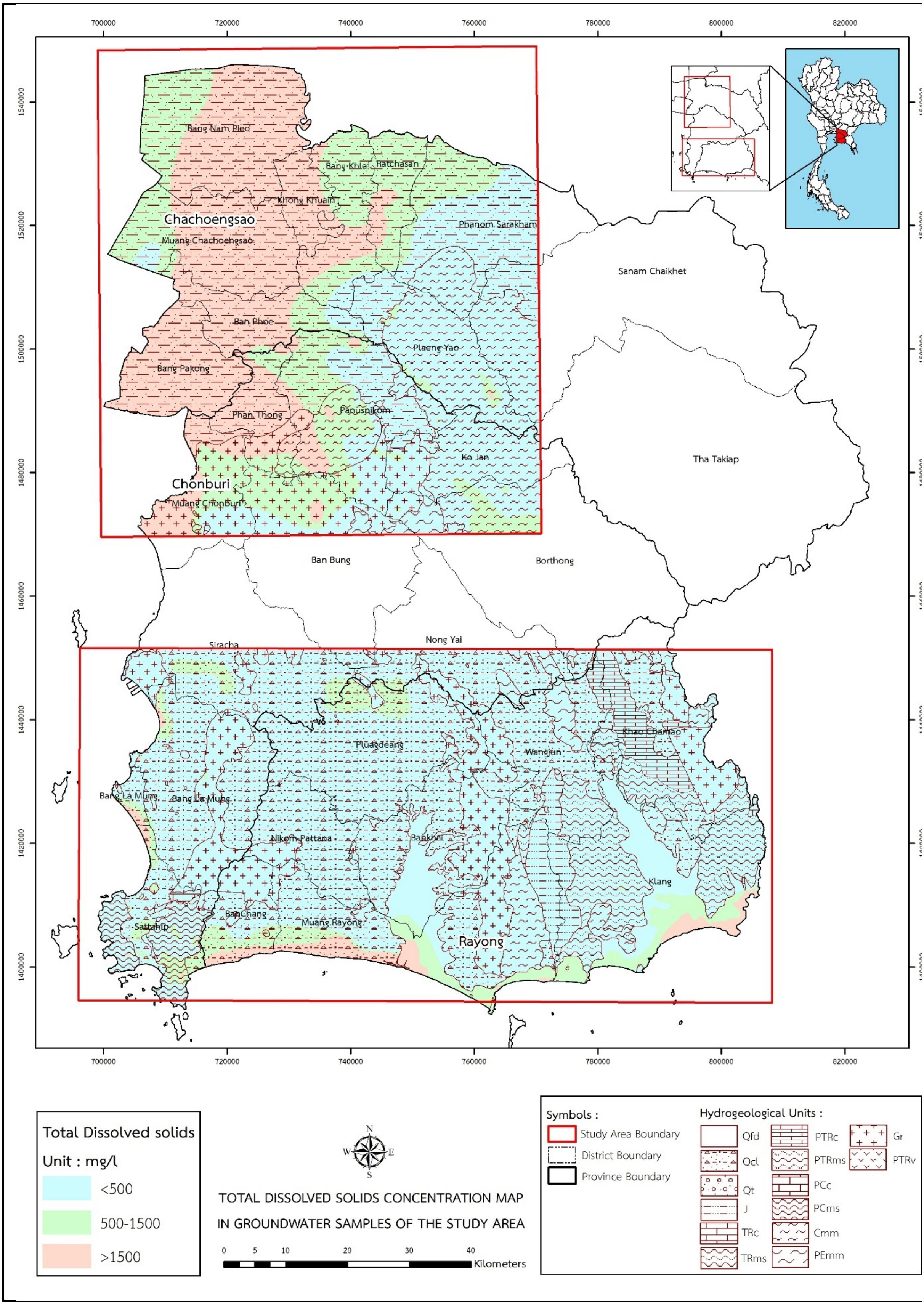


Figure 24 Total Dissolved Solids (TDS) Map

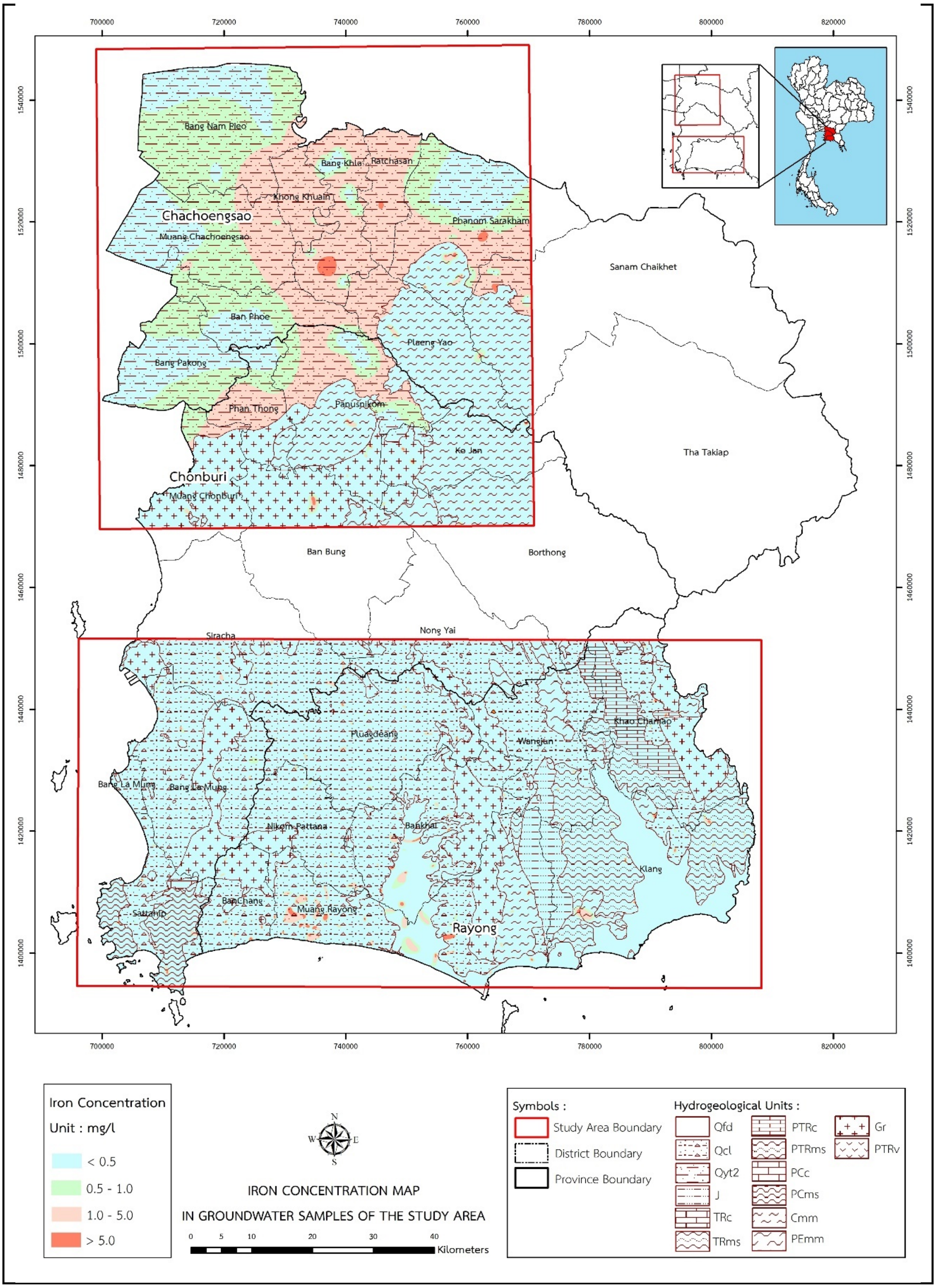


Figure 25 Iron (Fe) Content Map

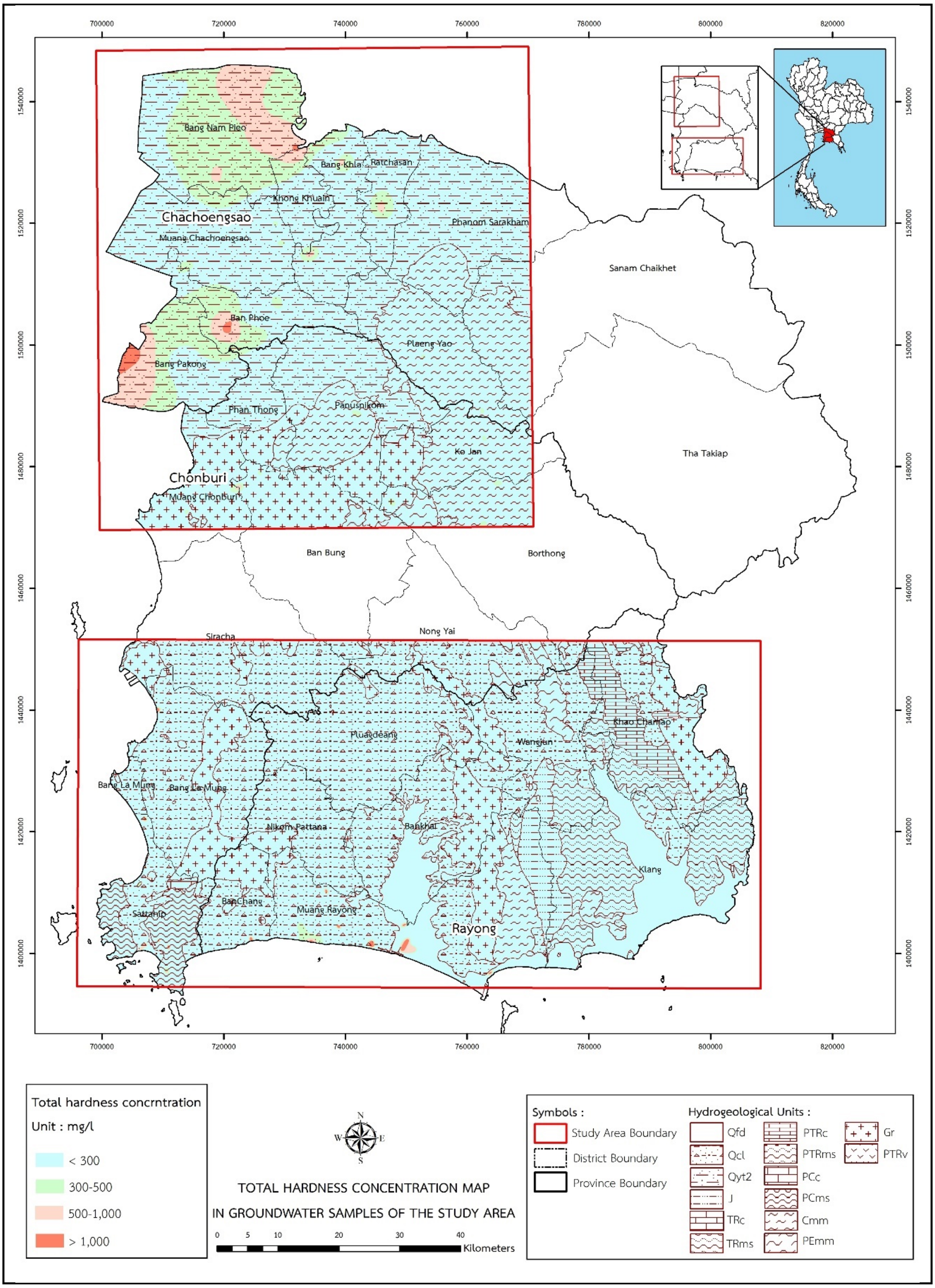


Figure 26 Total Hardness Map

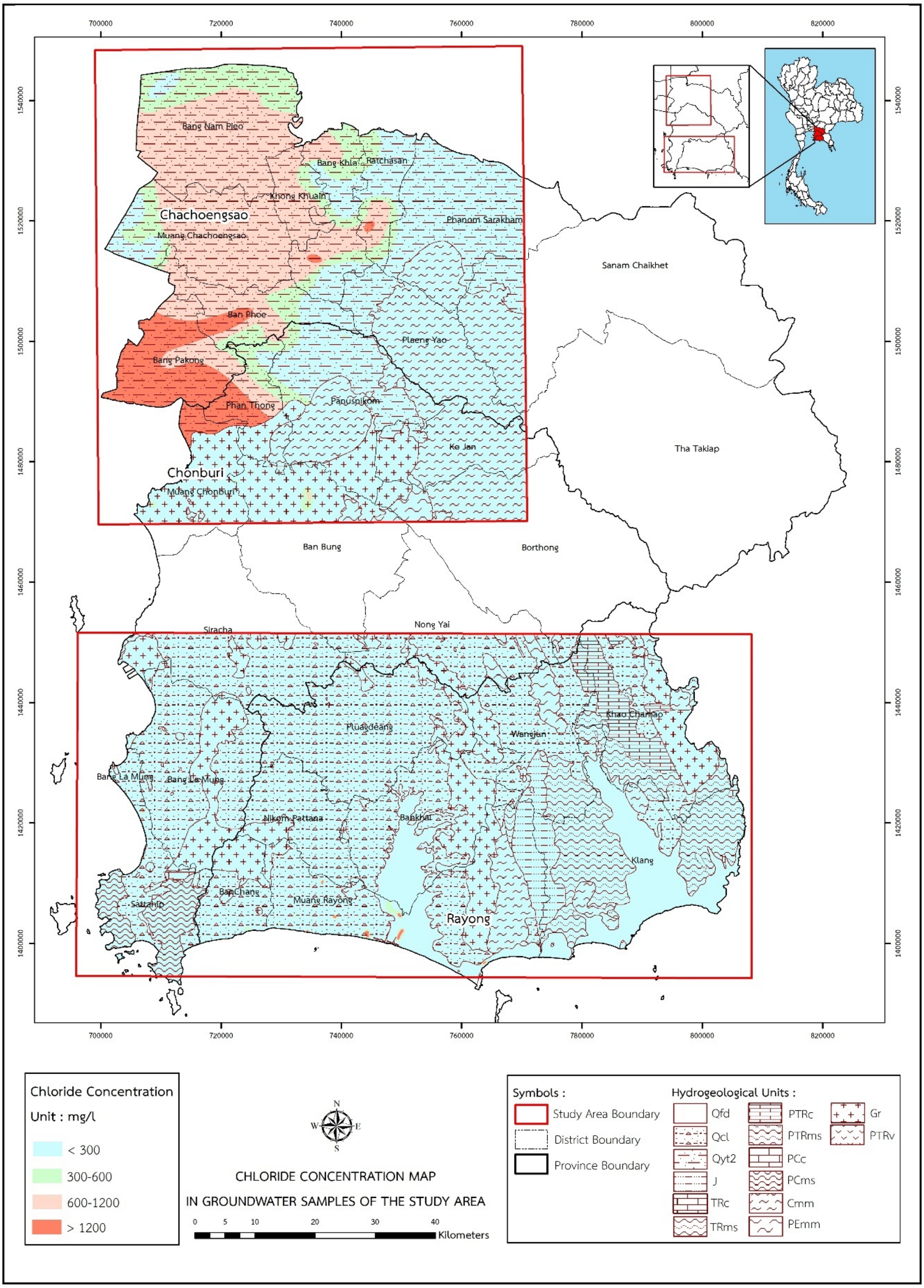


Figure 27 Chloride Content Map

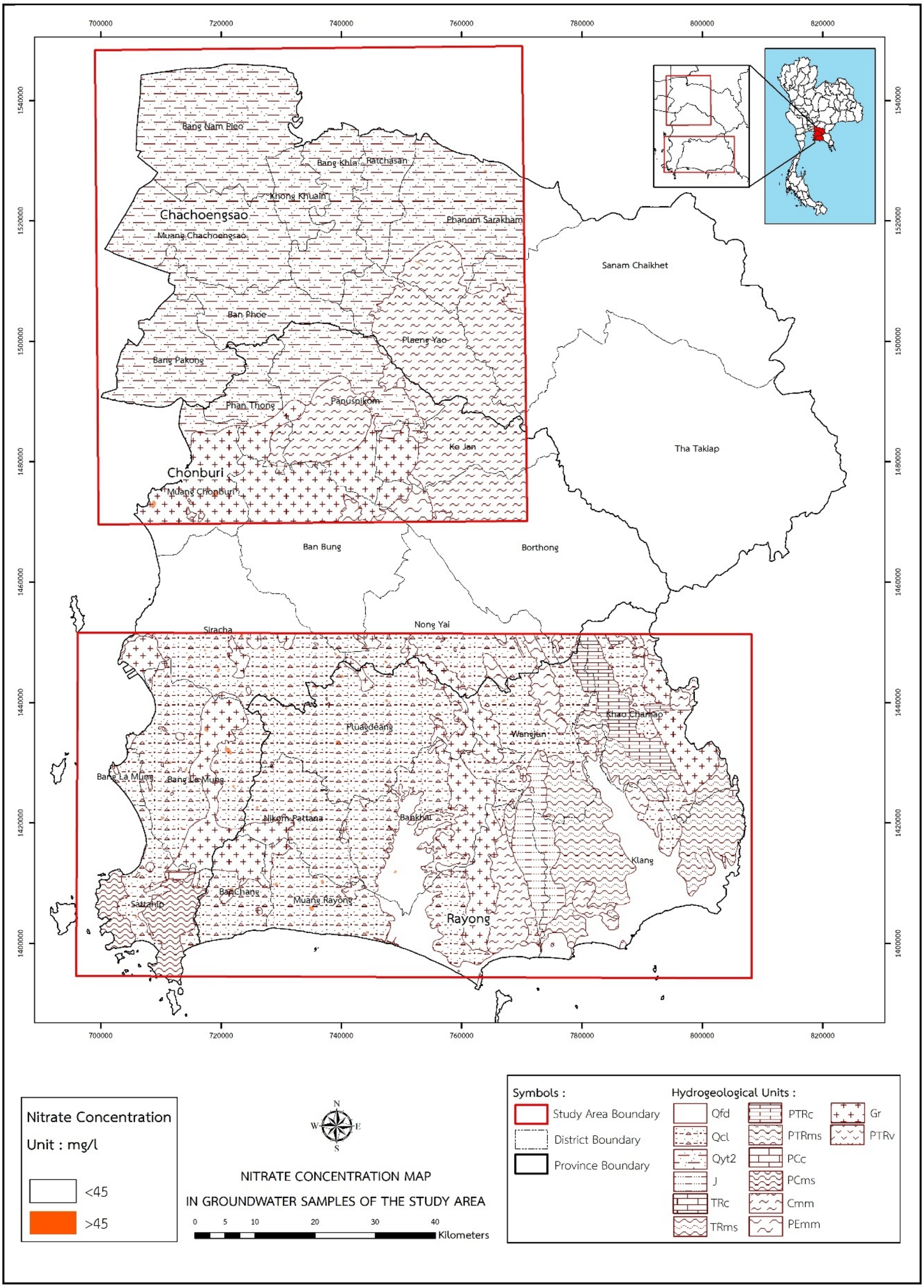


Figure 28 Nitrate (NO_3) Map

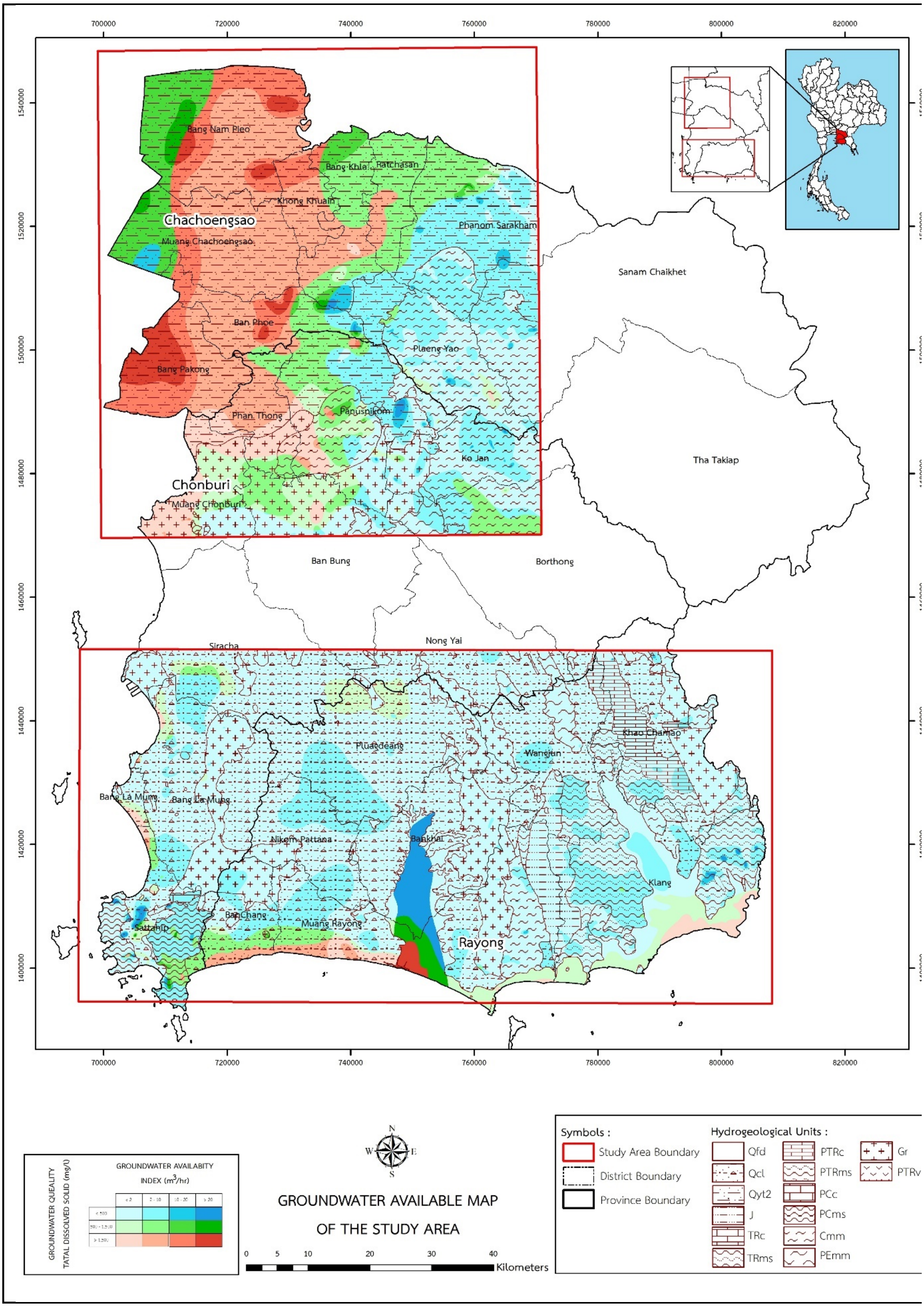


Figure 29 Groundwater Potential Zone Map in EEC Area

4.1.4.5 Quantitative and Qualitative Application of Potential Groundwater Sources

For quantitative and qualitative application of potential groundwater sources, the research team used the groundwater potential zone map to categorise areas that are suitable to develop groundwater based on their hydrogeological potential as shown in Figure 29. The areas are divided into 5 groups as follows.

Urban Development Zone and Commercial Development Zone:

Based on the groundwater potential zone map;

Areas with groundwater amount 2-10 cubic/hour and TDS < 500 ml/l and 10-20 cubic/hour and TDS < 500 ml/l.

Urban Development Zone, Commercial Development Zone, and Industrial Development Zone:

Based on the groundwater potential zone map;

Areas with groundwater amount >20 cubic/hour and TDS < 500 ml/l based on the groundwater potential zone map.

Industrial Development Zone:

Based on the groundwater potential zone map;

Areas with groundwater amount 10-20 cubic/hour and TDS 500-1,500 ml/l

Areas with groundwater amount > 20 cubic/hour and TDS > 1,500 ml/l

Areas with groundwater amount 10-20 cubic/hour and TDS > 1,500 ml/l

Areas with groundwater amount > 20 cubic/hour and TDS > 1,500 ml/l

Natural Resources and Environment Conservation Zone:

Based on the groundwater potential zone map;

Areas with groundwater amount < 2 cubic/hour and TDS 500-1,500 ml/l

Areas with groundwater amount 2-10 cubic/hour and TDS 500-1,500 ml/l

Areas with groundwater amount < 2 cubic/hour and TDS > 1,500 ml/l

Areas with groundwater amount 2-10 cubic/hour and TDS > 1,500 ml/l

Agricultural Zone and Natural Resources and Environment Conservation Zone:

Based on the groundwater potential zone map;

Areas with groundwater amount < 2 cubic/hour and TDS < 500 ml/l

Areas with groundwater amount 2-10 cubic/hour and TDS < 500 ml/l

After mapping the groundwater potential zones, the research team used the land use scope of 2037 (Department of Public Works and Town and Country Planning, 2019) to be overlayed to create the land use map as displayed in Figure 31, with the classification of land use as follows.

1. Urban Zone
2. Special Economic Promotion Zone for Industrial Development
3. Commercial Centre Zone
4. Special Economic Promotion Zone for Special Targeted Industries

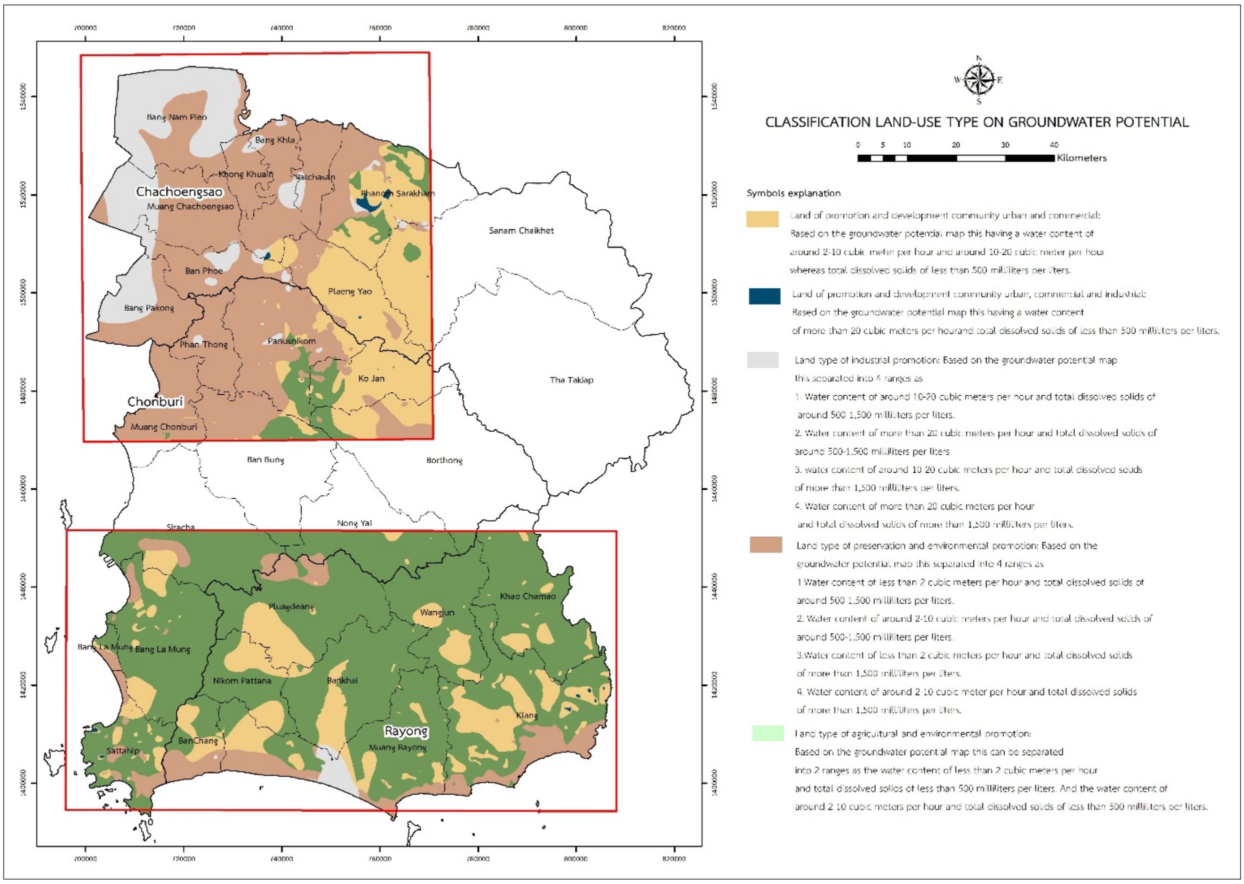


Figure 30 Suitable Areas for Groundwater Development by Land Use Classification

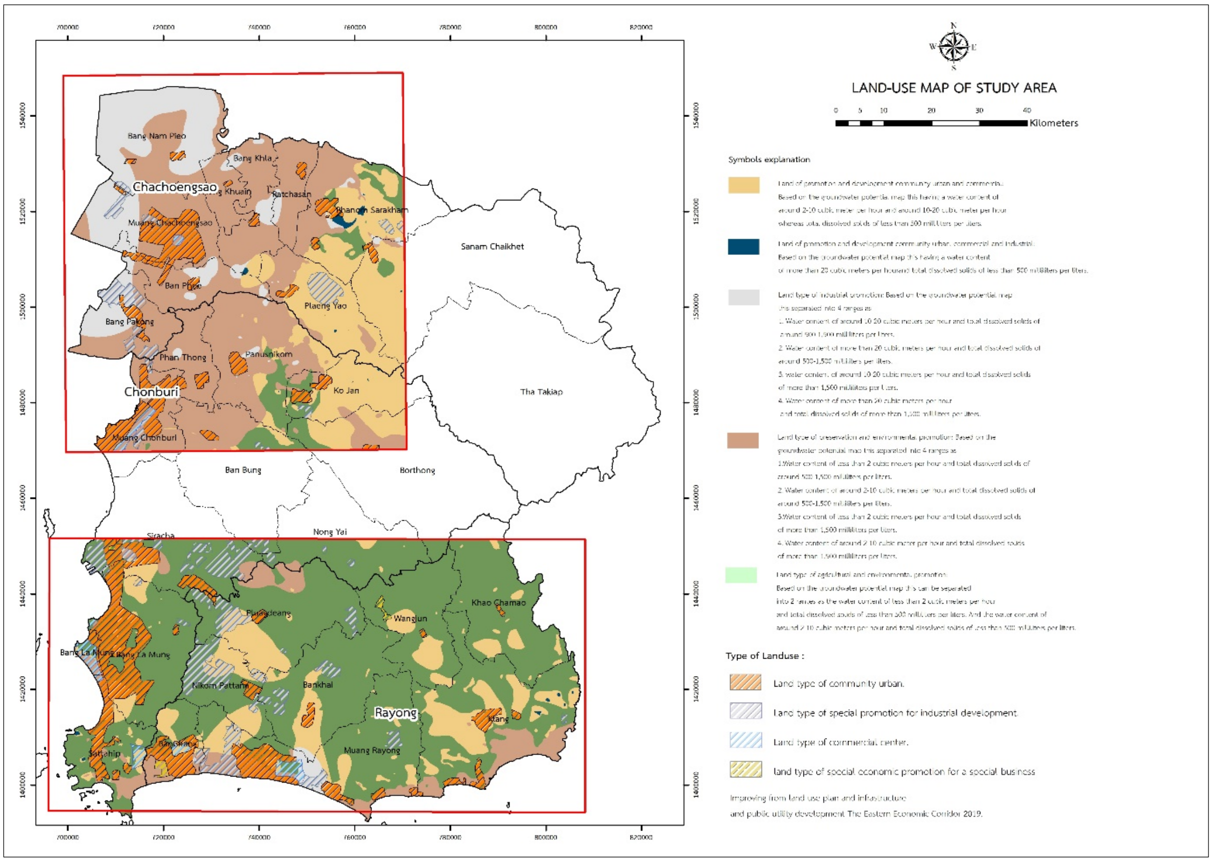


Figure 31 Land Use Map

4.1.5 Groundwater Potential Assessment (Quantitative and Qualitative)

Groundwater potential assessment in EEC area covering Chachoengsao, Chonburi, and Rayong Province, is conducted by analysing groundwater sources detailed map at 1:50,000 scale with the hydrogeological conceptual models of Sattahip District and Rayong-Ban Khai Basin to estimate developable groundwater amount without causing any long-term problems to aquifers because water demand tends to increase from urban development, industrial development, and agricultural expansion.

The analysis begins with hydrogeological study by collecting and analysing hydrogeological data and fieldworks data, then mapping the groundwater sources map to show groundwater amount that could be developed sustainably. The calibrated groundwater models were used to assess potential of aquifers for safe yield estimation, using the simulation result as a criterion. After that, the research team started pumping test in various areas of each aquifer with condition that the drawdown must not reduce lower than 20 metres and TDS must not exceed 1,000 mg/l in the next 10 years.

Subsequently, the research team generated the sustainable groundwater use map to evaluate the developable groundwater amount by District which could be used for groundwater management and planning in EEC area, in terms of identifying groundwater sites and safe level of groundwater use. The results are shown in Table 2.

From Table 2, there are 5 potential Districts, namely Bang Nam Priao District and Phanat Nikhom District of Chachoengsao Province; Sattahip District of Chonburi Province; Ban Khai District, and Mueang Rayong District of Rayong Province. Additionally, according to the groundwater sources map by District, even though some Districts have high amount of developable groundwater, the water quality was poor (Table 3).

Table 2 Amount of Developable Groundwater by District in EEC Area

Province	District	Water storage (million cubic metres)*	Water Added to Groundwater Source Annually (million cubic metres/year)*	Amount of Developable Groundwater (Estimated by Depth) (cubic metre/year)	Total Dissolved Solids (mg/l)
Chachoengsao	Khlong Khuean	650	14	10,372,509	TDS>1,000
	Bang Khla	1,429	32	23,400,103	TDS>1,000
	Bang Nam Priao	3,013	66	51,797,413	TDS>1,000
	Bang Pakong	1,579	35	23,909,331	TDS>1,000
	Ban Pho	1,281	28	19,002,951	TDS>1,000
	Plaeng Yao	766	44	8,691,805	TDS<1,000
	Phanom Sarakham	2,429	68	26,409,676	TDS<1,000
	Mueang Chachoengsao	1,956	52	38,666,222	TDS>1,000
	Ratchasan	877	19	10,869,884	TDS>1,000
	Sanam Chai Khet	3,220	143	4,074,589	Ban Sang, Nong Yao, Phanom Sarakham, Mueang Kao Sub-district; TDS>1,000
	Total			**131,624,457**	

Table 2 Amount of Developable Groundwater by District in EEC Area (cont.)

Province	District	Water storage (million cubic metres)*	Water Added to Groundwater Source Annually (million cubic metres/year)*	Amount of Developable Groundwater (Estimated by Depth) (cubic metre/year)	Total Dissolved Solids (mg/l)
Chonburi	Ko Chan	286	35	2,450,966	Ko Chan and Tha Bun Mi Sub-district; TDS>1,000
	Bo Thong	1,817	108	2,034,694	Bo Kwang Thong and Wat Suwan Sub-district; TDS>1,000
	Bang Lamung	600	68	1,417,332	Bang Lamung, Huai Yai, Na Kluea, Pattaya, and Pong Sub-district; TDS>1,000
	Ban Bueng	656	77	867,930	Map Phai, Nong Bon Daeng, Nong Chak, Nong Samsak, and Ban Bueng Sub-district; TDS>1,000
	Phanat Nikhom	599	62	1,910,306	Mon Nang, Thung Khwang, Nong Khayat, Na Matum, Ban Chang, Na Wang Hin, Phanat Nikhom, Tha Kham, Wat Luang, Wat Bot, Na Phrathat, Rai Lak Thong, Khok Phlo, and Sa Si Liam Sub-district; TDS>1,000
	Phan Thong	47	22	3,116,487	Khok Khi Non, Bang Hak, Ko Loi, Na Pradu, Bang Nang, Ban Kao, Phan Thong, Nong Tamlueng, Nong Hong, Map Pong, and Nong Kakha Sub-district; TDS>1,000
	Mueang Chonburi	316	32	1,149,750	Khlong Tamru, Nong Mai Daeng, Na Pa, Don Hua Lo, Samnak Bok, Ban Suan, Ban Khot, Bang Pla Soi, Makham Yong, Huai Kapi, Nong Ri, Samet, Ang Sila, Ban Puek, Saen Suk, Nong Khang Khok, and Bang Sai Sub-district; TDS>1,000

Table 2 Amount of Developable Groundwater by District in EEC Area (cont.)

Province	District	Water storage (million cubic metres)*	Water Added to Groundwater Source Annually (million cubic metres/year)*	Amount of Developable Groundwater (Estimated by Depth) (cubic metre/year)	Total Dissolved Solids (mg/l)
	Si Racha	808	80	1,432,926	TDS<1,000
	Sattahip	883	33	3,382,293	Sattahip and Na Chom Thian Sub-district; TDS>1,000
	Nong Yai	454	59	206,771	TDS<1,000
	Total			**17,969,455**	
Rayong	Khao Chamao	665	67	1,137,425	TDS<1,000
	Nikhom Phatthana	466	33	3,440,439	TDS<1,000
	Klaeng	1,365	103	5,044,347	Thang Kwian, Wang Wa, Noen Kho, and Kram Sub-district; TDS>1,000
	Ban Khai	890	67	51,531,866	TDS<1,000
	Ban Chang	312	23	1,927,614	TDS<1,000
	Pluak Daeng	1,088	74	2,587,530	TDS<1,000
	Mueang Rayong	1,201	94	68,583,052	TDS<1,000
	Wang Chan	686	52	530,391	TDS<1,000
	Total			**134,782,664**	

Note * Department of Groundwater Resources (2017)

Table 3 Amount of Developable Groundwater of Selected Districts

District	Province	Water Storage (million cubic metres)*	Water Added to Groundwater Source Annually (million cubic metres/year)*	Developable Groundwater (Estimated by Depth) (cubic metre/year)	Recommended Borehole Depth (metre)
Bang Nam Priao	Chachoengsao	3,013	66	51,797,413	140
Phanom Sarakham	Chachoengsao	2,429	68	26,409,676	120
Sattahip	Chonburi	883	33	3,382,293	80
Ban Khai	Rayong	890	67	51,531,866	140
Mueang Rayong	Rayong	1,201	94	68,583,052	140

Note * Department of Groundwater Resources (2017)

4.2 Water Usage and Water Demand

4.2.1 Water Usage and Water Demand

To understand current water situation in the study area, the research team categorised water demand into 4 groups as 1) for agriculture; 2) for consumption and tourism; 3) for industries; and 4) for ecological conservation. The research team collected relevant secondary data from the study area, such as rainfall, runoff, land utilisation, livestock farming registration, population, tourist number, and factory registration, to analyse the current water demand (2019) and to estimate the water demand in the next 20 years (2039). The study results are as follows.

4.2.1.1 Water Demand for Agriculture

Water demand for agriculture is comprised of demand for agriculture in irrigated and non-irrigated area and demand for livestock farming in 2019 and in 2039 (estimated) of each province in EEC. The result shows that current water demand for agriculture in EEC is 2,767 million cubic metres/year. Chachoengsao has the highest water demand at 1,137 million cubic metres/year, following by Chonburi and Rayong at 841 and 789 million cubic metres/year respectively. In 2039, the water demand for agriculture will increase to 3,383.26 million cubic metres/year as demonstrated in Table 4.

Table 4 Water Demand for Agriculture in EEC

	Water Demand for Agriculture (million cubic metres/year)	
	Current	Estimated
Chachoengsao	1,171.49	1,314.31
Chonburi	679.59	997.29
Rayong	939.21	1,071.66
Total	**2,790.29**	**3,383.26**

4.2.1.2 Water Demand for Consumption and Tourism

Water demand for consumption and tourism is comprised of demand from households living in urban area and demand from households living in rural areas, estimated by standard water consumption rate identified in Basic Minimum Needs Survey. Population data were obtained from Bureau of Registration Administration, Department of

Provincial Administration, Ministry of Interior, and tourist numbers in study area were obtained from Tourism Authority of Thailand. The result shows that current water demand for consumption and tourism in EEC is 137.19 million cubic metres/year. Chonburi has the highest water demand at 92.96 million cubic metres/year, following by Rayong and Chachoengsao at 25.55 and 18.69 million cubic metres/year respectively. In 2039, the water demand for consumption and tourism will increase to 282.64 million cubic metres/year as demonstrated in Table 5.

Table 5 Water Demand for Consumption and Tourism in EEC

	Water Demand for Consumption and Tourism (million cubic metres/year)	
	Current	**Estimated**
Chachoengsao	18.69	58.30
Chonburi	93.07	464.51
Rayong	31.41	282.64
Total	**143.17**	**805.45**

4.2.1.3 Water Demand for Industries

Water demand for industries is comprised of demand from factories in industrial clusters and demand from factories scattering inside and outside city planning area. The result shows that current water demand for industries is 664.31 million cubic metres/year. Rayong has the highest water demand at 327.08 million cubic metres/year, following by Chonburi and Chachoengsao at 234.31 and 102.92 million cubic metres/year respectively. In 2039, the water demand for industries will increase to 1,005.85 million cubic metres/year as shown in Table 6.

Table 6 Water Demand for Industries in EEC

	Water Demand for Industries (million cubic metres/year)	
	Current	**Estimated**
Chachoengsao	102.92	154.70
Chonburi	234.31	386.12
Rayong	327.08	465.03
Total EEC	**664.31**	**1,005.85**

4.2.1.4 Water Demand for Downstream Ecological Conservation

Water demand for downstream ecological conservation is normally derived from ecological and environmental analysis to balance downstream ecosystem, and sometimes from water demand in downstream for various purposes, such as saltwater and wastewater reduction, water level balance for ship navigation, consumption, and industries. Hence, the amount of downstream water that is needed to be conserved is different in each stream. The Royal Irrigation Department has allocated water for ecological conservation and saltwater intrusion control as shown in Table 7.

Table 7 Water Demand for Downstream Ecological Conservation of Reservoirs in EEC

Reservoir	Water Demand for Downstream Ecological Conservation		Duration (week)
	Total Water Amount (million cubic metre)	Average Flow Rate (cubic metre/sec)	
Prasae	5.43	0.35	26
Nong Pla Lai	16	1.03	26
Khlong Si Yat	15.1	1.16	22

4.2.2 Water Balance Analysis

Chachoengsao, Chonburi, and Rayong Province are located in Bang Pakong River Basin and East Coast Gulf Basin with large and medium-sized water reservoirs, managed by Royal Irrigation Department, allocating water for agriculture, consumption, industries, ecological conservation, and saltwater intrusion control. Moreover, Eastern Water Resources Development and Management Public Company Limited (East Water) operates water utility business by transmitting raw water through large water pipe to feed the water to industries and for consumption in EEC area.

This study analysed water balance of sub-district in 3 EEC Provinces (Chachoengsao, Chonburi, and Rayong) by comparing water demand with water supply in the area. Nonetheless, this study focuses on the large-scale groundwater development in areas facing water scarcity and areas that surface water is not sufficient or unusable. Therefore, water demand for agriculture covers only non-irrigated areas, while water demand for consumption and tourism covers the whole study area. Water demand for industries includes only demand of industries scattering outside industrial promotion zone/innovation zone/special economic zone, because water demand of industries in these particular zones are already served by East Water or have certain water supplies.

4.2.2.1 Current Situation

The research team compared water demand and water supply in the study area and found that, in 2019, Chachoengsao Province had water demand for agriculture in non-irrigated area at 257.62 million cubic metres/year and groundwater developed for agricultural use at 2.36 million cubic metres/year, resulting in the water scarcity at 255.26 million cubic metres/year. In terms of water demand for consumption, tourism, and industries, the total demand was 106.54 million cubic metres/year, while water supplied by Provincial Waterworks Authority plus water budget was 64.38 million cubic metres/year, resulting in water scarcity at 42.16 million cubic metres/year.

In Chonburi Province, water demand for agriculture in non-irrigated area was 823.46 million cubic metres/year and groundwater developed for agricultural use was 2.12 million cubic metres/year, resulting in water scarcity at 821.34 million cubic metres/year. Water demand for consumption, tourism, and industries was 291.35 million cubic metres/year, while water supplied by Provincial Waterworks Authority plus water budget from groundwater was 226.58 million cubic metres/year, resulting in water scarcity at 64.77 million cubic metres/year.

In Rayong Province, water demand for agriculture in non-irrigated area was 407.07 million cubic metres/year and groundwater developed for agricultural use was only 3.74 million cubic metres/year, resulting in water scarcity at 403.33 million cubic metres/year.

Water demand for consumption, tourism, and industries was 167.75 million cubic metres/year, while water supplied by Provincial Waterworks Authority plus water budget from groundwater was 71.64 million cubic metres/year, resulting in water scarcity at 95.95 million cubic metres/year. The analysis can be seen in Table 8.

Table 8 Water Balance Analysis (as of 2019)

Unit: million cubic metres/year

Province	Agricultural Water Balance for Non-irrigated Area			Water Balance for Consumption, Tourism, and Industries					Water Storages, Department of Water Resource	Water Scarcity	Groundwater Potential
	Total Water Demand for Agriculture	Water Budget from Groundwater Wells	Agricultural Water Balance	Consumption & Tourism	Industries	Water Budget: Waterworks Authorities	Water Budget: Groundwater Wells	Water Balance			
Chachoengsao	257.62	2.36	-255.26	18.68	87.86	57.99	6.39	-42.16	21.85	-275.56	206.82
Chonburi	823.46	2.12	-821.34	93.07	191.85	209.52	17.05	-64.77	19.66	-866.44	17.97
Rayong	407.07	3.74	-403.33	31.41	136.34	51.35	20.29	-95.95	6.80	-492.48	134.78

4.2.2.2 Water Balance Analysis (2039 Estimated)

To estimate future water balance, the research team estimated water demand in the next 20 years of each activity and balance it with future water supply planned by relevant authorities.

The result shows that Chachoengsao Province will still have water demand for agriculture in non-irrigated area at 257.62 million cubic metres/year and will develop groundwater for agricultural use at 2.36 million cubic metres/year, resulting in the water scarcity at 255.26 million cubic metres/year. In terms of water demand for consumption, tourism, and industries, the total demand will rise to 186.31 million cubic metres/year, while water supplied by Provincial Waterworks Authority plus water budget will be 171.62 million cubic metres/year, resulting in water scarcity at 14.70 million cubic metres/year.

In Chonburi Province, water demand for agriculture in non-irrigated area will be 823.46 million cubic metres/year and groundwater developed for agricultural use will be 2.12 million cubic metres/year, resulting in water scarcity at 821.34 million cubic metres/year. Water demand for consumption, tourism, and industries will increase to 749.25 million cubic metres/year, while water supplied by Provincial Waterworks Authority plus water budget from groundwater was 336.45 million cubic metres/year, resulting in water scarcity at 412.80 million cubic metres/year.

In Rayong Province, water demand for agriculture in non-irrigated area will be 407.07 million cubic metres/year and groundwater developed for agricultural use will be 3.74 million cubic metres/year, resulting in water scarcity at 403.33 million cubic metres/year. Water demand for consumption, tourism, and industries will be 509.12 million cubic metres/year, while water supplied by Provincial Waterworks Authority plus water budget from groundwater will be just 143.34 million cubic metres/year, resulting in water scarcity at 366.39 million cubic metres/year. The analysis can be seen in Table 9.

Table 9 Water Balance Analysis (2039 Estimated)

Unit: million cubic metres/year

Province	Agricultural Water Balance for Non-irrigated Area			Water Balance for Consumption, Tourism, and Industries					Water Storages, Department of Water Resource	Water Scarcity	Groundwater Potential
	Total Water Demand for Agriculture	Water Budget from Groundwater Wells	Agricultural Water Balance	Consumption & Tourism	Industries	Water Budget: Waterworks Authorities	Water Budget: Groundwater Wells	Water Balance			
Chachoengsao	257.62	2.36	-255.26	58.30	128.01	165.22	6.39	-14.70	21.85	-248.10	206.82
Chonburi	823.46	2.12	-821.34	464.51	284.74	319.40	17.05	-412.80	19.66	-1,214.47	17.97
Rayong	407.07	3.74	-403.33	282.64	226.48	122.44	20.29	-366.39	6.80	-762.95	233.27

4.3 Economic Viability and Real Cost Analysis of Groundwater Utilisation in EEC

4.3.1 Economic Viability

Economic viability of the large-scale groundwater development in EEC Provinces (Rayong, Chonburi, and Chachoengsao) (Table 10-12) used Cost-Benefit Analysis method to analyse cost and benefit of important stakeholders, namely households, agricultural sector, industrial sector, tourism sector, and government sector, based on water demand, water supply, and water balance in present day and in the next 20 years. Furthermore, groundwater potential data are obtained from field survey, mapping of groundwater sources at 1:50,000 scale, and mapping suitable areas for groundwater development. The findings show that:

- The large-scale groundwater development in Rayong Province is economically viable in Klaeng, Ban Khai, Ban Chang, and Pluak Daeng District.

- The large-scale groundwater development in Chonburi Province is economically viable in Ko Chan, Bo Thong, Ban Bueng, Phanat Nikhom, and Sattahip District.
- The large-scale groundwater development in Chachoengsao Province is economically viable in all Districts (Mueang Chachoengsao, Ban Pho, Bang Pakong, Bang Nam Priao, Bang Khla, Plaeng Yao, Phanom Sarakham, Ratchasan, Sanam Chai Khet, and Khlong Khuean)

Table 10 Economic Viability of Groundwater Development in Rayong Province

District	Water Scarcity (million cubic metres/year)		Groundwater Potential		Economic Viability			
	Current (as of 2020)	Estimated (2039)	Amount of Developable Groundwater (million cubic metres/year)	Total Dissolved Solids (mg/l)	NPV (million baht/well)	IRR	B/C Ratio	Payback Period
Khao Chamao	56.86	60.65	1.14	TDS <1,000	-10.40	-7.95%	0.49	More than 10 years
Nikhom Phatthana	43.47	69.09	3.44	TDS <1,000	-8.55	-3.60%	0.59	More than 10 years
Klaeng	153.82	164.81	5.04	Thang Kwian, Wang Wa, Noen Kho, and Kram Sub-district; TDS >1,000	9.47	25.54%	1.56	3 years 5 months
Ban Khai	38.98	46.33	51.53	TDS <1,000	10.44	26.69%	1.61	3 years 4 months
Ban Chang	25.26	25.47	1.93	TDS <1,000	13.09	30.31%	1.76	2 years 12 months
Pluak Daeng	24.71	34.58	2.59	TDS <1,000	13.18	30.40%	1.76	2 years 12 months
Mueang Rayong	134.01	180.36	68.58	TDS <1,000	-8.89	-4.10%	0.58	More than 10 years
Wang Chan	24.75	27.51	0.53	TDS <1,000	-10.09	-6.99%	0.51	More than 10 years

Source: From survey and calculation under this research

Table 11 Economic Viability of Groundwater Development in Chonburi Province

District	Water Scarcity (million cubic metres/year)		Groundwater Potential		Economic Viability			
	Current (as of 2020)	Estimated (2039)	Amount of Developable Groundwater (million cubic metres/year)	Total Dissolved Solids (mg/l)	NPV (million baht/well)	IRR	B/C Ratio	Payback Period
Ko Chan	58.62	58.86	2.45	Ko Chan and Tha Bun Mi Sub-district; TDS >1,000	8.54	24.32%	1.51	3 years 7 months
Bo Thong	127.42	128.81	2.03	Bo Kwang Thong and Wat Suwan Sub-district; TDS >1,000	8.16	23.81%	1.49	3 years 8 months
Bang Lamung	85.98	145.34	1.42	Bang Lamung, Huai Yai, Na Kluea, Pattaya, and Pong Sub-district; TDS >1,000	-7.84	-1.80%	0.63	9 years 11 months
Ban Bueng	218.08	227.45	0.87	Map Phai, Nong Bon Daeng, Nong Chak, Nong Samsak, and Ban Bueng Sub-district; TDS >1,000	9.22	25.22%	1.55	3 years 6 months
Phanat Nikhom	111.51	125.27	1.91	Mon Nang, Thung Khwang, Nong Khayat, Na Matum, Ban Chang, Na Wang Hin, Phanat Nikhom, Tha Kham, Wat Luang, Wat Bot, Na Phrathat, Rai Lak Thong, Khok Phlo, and Sa Si Liam Sub-district; TDS >1,000	9.68	25.85%	1.57	3 years 5 months
Phan Thong	25.83	27.47	3.12	Khok Khi Non, Bang Hak, Ko Loi, Na Pradu, Bang Nang, Ban Kao, Phan Thong, Nong Tamlueng, Nong Hong, Map Pong, and Nong Kakha Sub-district; TDS >1,000	-9.22	-4.77%	0.56	More than 10 years
Mueang Chonburi	21.66	66.66	1.15	Khlong Tamru, Nong Mai Daeng, Na Pa, Don Hua Lo, Samnak Bok, Ban Suan, Ban Khot, Bang Pla Soi, Makham Yong, Huai Kapi, Nong Ri, Samet, Ang Sila, Ban Puek, Saen Suk, Nong Khang Khok, and Bang Sai Sub-district; TDS >1,000	-6.15	1.59%	0.73	8 years 4 months
Si Racha	145.24	211.59	1.43	TDS <1,000	-8.10	-2.60%	0.62	More than 10 years

Table 11 Economic Viability of Groundwater Development in Chonburi Province (cont.)

District	Water Scarcity (million cubic metres/year)		Groundwater Potential		Economic Viability			
	Current (as of 2020)	Estimated (2039)	Amount of Developable Groundwater (million cubic metres/year)	Total Dissolved Solids (mg/l)	NPV (million baht/well)	IRR	B/C Ratio	Payback Period
Sattahip	15.44	68.95	3.38	Sattahip and Na Chom Thian Sub-district; TDS >1,000	21.42	40.59%	2.20	2 years 5 months
Nong Yai	119.57	122.56	0.21	TDS <1,000	-10.27	-7.68%	0.50	More than 10 years

Source: From survey and calculation under this research

Table 12 Economic Viability of Groundwater Development in Chachoengsao Province

District	Water Scarcity (million cubic metres/year)		Groundwater Potential		Economic Viability			
	Current (as of 2020)	Estimated (2039)	Amount of Developable Groundwater (million cubic metres/year)	Total Dissolved Solids (mg/l)	NPV (million baht/well)	IRR	B/C Ratio	Payback Period
Khlong Khuean	14.20	14.40	10.37	TDS >1,000	8.17	23.74%	1.49	3 years 8 months
Bang Khla	13.98	14.81	23.40	TDS >1,000	10.99	27.39%	1.64	3 years 3 months
Bang Nam Priao	20.93	30.18	51.80	TDS >1,000	15.14	32.68%	1.86	2 years 10 months
Bang Pakong	20.91	39.24	23.91	TDS >1,000	15.53	33.06%	1.87	2 years 10 months
Ban Pho	7.15	11.27	19.00	TDS >1,000	15.77	33.38%	1.89	2 years 10 months
Plaeng Yao	44.16	47.76	8.69	TDS <1,000	9.51	25.56%	1.56	3 years 5 months
Phanom Sarakham	52.75	51.90	26.41	TDS <1,000	9.31	25.23%	1.55	3 years 6 months
Mueang Chachoengsao	14.86	25.49	38.67	TDS >1,000	17.02	35.09%	1.96	2 years 8 months
Ratchasan	8.29	8.58	10.87	TDS >1,000	9.02	24.90%	1.53	3 years 6 months
Sanam Chai Khet	64.10	64.73	4.07	Ban Sang, Nong Yao, Phanom Sarakham, Mueang Kao Sub-district; TDS>1,000	8.35	23.99%	1.50	3 years 7 months

Source: From survey and calculation under this research

From the field survey and groundwater potential data, the research team found that there are 4 potential areas that could be a pilot project for the large-scale groundwater development to strengthen input security in EEC, namely;

1) Ban Khai District, Rayong Province (developable groundwater amount = 51.53 million cubic metres/year)

2) Sattahip District, Chonburi Province (developable groundwater amount = 3.38 million cubic metres/year)

3) Bang Nam Priao District, Chachoengsao Province (developable groundwater amount = 51.80 million cubic metres/year)

4) Phanom Sarakham District, Chachoengsao Province (developable groundwater amount = 26.41 million cubic metres/year)

Economic viability of the 4 pilot areas were economically viable because

1) Ban Khai District, Rayong Province: NPV = 10.44 million baht/well, IRR = 26.69%, B/C Ratio = 1.61, and Payback Period = 3 years 4 months

2) Sattahip District, Chonburi Province: NPV = 21.42 million baht/well, IRR = 40.59%, B/C Ratio = 2.20, and Payback Period = 2 years 5 months

3) Bang Nam Priao District, Chachoengsao Province: NPV = 15.14 million baht/well, IRR = 32.68%, B/C Ratio = 1.86, and Payback Period = 2 years 10 months

4) Phanom Sarakham District, Chachoengsao Province: NPV = 9.31 million baht/well, IRR = 25.23%, B/C Ratio = 1.55, and Payback Period = 3 years 6 months

The results are shown in Table 13 and Table 14.

Table 13 Assessment of Groundwater Potential, Water Scarcity, and Economic Viability of Large-scale Groundwater Development in 4 Pilot Areas in EEC

District	Water Scarcity (million cubic metres/year)		Groundwater Potential		Economic Viability			
	Current (2020)	Estimated (2039)	Amount of Developable Groundwater (million cubic metres/year)	Total Dissolved Solids (mg/l)	NPV (million baht/well)	IRR	B/C Ratio	Payback Period
Ban Khai	38.98	46.33	51.53	TDS <1,000	10.44	26.69%	1.61	3 years 4 months
Sattahip	15.44	68.95	3.38	Sattahip and Na Chom Thian Sub-district; TDS >1,000	21.42	40.59%	2.20	2 years 5 months
Bang Nam Priao	20.93	30.18	51.80	TDS >1,000	15.14	32.68%	1.86	2 years 10 months
Phanom Sarakham	52.75	51.90	26.41	TDS <1,000	9.31	25.23%	1.55	3 years 6 months

Source: From survey and analysis under this research

Table 14 Analysis of Water Storage, Water Added to Groundwater Sources Annually, and Recommended Borehole Depth

District	Water Storage (million cubic metres)*	Water Added to Groundwater Source Annually (million cubic metres/year)*	Recommended Borehole Depth (metre)
Ban Khai	890	67	140
Sattahip	883	33	80
Bang Nam Priao	3,013	66	140
Phanom Sarakham	2,429	68	120

Note * Department of Groundwater Resources (2017)

Source: From survey and analysis under this research

4.3.2 Real Cost Analysis of Groundwater Utilisation in EEC

To get information about water consumption problems and willingness to pay for groundwater in EEC, the research team collected information from 382 sampling persons from agricultural sector (45.81%), household consumption (30.37%), tourism sector (20.16%), and industrial sector (3.66%). The results showed that 69.11% found problems in their water consumption. In terms of water scarcity, agricultural sector faced the highest water shortage at 51.23%, following by consumption (33.61%), tourism sector (13.11%), and industrial sector

(2.05%). Most of the respondents said their water shortage was in serious level and they have to face this problem every year from February to May. Respondents from all sectors were concerned about future water volume when EEC is fully developed.

Additionally, 77.75% were willing to pay for groundwater with average price at 7.04 baht/unit. Household consumption had the highest willingness to pay at 12.00 baht/unit with average at 2.07 baht/unit. Agricultural sector had the highest willingness to pay at 6.00 baht/unit with average at 2.07 baht/unit. Tourism had the highest willingness to pay at 15.00 baht/unit with average at 7.75 baht/unit. And Industrial sector had the highest willingness to pay at 20 baht/unit with average at 14.75 baht/unit.

For real cost analysis of groundwater utilisation in EEC, the research team has developed new cost structure which comprises of drilling cost, groundwater laboratory test and analysis cost, water storage and distribution cost, and maintenance and management cost, and with the condition that the well age is 10 and 20 years. The cost estimation is divided into 2 parts as 1) cost when borehole is 30-400 metres deep, to be a reference for those who wants to develop their own groundwater well; and 2) cost by district in study area, based on 3 following Scenarios. Scenario 1 = bore cost only, Scenario 2 = bore cost + storage tank installation, and Scenario 3 = bore cost + storage tank installation + 20-kilometre water distribution system installation.

According to groundwater potential analysis and economic viability, a suitable area to be the groundwater development pilot project in Rayong Province is Ban Khai District and Mueang Rayong District. Ban Khai District recommended borehole depth at 140 metres. Estimated total cost for each Scenario is as follows.

Scenario 1 (10-year well) = 2.58 million baht/well, unit cost = 2.95 baht/cubic metre
Scenario 1 (20-year well) = 4.81 million baht/well, unit cost = 2.75 baht/cubic metre
Scenario 2 (10-year well) = 22.16 million baht/well, unit cost = 25.30 baht/cubic metre
Scenario 2 (20-year well) = 29.55 million baht/well, unit cost = 16.87 baht/cubic metre
Scenario 3 (10-year well) = 36.44 million baht/well, unit cost = 41.61 baht/cubic metre
Scenario 3 (20-year well) = 43.83 million baht/well, unit cost = 25.02 baht/cubic metre

Mueang Rayong District recommended borehole depth at 140 metres. Estimated total cost for each Scenario is as follows.

Scenario 1 (10-year well) = 2.59 million baht/well, unit cost = 8.89 baht/cubic metre

Scenario 1 (20-year well) = 4.81 million baht/well, unit cost = 8.24 baht/cubic metre

Scenario 2 (10-year well) = 22.17 million baht/well, unit cost = 75.95 baht/cubic metre

Scenario 2 (20-year well) = 29.55 million baht/well, unit cost = 50.60 baht/cubic metre

Scenario 3 (10-year well) = 36.45 million baht/well, unit cost = 124.86 baht/cubic metre

Scenario 3 (20-year well) = 43.83 million baht/well, unit cost = 75.05 baht/cubic metre

The suitable area to be the groundwater development pilot project in Chonburi Province is Sattahip District with recommended borehole depth at 70 metres. Estimated total costs for each Scenario are as follows.

Scenario 1 (10-year well) = 0.297 million baht/well, unit cost = 0.34 baht/cubic metre

Scenario 1 (20-year well) = 0.382 million baht/well, unit cost = 0.22 baht/cubic metre

Scenario 2 (10-year well) = 22.02 million baht/well, unit cost = 25.14 baht/cubic metre

Scenario 2 (20-year well) = 27.26 million baht/well, unit cost = 15.56 baht/cubic metre

Scenario 3 (10-year well) = 36.30 million baht/well, unit cost = 41.44 baht/cubic metre

Scenario 3 (20-year well) = 41.54 million baht/well, unit cost = 23.71 baht/cubic metre

The suitable areas to be the groundwater development pilot project in Rayong Province are Bang Nam Priao District and Phanom Sarakham District.

Bang Nam Priao District recommended borehole depth at 140 metres. Estimated total cost for each Scenario is as follows.

Scenario 1 (10-year well) = 0.453 million baht/well, unit cost = 0.52 baht/cubic metre

Scenario 1 (20-year well) = 0.537 million baht/well, unit cost = 0.31 baht/cubic metre

Scenario 2 (10-year well) = 22.17 million baht/well, unit cost = 25.32 baht/cubic metre

Scenario 2 (20-year well) = 27.41 million baht/well, unit cost = 15.65 baht/cubic metre

Scenario 3 (10-year well) = 36.45 million baht/well, unit cost = 41.62 baht/cubic metre

Scenario 3 (20-year well) = 41.69 million baht/well, unit cost = 23.80 baht/cubic metre

Phanom Sarakham District recommended borehole depth at 120 metres. Estimated total cost for each Scenario is as follows.

Scenario 1 (10-year well) = 0.410 million baht/well, unit cost = 0.47 baht/cubic metre

Scenario 1 (20-year well) = 0.494 million baht/well, unit cost = 0.28 baht/cubic metre

Scenario 2 (10-year well) = 22.13 million baht/well, unit cost = 25.27 baht/cubic metre

Scenario 2 (20-year well) = 27.37 million baht/well, unit cost = 15.62 baht/cubic metre

Scenario 3 (10-year well) = 36.41 million baht/well, unit cost = 41.57 baht/cubic metre

Scenario 3 (20-year well) = 41.65 million baht/well, unit cost = 23.71 baht/cubic metre

If the groundwater well is well maintained to last for 20 years, the unit cost in all Scenarios will be lower than the 10-year well.

The real cost analysis of groundwater utilisation in EEC has 2 approaches. First is to calculate only cost of groundwater use (estimated unit cost + groundwater use fee 3.5 baht/cubic metre according to Groundwater Act B.E. 2520 (1977)). Second is to include sustainability factor into the calculation by adding groundwater conservation fee at 85% of the total cost of groundwater use (estimated unit cost + groundwater use fee 3.5 baht/cubic metre according to Groundwater Act B.E. 2520 (1977)). The real cost analysis found that the second approach is more preferrable.

The real cost analysis of Ban Khai District, Rayong Province are as follows.

Scenario 1 (10-year well): real cost = 11.94 baht/cubic metre

Scenario 1 (20-year well): real cost = 11.56 baht/cubic metre

Scenario 2 (10-year well): real cost = 34.29 baht/cubic metre

Scenario 2 (20-year well): real cost = 25.68 baht/cubic metre

Scenario 3 (10-year well): real cost = 50.59 baht/cubic metre

Scenario 3 (20-year well): real cost = 33.83 baht/cubic metre

And Mueang Rayong District, Rayong Province are as follows.

Scenario 1 (10-year well): real cost = 22.93 baht/cubic metre

Scenario 1 (20-year well): real cost = 21.73 baht/cubic metre

Scenario 2 (10-year well): real cost = 89.98 baht/cubic metre

Scenario 2 (20-year well): real cost = 64.08 baht/cubic metre

Scenario 3 (10-year well): real cost = 138.89 baht/cubic metre

Scenario 3 (20-year well): real cost = 88.54 baht/cubic metre

The real cost analysis of Sattahip District, Chonburi Province are as follows.

Scenario 1 (10-year well): real cost = 11.67 baht/cubic metre

Scenario 1 (20-year well): real cost = 11.43 baht/cubic metre

Scenario 2 (10-year well): real cost = 34.03 baht/cubic metre

Scenario 2 (20-year well): real cost = 25.55 baht/cubic metre

Scenario 3 (10-year well): real cost = 50.33 baht/cubic metre

Scenario 3 (20-year well): real cost = 33.70 baht/cubic metre

The real cost analysis of Bang Nam Priao District, Chachoengsao Province are as follows.

Scenario 1 (10-year well): real cost = 11.96 baht/cubic metre

Scenario 1 (20-year well): real cost = 11.57 baht/cubic metre

Scenario 2 (10-year well): real cost = 34.31 baht/cubic metre

Scenario 2 (20-year well): real cost = 25.69 baht/cubic metre

Scenario 3 (10-year well): real cost = 50.61 baht/cubic metre

Scenario 3 (20-year well): real cost = 33.84 baht/cubic metre

The real cost analysis of Phanom Sarakham District, Chachoengsao Province are as follows.

Scenario 1 (10-year well): real cost = 11.87 baht/cubic metre

Scenario 1 (20-year well): real cost = 11.52 baht/cubic metre

Scenario 2 (10-year well): real cost = 34.22 baht/cubic metre

Scenario 2 (20-year well): real cost = 25.64 baht/cubic metre

Scenario 3 (10-year well): real cost = 50.52 baht/cubic metre

Scenario 3 (20-year well): real cost = 33.79 baht/cubic metre

4.4 Groundwater Resources Planning and Development

Groundwater resources planning and development in EEC focuses on creating an integrated spatial plan with public participation under following procedures.

1) Analyse and review strategies, work plans, and policies related to groundwater resources planning and development in EEC, namely National Strategy (2018-2037), Twelfth National Economic and Social Development Plan (2017-2021), EEC 5-year Development Plan (2017-2022), Master Plan on Water Resource Management (2018-2037), Master Plan on Water Resource Management and Development in Eastern Region, and 20-year Strategy of Groundwater Management in Thailand (2017-2036).

2) Collect, review, and analyse data. Data are obtained from secondary sources, including geology setting, structural geology data, surface water data, meteorological data, hydrological data, land use data, groundwater well and groundwater usage data, water demand, water supply, social data, and other related data.

3) Geological survey and assess groundwater potential (quantity and quality) in 3 Provinces of EEC (Rayong, Chonburi, and Chachoengsao), and generate maps of groundwater sources at 1:50,000 scale with other relevant illustrated maps including suitable areas for groundwater development for each purpose.

4) Organise field surveys, focus group meetings, meetings of relevant organisations, and public hearings to listen to stakeholders and local citizen's voices, and organizing seminars to disseminate study results and get feedbacks

5) Analyse water usage, water demand for consumption, agriculture, industries, tourism, and assessing water scarcity of 3 Provinces in present day and in the next 20 years.

6) Conduct economic viability of the large-scale groundwater development and real cost analysis of groundwater utilisation in EEC

7) Generate groundwater resources planning and development in EEC in short term (5-year), medium term (10-year), and long term (20-year) which consist of

7.1) Supporting public participation of citizen and relevant sectors and organisations

7.2) Large-scale groundwater development in EEC area (Rayong, Chonburi, and Chachoengsao)

7.3) Effective and sustainable allocation and utilisation (for agriculture, consumption, tourism, and industries) of large-scale groundwater development in EEC

7.4) Groundwater conservation for sustainable and effective groundwater utilisation

7.5) Amend laws and regulations related to collection of groundwater use fees and groundwater conservation fees in EEC for effective groundwater utilisation with maximum benefits

7.6) Monitor quantity and quality of groundwater

Groundwater resources planning and development in EEC is shown in Table 15.

Table 15 Groundwater Resources Planning and Development in EEC

No.	Work Plan	Duration (Year)																			
		Short-term					Medium-term					Long-term									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Amendment of related laws and regulations by indicating EEC area in 3 Provinces (Rayong, Chonburi, and Chachoengsao) as groundwater critical area and imposition of groundwater use fees and groundwater conservation fees in all EEC area for effective groundwater utilisation with maximum benefits	■	■	■																	
	1.1 Supporting public participation of citizen and relevant sectors and organisations by taking their comments and suggestions into account and working cooperatively	■																			
	1.2 Researching about improvement of laws and regulations related to groundwater, such as Groundwater Act B.E. 2520 (1977) and laws relevant to groundwater use fees and groundwater conservation fees	■																			
	1.3 Amending related laws and regulations by identifying EEC area in 3 Provinces (Rayong, Chonburi, and Chachoengsao) as groundwater critical area and imposition of groundwater use fees and groundwater conservation fees in all EEC area	■	■	■																	

Table 15 Groundwater Resources Planning and Development in EEC (cont.)

No.	Work Plan	Duration (Year)																			
		Short-term					Medium-term					Long-term									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
2	**Large-scale groundwater development in EEC area (Rayong, Chonburi, and Chachoengsao)**																				
	2.1 Rayong Province (Ban Khai District): 2.1.1 Developing Large-scale groundwater sources in Ban Khai Sub-district, Rayong Province 2.1.2 Supporting public participation of citizen and relevant sectors and organisations by taking their comments and suggestions into account, networking, and working cooperatively, and public relation through various types of media																				
	2.2 Chonburi Province (Sattahip District) 2.2.1 Developing Large-scale groundwater sources in Sattahip District, Chonburi Province 2.2.2 Supporting public participation of citizen and relevant sectors and organisations by taking their comments and suggestions into account, networking, and working cooperatively, and public relation through various types of media																				
	2.3 Chachoengsao Province (Bang Nam Priao and Phanom Sarakham District): 2.3.1 Developing Large-scale groundwater sources in Bang Nam Priao and Phanom Sarakham District, Chachoengsao Province 2.3.2 Supporting public participation of citizen and relevant sectors and organisations by taking their comments and suggestions into account, networking, and working cooperatively, and																				

Table 15 Groundwater Resources Planning and Development in EEC (cont.)

No.	Work Plan	Duration (Year)																			
		Short-term					Medium-term					Long-term									
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	public relation through various types of media																				
3	**Effective and sustainable allocation and utilisation (for agriculture, consumption, tourism, and industries) of large-scale groundwater development in EEC**						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4	**Groundwater conservation for sustainable and effective groundwater utilisation** - Increasing effectiveness of management - Conserving upstream areas or groundwater recharge areas - Controlling amount of groundwater usage - Identifying EEC area in 3 Provinces as groundwater critical area and imposition of groundwater use fees and groundwater conservation fees	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
5	**Monitoring quantity and quality of groundwater** - Level and quantity of groundwater data - Dispersion and concentration of contaminants in groundwater data	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■