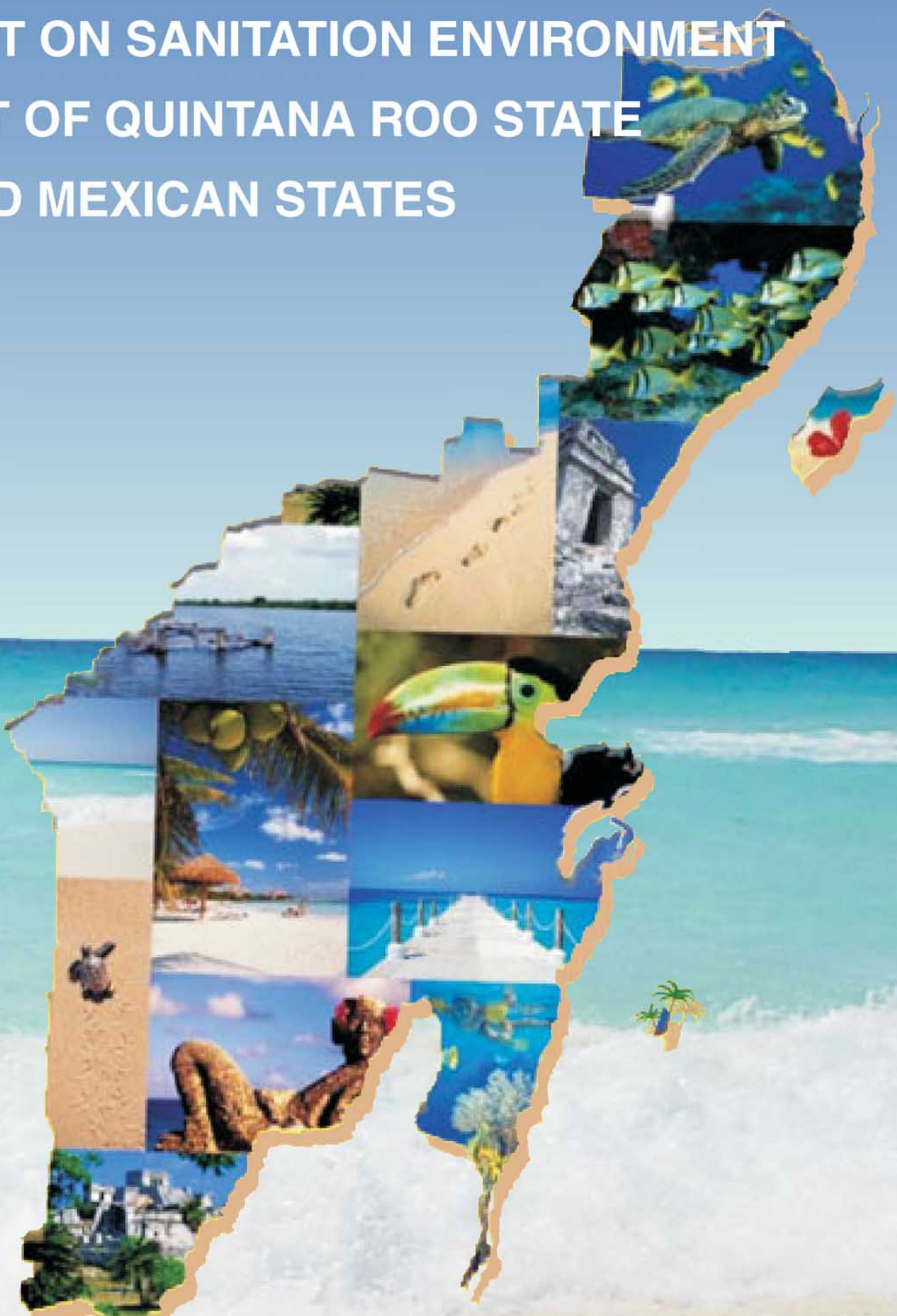
NO.

Japan International Cooperation Agency (JICA)
Ministry of the Environment and Natural Resources of Mexico (SEMARNAT)

THE STUDY OF MANAGEMENT ON SANITATION ENVIRONMENT IN THE COAST OF QUINTANA ROO STATE IN THE UNITED MEXICAN STATES



Final Report
Volume IV

ANNEX II

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The Study of
Management on Sanitation Environment
in the Coast of Quintana Roo State
in the United Mexican States

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In this report, the project cost is estimated by using the November 2003 price and an exchange rate of US$1.00 = 11.00 Mexican pesos = JP¥ 110.

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Abbreviations

AMSLM	Average Mean Sea Level Meters
AC	Civil Association
APAS	Potable Water, Sewerage and Sanitation
B/C	Benefit Cost
BANOBRAS	National Bank of Public Works and Services (*Banco Nacional de Obras y Servicios Públcios*)
BOD	Biochemical Oxygen Demand
C/P	Counterpart
CAPA	Commission of Potable Water and Sewerage (*Comisión de Agua Potable y Alcantarillado*)
CECADESU	Training Center for Sustainable Development
CEPIS	Panamerican Center for Sanitary Enginnering and Environmental Siences (*Centro Panamericano de Ingeniería Sanitaria y Ciencias del Ambiente*)
CNA	National Committee of Water (*Comisión Nacional del Agua*)
CNANP	National Committee of Natural Protected Areas (*Comision Nacional de Aguas Naturales Protegidas*)
COD	Chemical Oxygen Demand
COESPO	State Council of Population
CONAPO	National Council of Population
COSEPRE	Cost of Services Provided
DF/R	Draft Final Report
EAP	Economic Activity Population
EC	Electric Conductivity
ECLAC	Economic Commission for Latin America and the Caribbean
ECOSE	Ecology and Business Commitment
ECOSUR	College of the Southern Border (*El Colegio de la Frontera Sur*)
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
EM	Electro Magnetic
F/R	Final Report
F/S	Feasibility Study
FCP	Felipe Carrillo Puerto
FIDECARIBE	Caribbean Trusteeship, State Tourism Agency
FONATUR	Tourism National Found (*Fondo Nacional para el Turismo*)
GDP	Gross Domestic Product
GIS	Geographic Information System
GNI	Gross National Income
GNP	Gross National Product
GWM	Ground Water Management
HDI	Human Development Index
IC/R	Inception Report
IEE	Initial Environmental Examination
IIRA	Institute of Environmental Impact and Risk
IMSS	Mexican Institute for Health Insurance
IMTA	Mexican Institute of Water Technology
INE	National Ecology Institute
INEGI	General Census of Population and Housing (*Instituto Nacional de Estadística, Geografía e Informatica*)
INI	National Institute for Indigenous People

ISSTE	Health Insurance Institute for State Workers
It/R	Interim Report
JICA	Japan International Cooperation Agency
LEEPA	Regulation of the Environment Balance and Protection of Quintana Roo State
LGEEPA	General Law of Ecological Balance and Environmental Protection
LGPGIR	General Law for the Prevention and Integral Management of Waste
M/M	Minutes of Meetings
M/P	Master Plan
MBPS	Municipal Bureau of Public Services
MLSS	Mixed-Liquor Volatile Suspended Solids
Mo/P	Model Project
MPNISP	Model of National and International Practices in Public Service
NA	Not Available
NGO	Non-Governmental Organization
NPV	Net Present Value
O&M	Operating and Maintenance
OD	Oxygen Demand
OPB	Othón Pompeyo Blanco
P/R	Progress Report
PDSD	Phased Disposal Site Development
PEDI	Integral Development Strategic Plan
PEDU	State Program of Urban Development (*Programa Estatal de Desarrollo Urbano*)
PEMEX	Oil Mexican Company
PMDU	Urban Development Municipality Programs
PND	National Development Plan
PNDU	National Program of Urban Development
POET	Program of Territorial and Ecological Ordinance
PROFEPA	Federal Environmental Protection Agency
SARH	Secretariat of Agricultural and Hydraulic Resources
SEANAP	System Estate of Natural Protected Areas
SECTUR	Ministry of Tourism
SEDEMAR	Navy
SEDENA	National Army Secretariat
SEDESOL	Ministry of Social Development (*Secretaría de Desarrollo Social*)
SEDUE	Secretariat of Urban Development and Ecology
SEDUMA	Ministry of Urban Development and Environment, Government of Quintana Roo State (*Secretaría de Desarrollo Urbano y Meido Ambiente, Gobierno del Estado de Quintana Roo*)
SEMARNAT	Ministry of Environment and Natural Resources (*Secretaría de Medio Ambiente y Recuross Naturales*)
SEPLADER	Secretariat of Regional Planning and Development
SIGIR	Information System for the Integral Management of Waste
SOL	Solidaridad
SS	Suspended Solids
SSA	Secretariat of Health and Assistance
SVI	Sludge Volume Index
SW	Solid Waste
SWM	Solid Waste Management
TDEM	Time-Domain Electromagnetic Method
TDS	Total Dissolved Solid
TEM	Transient Electromagnetic Method

TS	Total Solid
TSS	Total Suspended Solids
UNEP	United Nation Environment Program
UNESCO	United Nation Educational, Scientific, and Cultural Organization
USAID	United States Agency for International Development
USMN	Unit of the Meteorological National Service
VES	Vertical Electric Sounding
VSS	Volatile Suspended Solids
WTP	Water Treatment Plant
WWM	Wastewater Management

Annex J

Outline of Model Projects

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J Outline of Model Projects

J.1 Roles of Model Project

First, a model project has a role to actually implement an activity listed in a master plan and to evaluate its feasibility.

Second, the model project is the initial stage of implementation of the master plan. It has a role to launch the implementation successfully. An executing agency and organizations concerned can actually see advantageous effects brought by the model project. Then, they can confidently implement the model project and the master plan.

In order to encourage the executing agency to establish ownership for the master plan, it is necessary to spark changes within the agency, because the master plan itself is a reform of the existing system. Generally, the existing system stands against changes. The model project is a good tool to bring changes within the existing system, as they can experience new challenges and can see effects through its implementation.

The model project is not an event to make something. It is a process to achieve a goal. Going through the process, a required system is established and necessary capabilities are obtained for implementing the master plan.

Summarising the above, the following four points can be raised as roles of the model project.

- Evaluate feasibility of activities listed in a master plan
- Launch implementation of the master plan
- Encourage an executing agency to establish ownership for the master plan
- Encourage establishment of a required system and acquisition of necessary capabilities to implement the master plan.

J.2 Selected Model Projects

The Mexican Counterpart and the Study Team selected some activities listed in the Master Plan. Then, those were carried out during a course of the Study as Model Projects. Titles and locations of the projects' sites are shown below.

No.	Title
1	Urban type wastewater treatment
2	Village type wastewater treatment
3	Establishment of an Integral SWM Information System
4	Capacity building of Executing Agency in OPB
5	Improvement of the exiting disposal site in OPB
6	Improvement of waste collection in OPB
7	Improvement of waste collection in FCP
8	Establishment of SWM in Costa Maya
9	Environmental education and recycling activity

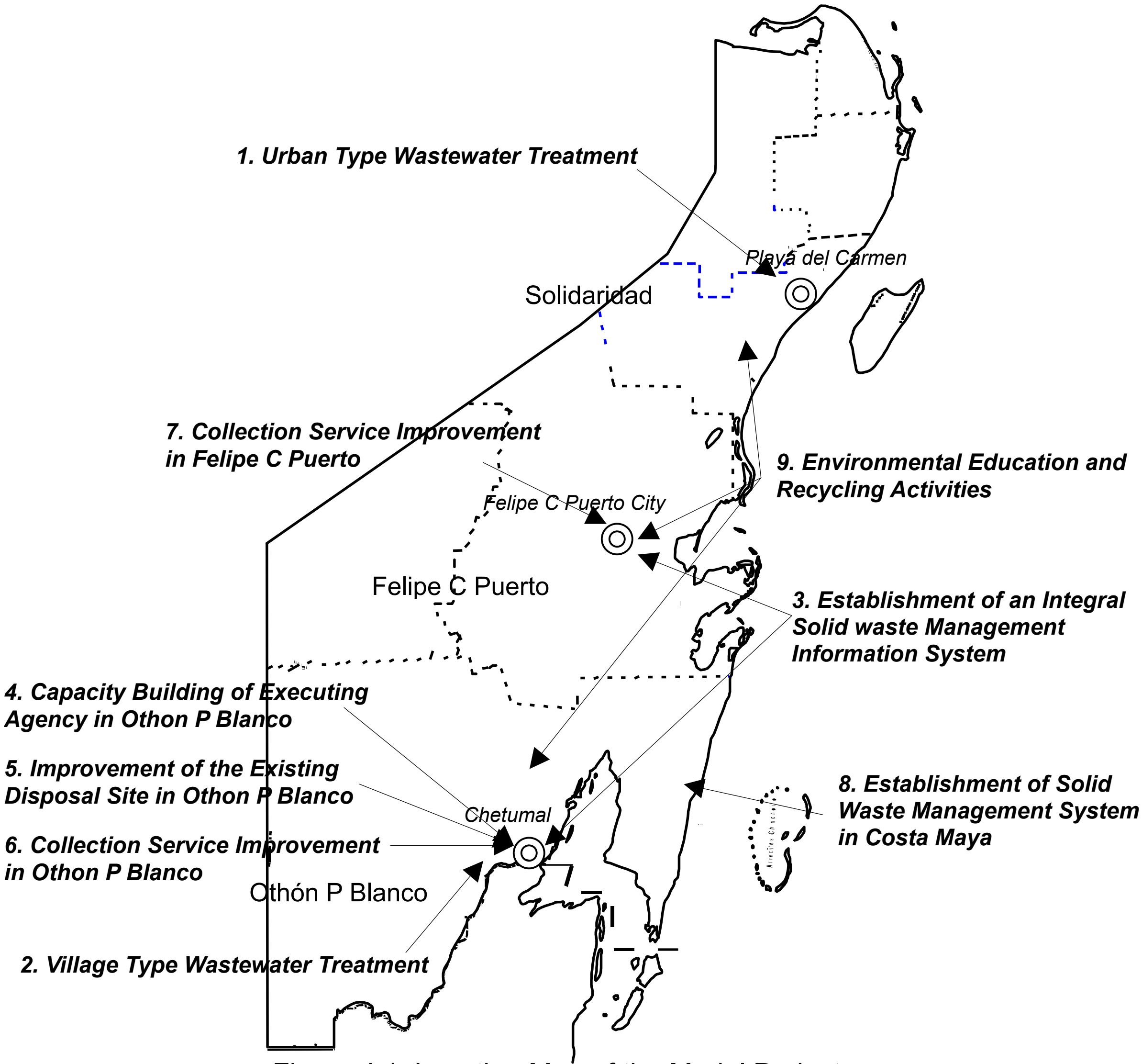

Figure J-1: Location Map of the Model Projects

J.3 Schedule of Model Projects

Figure J-2 shows schedule of the Model Projects. The preparation stage was about two months, where analysis of the present situation and planning of the Mo/Ps were carried out. Also about two months were allowed for the implementation stage, where the Counterparts and the Study Team closely worked and draft manuals were prepared in some Mo/Ps. From March to June 2004, the Mo/Ps were continuously implemented and monitored by the Counterparts themselves according to the prepared manuals. Finally, the Mo/Ps were evaluated based on data obtained from the monitoring in June 2004.

The following is the overall schedule of the Model Projects.

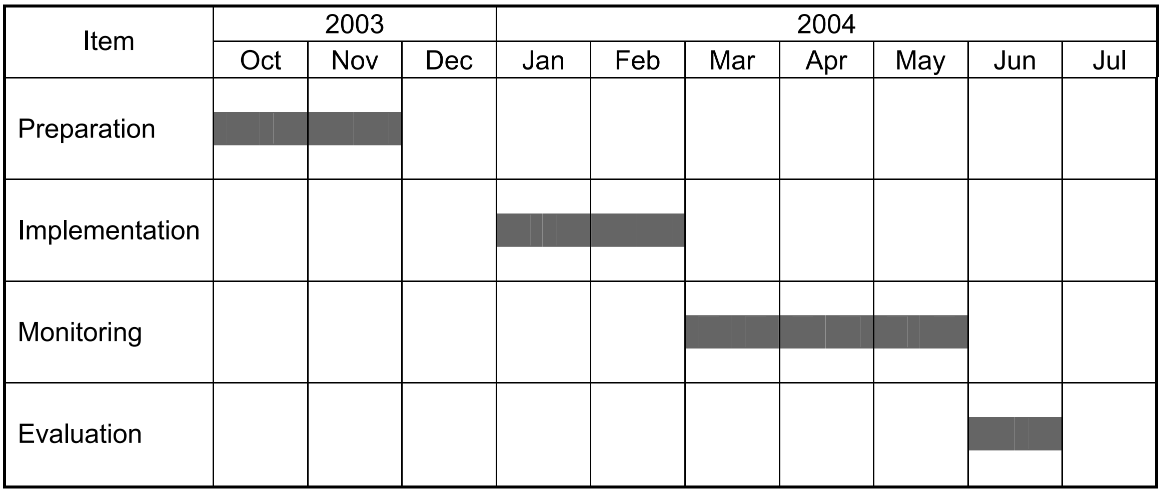

Figure J-2: Schedule of Model Projects

Annex K

Urban Type Wastewater Treatment

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K Urban Type Waste Water Treatment

K.1 Electromagnetic Survey

K.1.1 Purpose of Survey

A geophysical survey by transient electromagnetic method (TEM) was carried out in Playa Del Carmen. The primary objective of the survey was to determine the composition and distribution of limestone aquifers as well as fresh-saline water interface in the study area.

K.1.2 Outline of the survey

K.1.2.1 About TEM

TEM is often referred to as time-domain electromagnetic method. In this method, the ground is energized by man-made magnetic field and its response is measured as a function of time to determine the resistivity of the earth as a function of depth. A steady current is passed through a loop of wire usually situated on the land surface which is inductively linked to the earth. TEM is particularly suitable in areas of high surface resistivities, such as desert, sand dunes or extrusive volcanic etc where the conventional direct current methods are difficult to apply. Vertical electric sounding (VES), one of a direct current method, is also applicable in the study area, however, TEM was employed considering the densely constructed town areas of Playa Del Carmen because VES requires a long straight survey line along the unpaved road. TEM equipment used in the survey was a Sirotem-S (Mark 3) system with fast turn-off accelerator capability, 50x50 and 25x25m sizes loops in coincident (single) loop configuration mode (Figure K-1). TEM survey was entrusted to moro ingenieria, s.c. and conducted under the guidance of the Study Team from August to September, 2003.

Figure K-1: TEM Equipment (SIROTEM-S)

K.1.2.2 Survey Area

TEM survey area is divided into five zones in Playa del Carmen: *a)* urban zone, *b)* actual sewage water treatment plant zone, *c)* new sewage water treatment plant zone (under construction), *d)* municipal landfill zone and *e)* wells battery pipeline zone. There are 10 survey lines, totalizing 217 TEM stations as shown in Table K-1 and Figure K-2.

Table K-1: Survey Area and Number of Stations

LINE	Number of Stations	ZONE
L100	27	Urban zone
L200	23	Urban zone
L300	16	Urban zone
L400	30	Urban zone
L500	25	Urban zone
L600	27	Urban zone
L700	19	Urban zone to New WTP
L800	16	Existing WTP
L900	16	Land fill
L1000	18	Urban zone to Well Fields
Total	217	

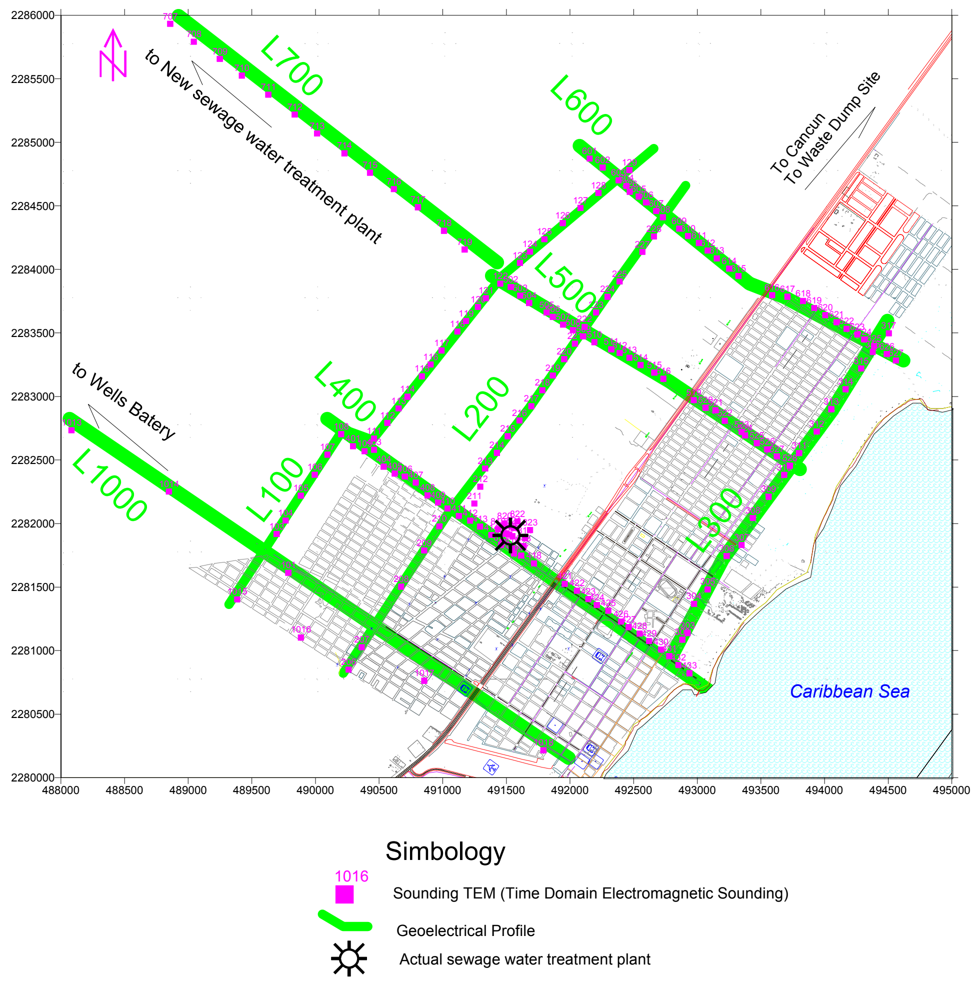


Figure K-2: TEM Survey Line Layout

In order to obtain information on the underground resistivity structure in detail, the survey lines were laid in the surrounding areas of the existing sewage water treatment plant, garbage landfill (waste dump site) and a new sewage treatment plant which is under construction, as shown in Figure K-3, Figure K-4, and Figure K-5.

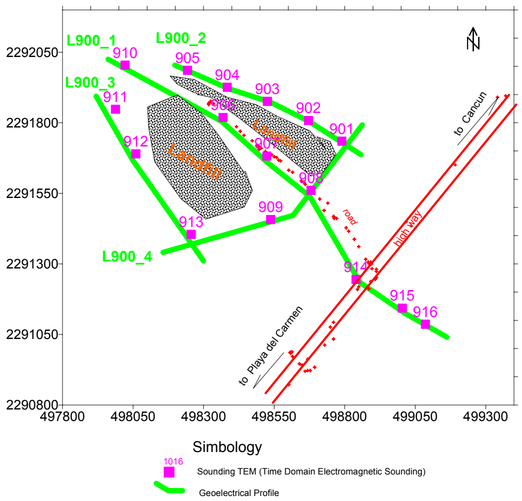


Figure K-3: Solid Waste Final Disposal Site

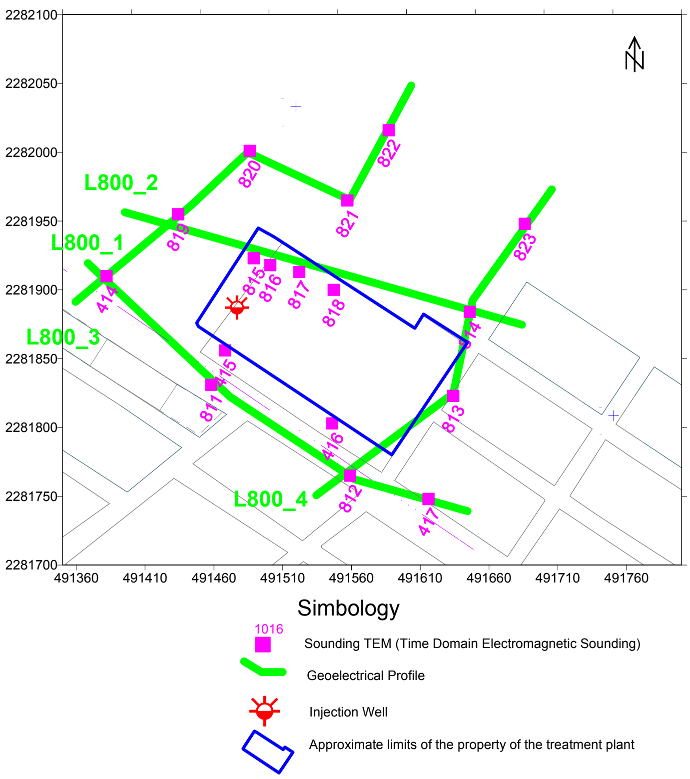


Figure K-4: Sewage Water Treatment Plant

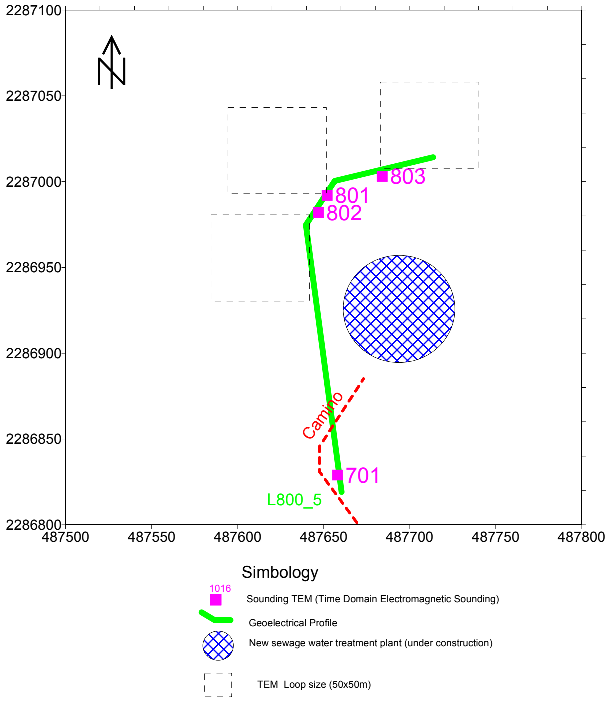


Figure K-5: New Sewage Water Treatment Plant

In addition to the above, the line 1000 was extended from the coast to the CAPA well field (battery wells) at a station interval of 1000m in order to explore the resistivity structure in the profile perpendicular to the coast of Playa Del Carmen (Figure K-6).

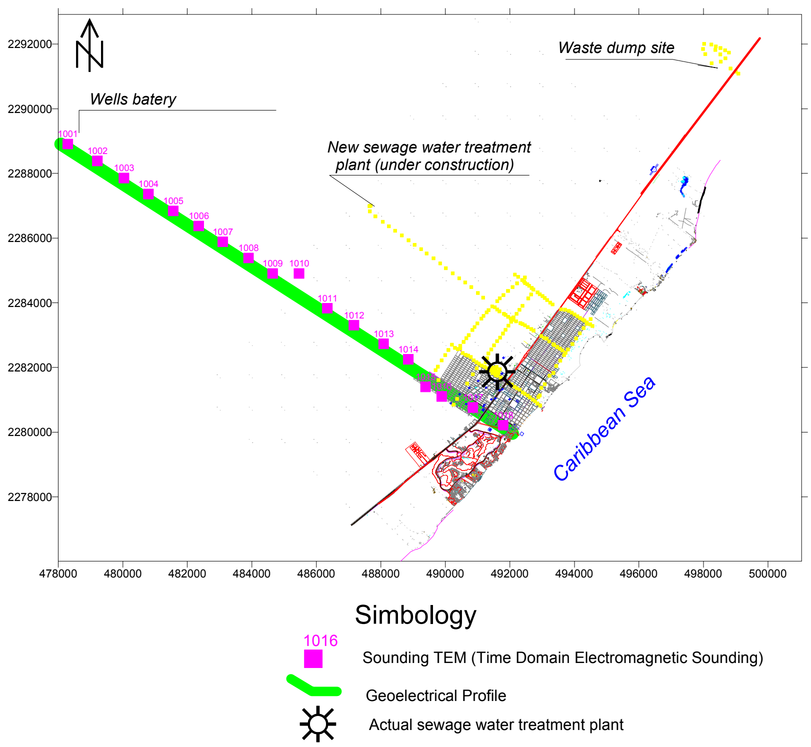


Figure K-6: Layout of Survey Line 1000

K.1.3 Interpretation of Results

K.1.3.1 Resistivity Unit

Based on the results of the survey, the resistivity layer can be divided into three units, U1, U2 and U3, at a boundary resistivity value of 4 ohm-m. U1 and U3 can be subdivided into two units at a boundary resistivity value of 25 ohm-m as shown in Table K-2.

Geophysical interpretation of the resistivity unit is described in the table. A boundary between U1 and U2 is estimated to be a fresh-saline water interface. U1 is a fresh water layer and U2 is a salt water layer consisting of porous and fissure limestone of high karst development. U3 is also estimated to be filled with saltwater, however, the layer is less developed in karst compared to U2.

Interpretation of the resistivity layer is not correlated with borehole geophysical logging, such as fluid conductivity and formation resistivity. It is necessary to compare the TEM resistivity with these geophysical logs and drill cutting samples in order to estimate hydrogeological feature and structure.

Table K-2: Geophysical Units Classification

RESISTIVITY UNIT	RESISTIVITY INTERVAL [ohm-m]	GEOPHYSICAL INTERPRETATION
U1a	Bigger than 25	Limestone or calcareous sandstone, partially saturated with fresh water
U1b	4 to 25	Limestone or calcareous sandstone, with saturation of fresh water
U2	Smaller than 4	Limestone with high karstic development, with brackish and/or salt water
U3a	4 to 25	Limestone with variable karstic development, with salt water
U3b	25 to 100	Limestone with low karstic development, with salt water

K.1.3.2 Resistivity Distribution

a. Urban zone

This zone represents the major part of the geophysical survey area. Resistivity profiles, which are parallel to the coastline, are L100, L200 and L300, while the perpendicular ones are L400, L500 and L600.

In general, U1 shows 4 to 100 ohm-m of resistivity with thickness of approximately 25 m. The resistivity indicates presence of terrestrial fresh water in upper part and brackish water (mixed with seawater) in its lower part. Thickness tends to increase toward inland.

U2 is widely distributed in all the profiles at an average thickness of 50m. Generally, thickness of U2 increases in the vicinity of the coast. It may be inferred that a large volume of seawater fills up the cavities or fissure in the limestone created by dissolution.

U3, which is underlying U2, shows relatively high resistivity and thickness of about 90 m. The resistivity ranges from 15 to 50 ohm-m. As the seawater is contained in its fissure or cavities in U3, this high resistivity may indicate a composition change in rock lithology. Increment of resistivity may be caused by minor dissolution development of limestone in which rock physical property originally occurred in its deposition time. Figure K-7 shows the profile of L400 as an example.

It is possible to see the horizontal distribution of the resistivity at different depths. Horizontal resistivity distribution maps at 10, 20, 25, 30, 40, 50, 75, 100 150m were created.

Figure K-8 shows a horizontal resistivity map at 20m depth. As seen in the map, north-western area of the Playa Del Carmen bounded by the national high way shows resistivity of 10 to 20 ohm-m (green color), which is indicating fresh water zone. It still occupies a large area. However, from the coast to the eastern town area, low resistivity of less than 4 ohm-m (blue color) is extended like a valley. This zone indicates seawater intrusion at 20m depth.

b. Existing Sewage Water Treatment Plant Zone

Thickness of fresh water layer (U1a) ranges from 10 to 20 m and varies place to place in the surrounding areas of the sewage water treatment plant (WTP). Thickness of brackish water layer (U1b) is also from 10 to 20m. Salt water layer (U2) thickness is variable in along the town road facing to WTP compound. It ranges from 30 to 90m. The injection well is estimated to penetrate U2 and reached to U3a as shown in Figure K-9.

c. New Sewage Water Treatment Plant Zone (under construction)

Thickness of U1a is 20m and U1b is 15 m. These layers are approximately flat. Thickness of underlying U2 is 80m in average and intercalates U3a of 10 to 15m thickness. Resistivity basement exists at depth of approximately 100 to 110m. A new injection well is currently being drilled by CAPA. The borehole logs may be correlated with this resistivity distribution.

d. Landfill Zone

In this area, U1 has average thickness of 20m and shows high resistivity values, which indicates a very compact limestone and a minor dissolution development. Thickness of U2 varies place to place. It ranges from 40 to 80m.

e. Well Battery Zone

The CAPA water supply wells are located in the area some 17 km apart from the town. Figure K-10 shows the profile along the road from the coast to the well field. As clearly seen in the profile, thickness of U1a is more than 40m in the well field, while it decreases to 20 m in the vicinity of the coastal town area. U1b is generally thin toward the well field. It should be noted that depth of the supply well is about 25m with high production rate of 25 litter/sec.

Seawater intrudes deep into inland as observed very clearly in the profile. Thickness varies place to place but it ranges from 40 to more than 80m. Relatively high resistivity layer of U3a and U3b exist as the basement rocks, which are extending from the well field to the coast at depth of 60 to 110m.

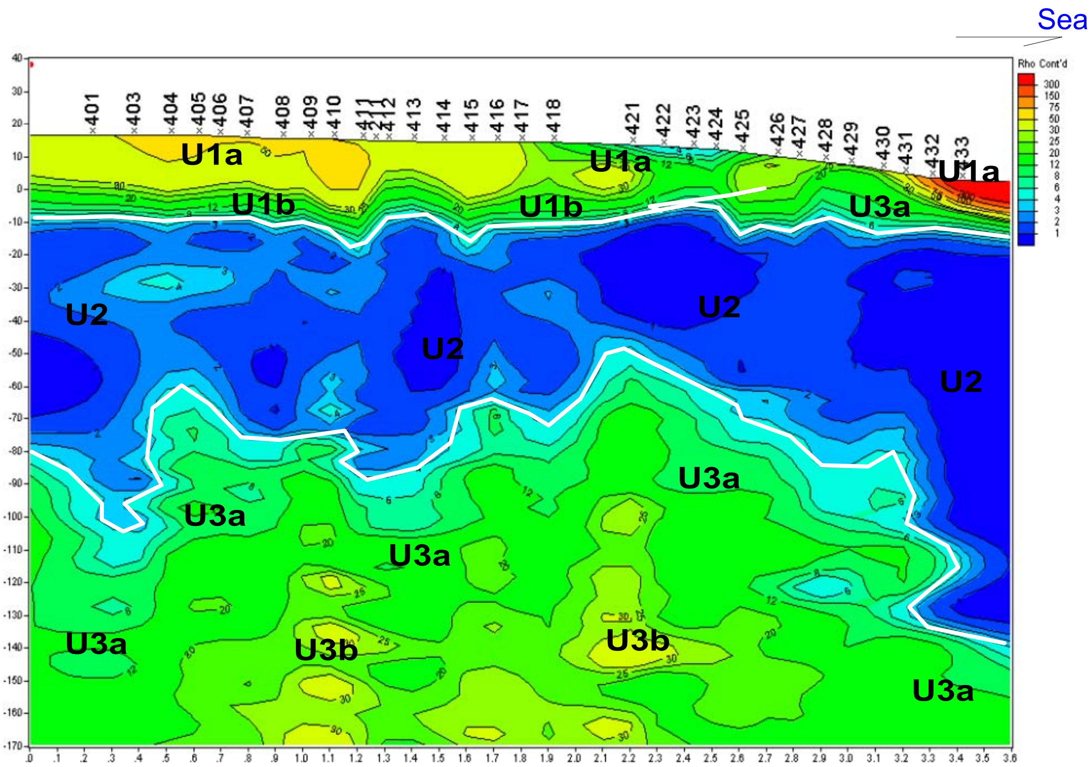


Figure K-7: RESISTIVITY PROFILE LINE 400

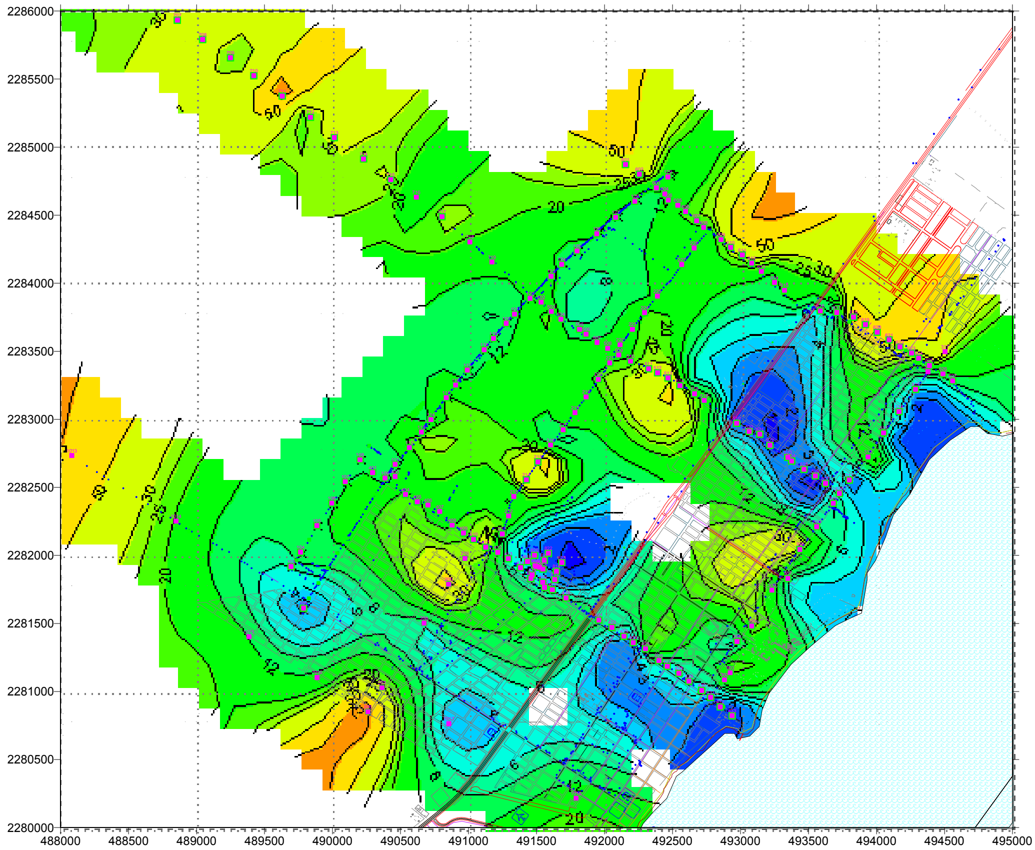


Figure K-8: RESISTIVITY MAP (Depth:20m)

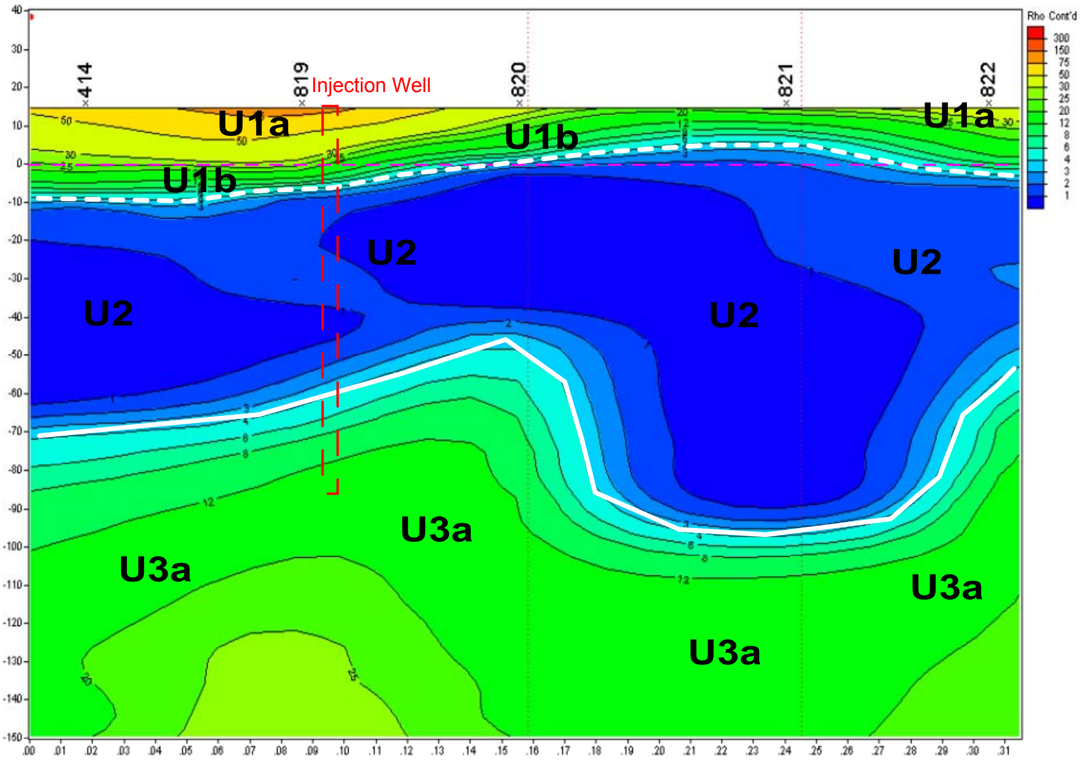


Figure K-9: RESISTIVITY PROFILE AT SEWAGE TREATMENT PLANT

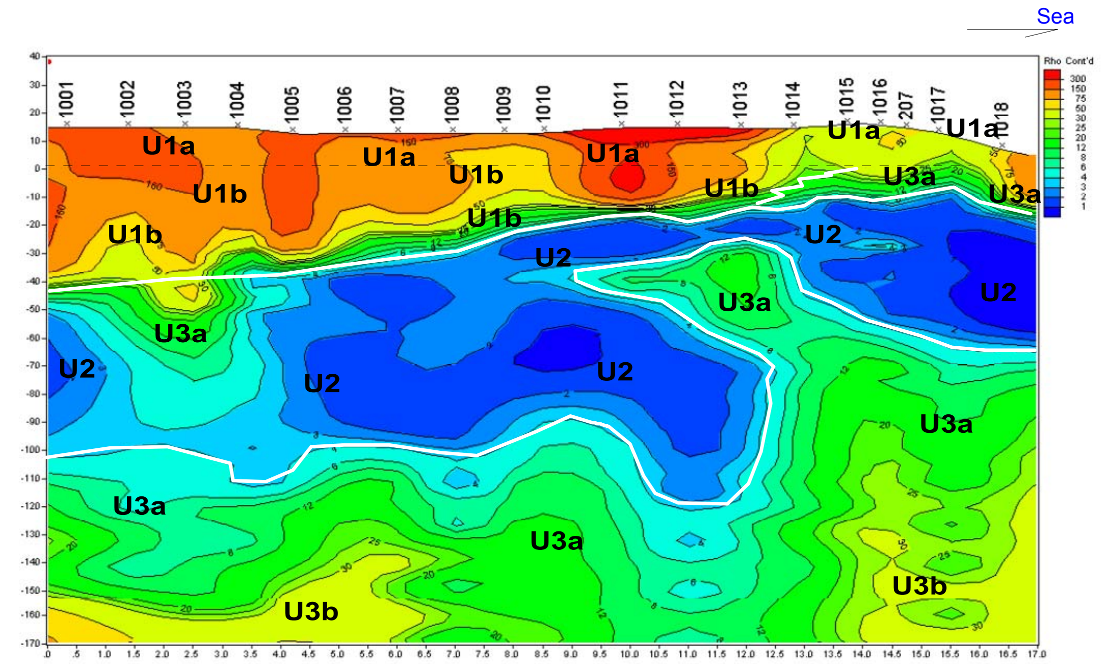


Figure K-10: RESITIVITY PROFILE LINE 1000

K.2 Construction of Monitoring Wells

K.2.1 Drilling Sites

Based on the geophysical survey, the monitoring wells were constructed from the down stream area of CAPA production wells to the coastal town area at different depths in order to confirm lithology of aquifers, distribution of fractures, presence of cavity, fresh water-saltwater interface and water quality etc.

These wells were constructed at different depths in the places and aquifers as shown in Table K-3.

Table K-3: Monitoring Well Construction

Site	Location	Well No.	Aquifers	Depth (m)
Wastewater Treatment Plant	20 38' 16N 87 04' 53W	1'	Upper fresh water	15.0
		2'	Lower fresh water	17.65
		3	Upper salt water	35.0
		4	Lower salt water	100.0
Waste disposal site	20 43' 41N 87 00' 58W	1'	Upper fresh water	15
		2'	Lower fresh water	20.45
Casa Ejidal	20 37' 57N 87 05' 07W	1'	Upper fresh water	15.40
		2'	Lower fresh water	17.35
CAPA Water Supply Reservoir	20 38' 51N 87 03' 52W	1'	Upper fresh water	14.75
		2'	Lower fresh water	17.00

The locations of the monitoring sites are shown in Figure K-11. After completion of borehole drilling, geophysical loggings were conducted. Dilution test was also conducted to determine the permeability of the aquifer.

After drilling operation and borehole tests completed, the casing and screen were placed down to the hole. In the proposed design, annular space between the bore wall and the casing are filled with cement steadily in order to avoid seepage of groundwater from the screen portion. However, due to abundance of the cavities and fractures in the limestone formations, it was impossible to fill the space with cement or bentonite. Therefore, the annular space was empty in the actual design (completed well design). In addition, the full screen was placed in the borehole. If the groundwater flows into the screen laterally, then groundwater can be collected properly at the position where sampler is placed. However, there is a possibility of mixing of groundwater because the downward and upward flow may occur in the well. Figure K-12 shows the proposed and actual design of the monitoring well.

After well completion, water levels and water quality were monitored monthly from the end of March to June 2004 . Groundwater samples were collected and analyzed in the laboratory.

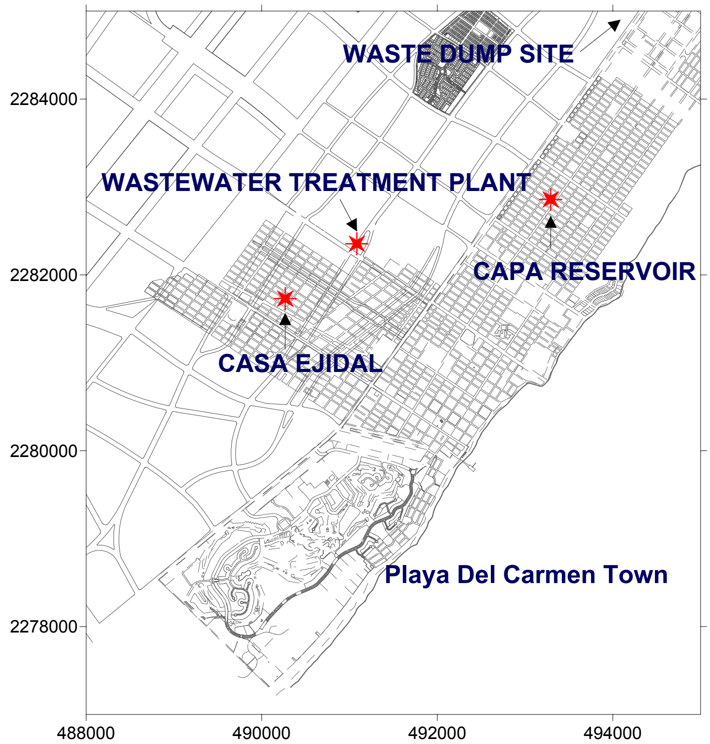


Figure K-11: Location of Drilling Sites

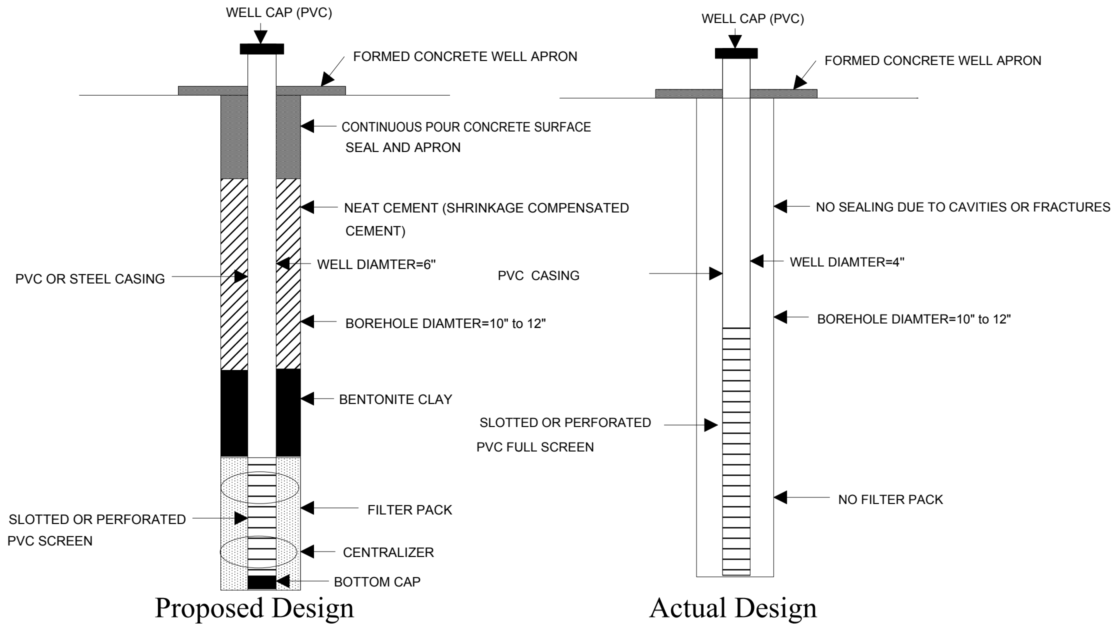


Figure K-12: Monitoring Well Design

K.2.2 Drilling Results

K.2.2.1 Wastewater Treatment Plant (WTP)

a. Lithology

Lithology of the WTP site can be divided into 8 formations as shown in Figure K-13 and described as follows:

1. Fine to medium calcareous sands of obscure brown color. It contains moderately angular or rounded gravels in 5% of the sands on the average (0-1 m).

2. Medium to coarse calcareous sands. It contains 2 to 5 % of moderately angular or rounded gravels. The size of gravel does not exceed 1 cm (1-6 m).

3. Clear brown color, moderately angular or rounded gravels constituted for calcareous fine grain. The size of these gravels is smaller than 1 cm (5-6 m).

4. Thick calcareous clear brown color sands with moderately angular or rounded gravels constituted by limestone; the percentage of gravels is 10%. Its size varies from 4 mm to 1.5 cm (6-10 m).

5. Thick calcareous clear brown color sands with calcareous gravels; the percentage of moderately angular or rounded gravels is 30% on the average. Their size varies from 4 mm to 1.5 cm (10-16 m).

6. Thick calcareous clear brown color sands with calcareous gravels; the percentage of the gravels is 5% (16-19 m).

7. Clear brown color fragment of sandy limestone of fine grain. It contains fragments of shells. The fragments are angular. Their size varies from some millimeters to 1.5 cm. This formation is poorly cemented (19-28 m).

8. White color limestone constituted by corals and fragments of fossils (28-35 m) .

The drilling velocity log shows that most of the formations can be penetrated speedily. These sections are abundant in fractures. However, thin and hard formation can be seen partly at depth from 5 to 10 m. On the other hand, from 65 m below ground surface, light brown color hard formation was encountered. Drilling velocity of the formation is very slow. This indicates the formation is compact and very hard. The formation is composed of muddy limestone or dolomite. This formation was detected by TDEM as mentioned in the previous chapter. It is, probably, distributed widely in the underground of Playa Del Carmen area.

b. Fresh / Saline water Interface

Figure K-13 also shows a depth profile of Electric Conductivity (EC). EC gradually increases with depth from water level (7.8 m) to 17 m. It ranges from 2,940 to 8,710 micro S/cm. A sharp rise can be observed from 21 m indicating 43,200 micro S/cm. This zone, from 17 to 21 m, is a transition zone to seawater and water is brackish. A thickness of fresh water is 9 to 10 m. Seawater exists from the depth of 21 m below.

c. Monitoring well

Four monitoring wells were constructed at different depths in WTP. Most deepest well (No.4) is 100 m. The wells were cased with 4 inches PVC pipe, however, No.4 well was cased with 2 inches pipe in order to insert the casing into small diameter borehole from 65 to 100 m of hard formation.

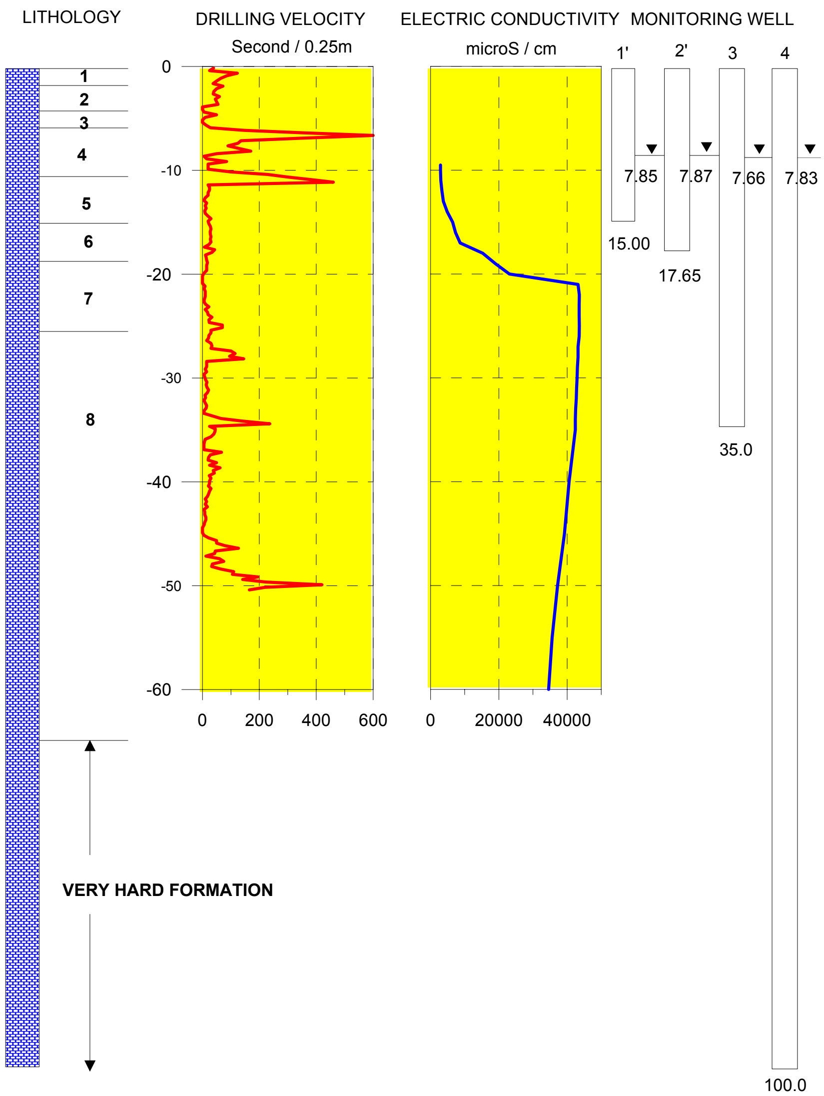


Figure K-13: Borehole Logs in WTP

K.2.2.2 Casa Ejidal

a. Lithology

Lithology of Casa Ejidal site can be divided into 3 formations in the shallow part as shown in Figure K-14. Due to presence of cavity and fractures, drilling log was not obtained from 7 m to deeper part. Lithological description of the shallow part is as follows:

1. Fine to medium obscure brown color calcareous sands with gravels. The gravels are contained approximately 5% of the sands. The size of the gravel is smaller than 1 cm (0-1 m).

2. Fine to medium clear brown to yellowish color calcareous sands with gravels constituted by sandy limestone of fine grain. The size does not exceed 1 cm. The gravels are contained 2 to 5% on the average (1-5 m).

3. Very fine white color calcareous sands with 2% of gravels of white color (5m -).

From 7 m below ground surface, the drilling encountered the cavities so that the lithologic logs were not recorded.

Drilling velocity ranges from 0 to 160 sec/0.25m. Hard formation does not exist except 0 to 5 m. This indicates abundance of fractures and cavities in the shallow formation (0-25m).

b. Fresh / Saline water Interface

A depth profile of EC in Casa Ejidal site is shown in Figure K-14. EC gradually increases with depth from water level (8.3 m) to 19 m. It ranges from 3,610 to 8,420 micro S/cm. A transition zone to seawater is located at depth from 19 to 22 m. The thickness of fresh water is 11 to 12 m. Seawater exists from the depth of 23 m below.

c. Monitoring well

Two monitoring wells were constructed at different depths in Casa Ejidal site. Deep well (No.2) is 17.35 m and shallow well (No.1) is 15.40 m . The wells were cased with 4 inches PVC pipe.

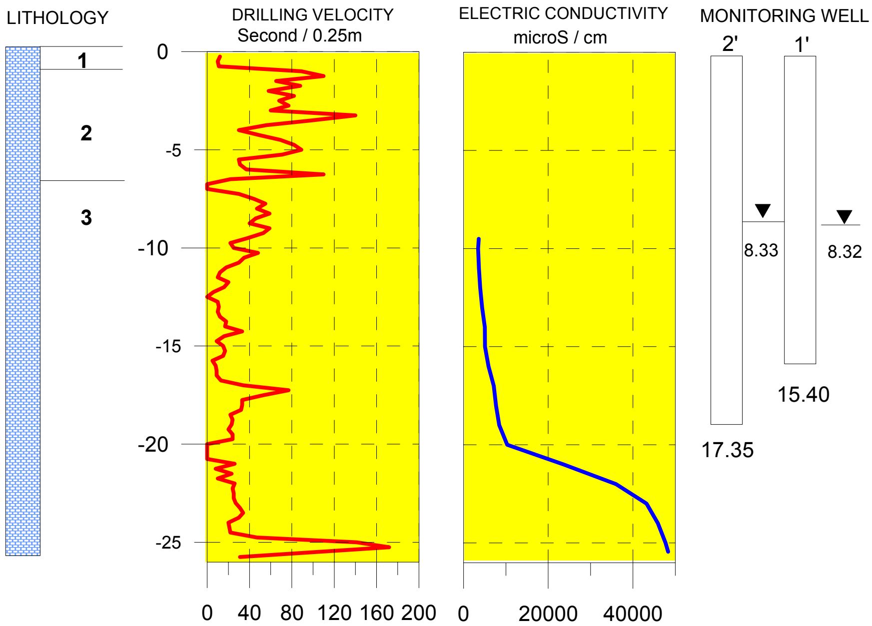


Figure K-14: Borehole Logs in Casa Ejidal

K.2.2.3 Waste Disposal Site

a. Lithology

Lithology of Waste Disposal Site can be divided into 7 formations as shown in Figure K-15. Lithological description of the formations is as follows:

1. Fine to medium clear brown color calcareous sands with gravels. The gravels are contained 5% of the sands. These gravels are moderately angular or rounded (0- 1 m).

2. Fine or fine to medium very clear brown color calcareous sands. They contain 30 to 45% of gravels. The gravels are moderately angular or rounded. The size varies from 4 mm to 1 cm. (1-3 m)

3. Thick clear brown color calcareous sands with 20% of gravels of sandy limestone.(3- 7 m)

4. White color calcareous sands with gravels of 20 to 30%. The gravels are calcareous and not well rounded.(7-9 m)

5. Medium to coarse white to yellowish color calcareous sands with 30% of gravels on the average. The gravels are constituted sandy calcareous very fine grain which is not well rounded.(9-13 m)

6. Splinters of sandy limestone of fine grain with fragments of shells and corals; the formation is poorly cemented. The splinters are clear brown color and angular. Their size varies from 1 mm to 1.5 cm.(13-19 m)

7. Splinters of calcareous rock constituted mainly by corals, in smaller proportion have fragments of shells. The splinters are irregular and angular and their size varies from 0.5 to 1.5 cm (19-22 m).

Drilling velocity ranges from 0 to 190 sec/0.25m. Thin hard bed partly exists from 10 to 25 m, however, the formation of 0 to 5 m is harder than the lower formation. This indicates abundance of fractures and cavities in the lower formation(5-25m).

b. Fresh / Saline water Interface

A depth profile of EC in Waste Disposal Site is shown in Figure K-15. EC gradually increases with depth from water level (3.95 m) to 19 m. It ranges from 1,121 to 3,820 micro S/cm. EC sharply rises at depth of 20 m indicating seawater of 46,500 micro S/cm. No transition zone is observed. A thickness of fresh water is 15 m. Seawater exists from the depth of 20 m below.

c. Monitoring well

Two monitoring wells were constructed at different depths in Waste Dump Site. Deep well (No.2) is 20.45 m and shallow well (No.1) is 15.0 m. The wells were cased with 4 inches PVC pipe.

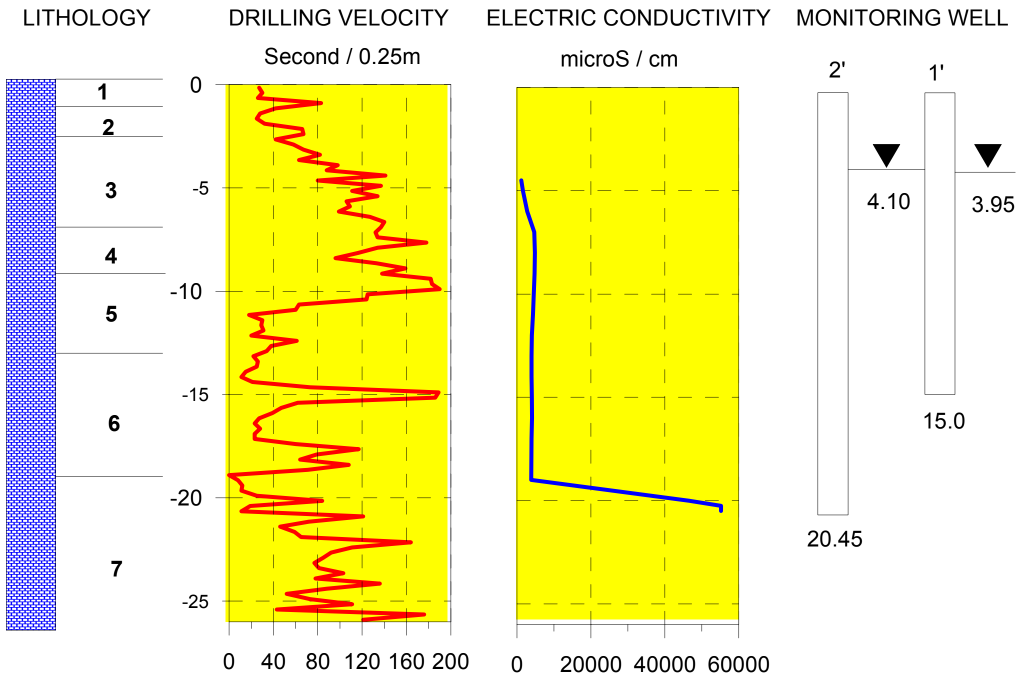


Figure K-15: Borehole Logs in Waste Disposal Site

K.2.2.4 CAPA Water Supply Reservoir

Lithology of CAPA water supply reservoir can be divided into 7 formations as shown in Figure K-16. Lithological description of the formations is as follows:

1. Fine to medium calcareous obscure brown color sands with gravels of yellowish white color. The gravel is moderately angular or rounded and the size varies from 5 mm to 1 cm. The content of gravels is 10% on the average(0-1 m).

2. Fine to medium clear brown color calcareous sands with gravels. The percentage of gravels varies from 2 to 4% on the average and the size is smaller than 1 cm (1-7 m).

3. Thick calcareous clear brown color sands with gravels. The percentage of moderately angular or rounded gravels varies from 30 to 50% on the average. The size varies from 0.5 cm to 1 cm (7-11 m).

4. Fine to medium grayish brown to obscure gray color calcareous sands with gravels containing fragments of shells. The percentage of gravels is 40% (11-15 m).

5. Limestone splinters constituted mainly by coral fragments. It contains small amount of shells and their fragments (15-16 m).

6. Medium to coarse grizzly brown color calcareous sands with poorly cemented gravels of limestone of yellowish white color. Their size varies from 0.6 to 3.5 cm. The percentage of gravels is 30% (16- 20 m).

7. Limestone splinters constituted mainly for corals, fragments of shells and very little sand. The splinters are angular irregularly (20m-).

Drilling velocity is less than 100 sec/0.25m from 0 m to 13 m indicating abundance of fracture. Hard formation partly exist from 20 m. However, the formations are totally abundant in fractures at this site.

a. Fresh / Saline water Interface

A depth profile of EC in CAPA Water Supply Reservoir is shown in Figure K-16. EC gradually increases with depth from water level (6.18 m) to 19 m. It ranges from 3,950 to 8,280 micro S/cm. EC sharply rises at depth of 21 m indicating seawater of 48,300 micro S/cm. A transition zone is 19 to 21 m. A thickness of fresh water is 13 m. Seawater exists from the depth of 21 m below.

b. Monitoring well

Two monitoring wells were constructed at different depths in CAPA Water Supply Reservoir. Deep well (No.2) is 17.0 m and shallow well (No.1) is 14.75 m. The wells were cased with 4 inches PVC pipe.

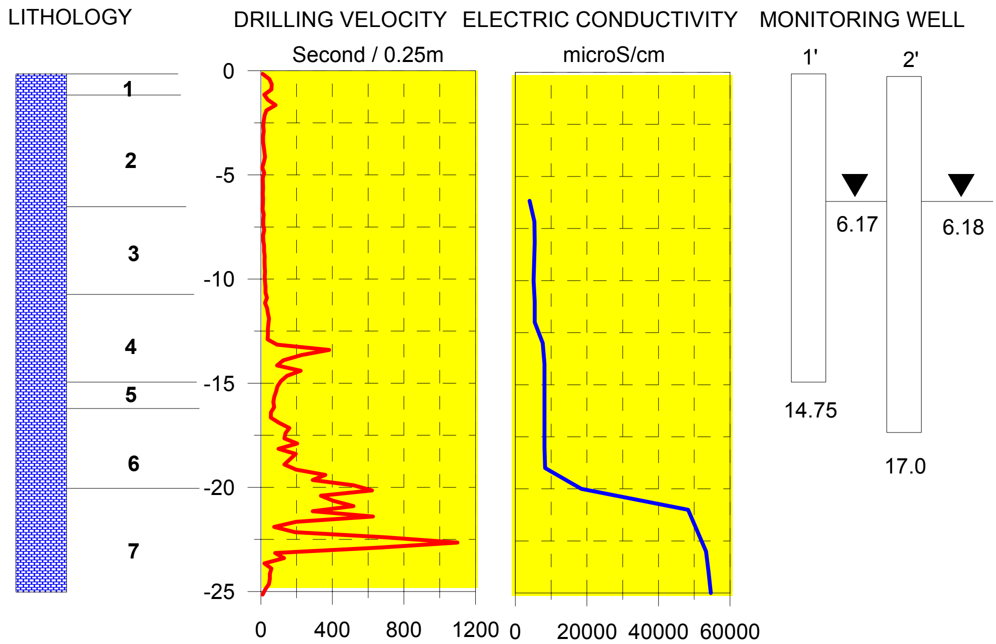


Figure K-16: Borehole Logs in CAPA Water Supply Reservoirs

K.2.3 Point Dilution Test

In order to measure groundwater velocities in the limestone aquifers, a point-dilution method (Drost et al, 1968)[1] was applied at the 10 (ten) boreholes.

Three litters of seawater were introduced at 30-50 cm below the water table. After injection, decline or rise of EC was monitored.

According to Drost, the velocity "v" is computed from

$$v = -(\pi r f / 2t)\ln\left[(c - c^*)/(c^\circ - c^*)\right]$$

where;

v : velocity of groundwater
r : the radius of the borehole
f : an empirical correction for influence of the well on groundwater flow
c : the conductivity at time "t"
c° : the conductivity at "t" equals zero after injection
c^* : the baseline conductivity before injection

[1] Point dilution method of investigating groundwater flow by means of radioisotopes, Water Resources Research, v.4, pp. 125-146

"f " was set to one (1) because the borehole is not cased during the test. EC was observed , then ln{(c-c*)/(c0-c*)} was computed to estimate gradient of the plots (Figure K-17 and Figure K-18) .

Table K-4 presents the velocities computed at the boreholes. The hydraulic conductivity was computed by Darcy's Law.

$$v_x = -K/n_e \cdot (dh/dl)$$

where vx is the average linear velocity, K is the hydraulic conductivity (coefficient of permeability), ne is the effective porosity and *(dh/dl)* is the hydraulic gradient.

(dh/dl) is assumed based on the INEGI water level data as 1/5000 or less. There are no data available on the effective porosity of limestone. Therefore, it was assumed as 0.2 considering abundance of fractures and/or cavities.

Table K-4: Velocity and Hydraulic Conductivity Estimated from Dilution Test

Site	Well No.	Diameter(cm)	Velocity (cm/sec)	Conductivity(cm/sec)
Wastewater Treatment Plant	1	20.32	0.0040	4.0
	2	20.32	0.0052	5.2
	3	20.32	0.0220	22.0
	4	20.32	0.0206	20.6
Waste disposal site	1	10.0	***	***
	2	10.0	0.0005	0.5
Casa Ejidal	1	25.4	0.0207	20.7
	2	25.4	0.0065	6.5
CAPA Water Supply Reservoir	1	25.4	0.0035	3.5
	2	25.4	0.0011	1.1

*** not analyzed

In the velocity calculations, the assumption is made that the borehole conductivity is constant across the diameter of the borehole and that flow and dispersion are not occurring in a vertical direction at the monitoring point. However, this assumption may not be valid. In Figure K-17 and Figure K-18, early time decline of EC was neglected in order to fit linear relationship between the time and ln{(c-c*)/(c0-c*)}. In addition, the hydraulic gradient and the effective porosity might be mere assumption. Therefore, the velocity and hydraulic conductivity in Table K-4 are just for reference.

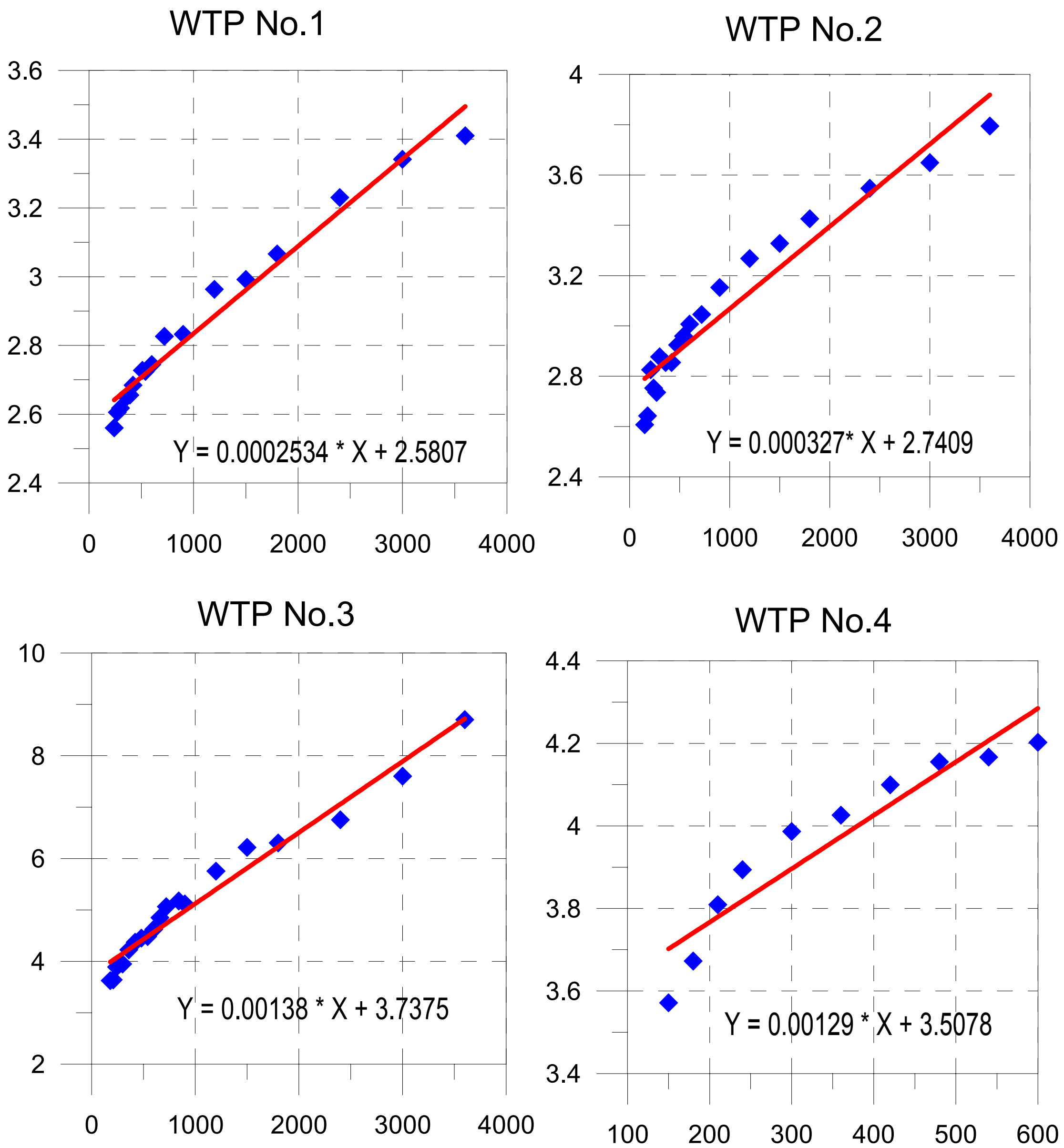


Figure K-17: Point Dilution Test in WTP Boreholes

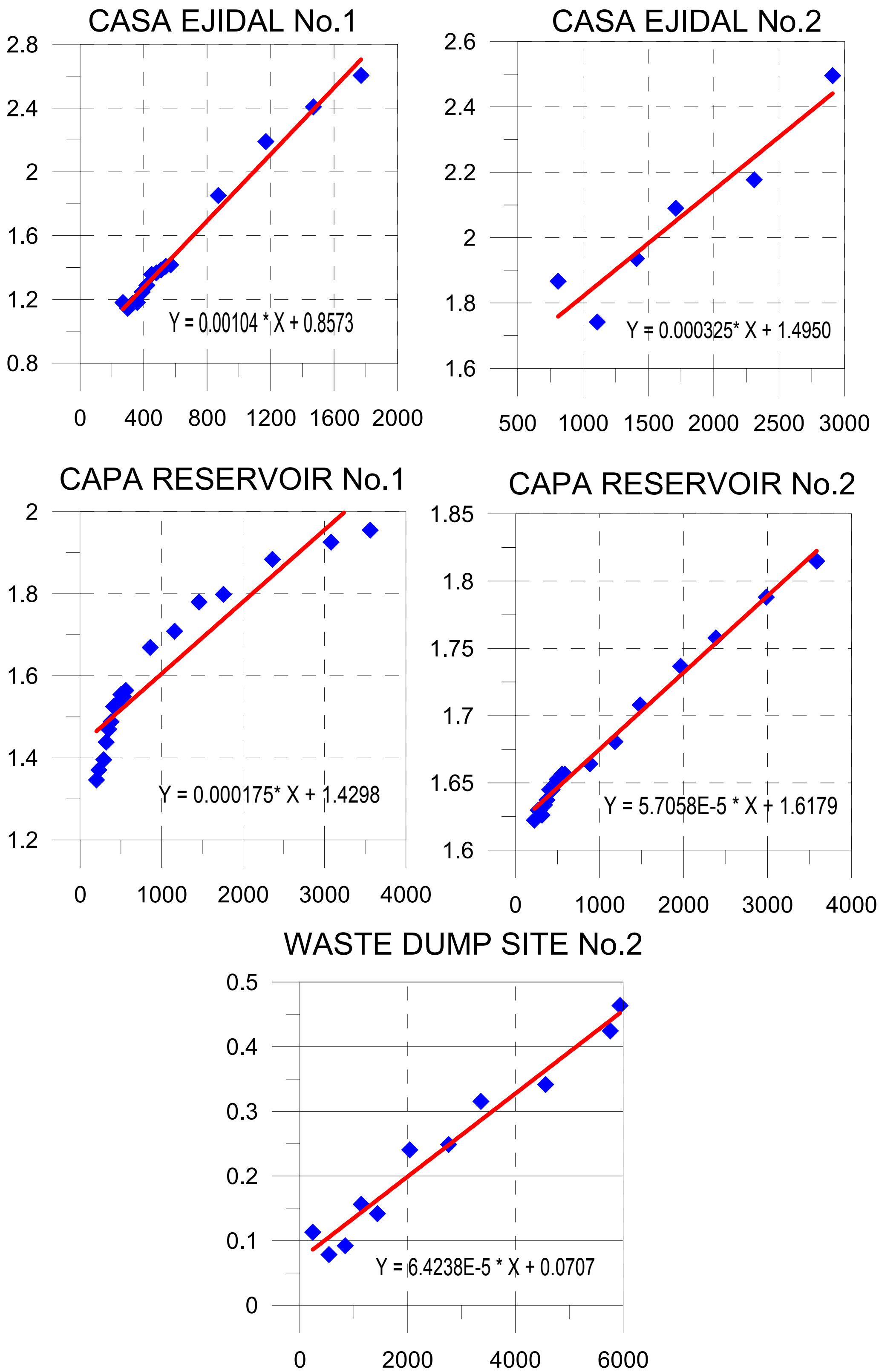


Figure K-18: Point Dilution Test in Casa Ejidal, CAPA Reservoir and Waste Dump Site Boreholes

K.3 Water Quality Analysis

K.3.1 Purpose

Groundwater quality is very important factor for supplying safe drinking water to the three municipalities of the study area. If groundwater is contaminated, near shore waters may also be affected because it finally flows out the coast through underground aquifers. However, the actual conditions of the groundwater quality were not clarified before the JICA study. It is well known that the groundwater quality varies with well location, well depth, well type, and aquifer. In the Yucatan Peninsula, the seawater aquifer exists under the fresh water aquifer and the municipal water supply wells are mostly located in the rural inland area some 15 km to 40 km away from the coast. Groundwater of those supply wells is not contaminated yet; however, fresh water aquifer might be contaminated due to disposal of waste water, particularly, in the urban area where the sewer system has not yet fully developed.

It is, therefore, emphasized in this study that the investigation of groundwater quality is very important to evaluate the groundwater contamination from the point of water environment. The results of water analysis can provide important information on groundwater quality for formulating the future management of waste water injection in the study area.

K.3.2 Groundwater Sampling and Analysis

Groundwater quality of the newly constructed monitoring wells was collected during a period from February to June 2004 after the completion of the monitoring well construction. The samples were sent to the laboratories in Merida.

K.3.2.1 Parameters and Sampling in February 2004

a. Parameters

In February 2004, groundwater samples were collected by the study team and the following physical, biological and chemical parameter were analyzed correspondingly applying the Mexican Standard of Drinking Water (NOM-127-SSA1-1994). Number of the parameter is thirty seven (37).

Temperature, Color, pH, General bacteria, Coliform, Electric conductivity, Hardness ($CaCO_3$) , Total Dissolved Solid, Arsenic (As), Alminum (Al), Ammonium (NH_4), Barium (Ba), Bicarbonate (HCO_3), Cadmium (Cd), Calcium (Ca), Carbonate (CO_3), Chloride (Cl), Chromium(Cr), Copper(Cu), Cyanide(Cn), Fluoride(F), Iron(Fe), Lead(Pb), Magnesium (Mg), Manganese (Mn), Mercury(Hg), Nickel(Ni), Nitrate(NO_3), Nitrite(NO_2), Phenol, Phosphate,(PO_4), Potassium(K), Silica (SiO_2), Sodium (Na), Sulfate (SO_4), Trichloroethylene ($CHCl{=}CCl_2$), Zinc (Zn)

b. Sampling

Groundwater samples were collected from the monitoring wells as presented in the following table. In addition to the groundwater, a treated water sample was collected at CAPA Wastewater Treatment Plant in Playa Del Carmen.

Table K-5: Sampling Location and Date

No.	Location	Name of Well	Well Depth	Sampling Depth	Date
1	Wastewater Treatment Plant	P1	15.0	9.0	28-Feb-04
2	Wastewater Treatment Plant	P2	17.6	16.0	28-Feb-04
3	Wastewater Treatment Plant	P3	35.0	30.0	28-Feb-04
4	Wastewater Treatment Plant	P4	100.0	61.0	28-Feb-04
5	Wastewater Treatment Plant	Treated Water	-	-	28-Feb-04
6	Waste Disposal Site	P1	15.0	8.0	29-Feb-04
7	Waste Disposal Site	P2	20.45	8.0	29-Feb-04
8	CAPA Reservoir	P1	14.7	10.0	29-Feb-04
9	CAPA Reservoir	P2	17.0	16.0	29-Feb-04
10	Casa Ejidal	P1	15.4	10.0	29-Feb-04
11	Casa Ejidal	P2	17.3	16.0	29-Feb-04

K.3.2.2 Parameters and Sampling in the Monitoring Period

Groundwater sampling and analysis were conducted four (4) times by the CNA team monthly from March to June 2004. The following ten (10) parameters were analyzed in the laboratory in Merida: Temperature, pH, Color, Nitrite (NO_2), Nitrate (NO_3), Electric conductivity (EC), Sulfate (SO_4), Total dissolved solids (TDS), General bacteria, Coliform.

K.3.3 Results of Laboratory Analysis

The results of laboratory analysis of groundwater samples collected from the monitoring wells are tabulated in Table K-7.

K.3.3.1 Analysis of 37 Parameters

a. Major Dissolved Ions

Table K-6 shows the concentration of major ions in meq/L. Almost all samples show (Na+K)-Cl type water, which means the groundwater is salinized by seawater. The samples from P3 and P4 of the wastewater treatment plant show particularly high concentration of Cl, (Na+K), Ca and Mg because these wells tap to seawater aquifer. Total amount of cation and anion of the treated water (No.5) is smallest among eleven (11) samples. However, as presented in Table K-7, Cl concentration of P3 and P4 shows 11,834 mg/L and 11,457 mg/L, respectively. Generally, Cl concentration of seawater is more than 30,000 mg/L. Comparing with this concentration, these two samples show lower concentration than seawater. This may indicates that the groundwater in these two wells is mixed with shallow saline or fresh water due to the well structure, more specifically, fully screened well casings.

Table K-6: Concentrations of Major Ions in the Monitoring Wells

No.	Na	K	(Na+K)	Ca	Mg	Cation Total	Cl	HCO3	SO4	Anion Total
	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	meq/L	Meq/L
1	14.78	0.48	15.26	6.38	3.51	25.14	17.16	6.35	2.22	25.73
2	56.68	1.08	57.76	7.93	20.49	86.19	60.38	9.40	6.46	76.24
3	282.18	6.64	288.83	20.89	65.70	375.42	333.83	4.93	37.59	376.35
4	245.85	5.46	251.31	17.30	58.35	326.97	323.19	4.95	37.36	365.50
5	10.54	0.48	11.02	5.42	2.77	19.22	10.85	2.78	2.22	15.85
6	19.98	0.31	20.30	4.84	5.47	30.61	21.15	5.45	2.19	28.78
7	25.07	0.47	25.54	5.42	8.53	39.49	32.19	5.52	3.52	41.22
8	18.17	0.56	18.72	6.09	7.06	31.88	17.02	4.48	2.25	23.76
9	38.51	0.87	39.39	6.33	10.86	56.58	52.93	5.42	5.12	63.47
10	18.29	0.44	18.72	5.28	5.35	29.35	23.41	5.62	2.48	31.51
11	24.95	0.56	25.51	4.94	6.33	36.78	32.98	5.55	3.61	42.15

Figure K-19 shows the trilinear diagram of the groundwater in the monitoring wells. Almost all samples are plotted on the right hand side of the diagram indicating high (Na+K) and Cl. No.3 and No.4 samples are plotted on the right edge of the diagram indicating typical seawater characteristics and their radius of total ions circle is the largest, although they may be mixed with fresh or saline water and amount of dissolved chloride is smaller than ordinary seawater.

Table K-7: Results of Water Quality Analysis

No.	Location	Name of well	Water temperature	pH	EC	Color	Odor	Floating matte	Total alkalinity	Chlorides	Total hardness	Hardness (Calcium)	Hardness (Magnesium)	Color
			° C		mS/cm	-	-		mg/L	mg/L	mg/L	mg/L	mg/L	-
	WHO Guide Line									250				
	Mexican Standard													
1	Carmen STP	P1	23	7.26	2,570	Agua Clara	Fétido	Ausencia	387.60	608.22	509.95	305.94	204.01	20
2	Carmen STP	P2	24	7.08	7,240	Agua Clara	Fétido	Ausencia	573.24	2,140.54	1,059.89	337.72	722.17	33
3	Carmen STP	P3	28	7.31	30,800	Agua Clara	Fétido	Ausencia	300.90	11,834.27	4,265.45	750.92	3,514.33	13
4	Carmen STP	P4	27	6.82	24,300	Agua Clara	Fétido	Ausencia	301.92	11,457.08	3,886.74	691.34	3,195.40	10
5	Carmen STP	Treated water	25	7.36	1,950	Agua Sucia	Fétido	Ausencia	169.32	384.73	434.52	246.34	188.18	29
6	Carmen Landfill	P1	20.5	7.23	3,150	Agua Clara	Fétido	Ausencia	332.52	749.66	613.91	325.80	208.11	0
7	Carmen Landfill	P2	20.8	6.96	4,420	Agua Turbia	Fétido	Ausencia	336.60	1,140.99	733.50	-	-	0
8	PDC reservoir	P1	25.5	7.33	2,630	Café Claro	Fetidez baja	Ausencia	273.36	603.50	478.37	-	-	200
9	PDC reservoir	P2	25.5	7.18	6,930	Agua Clara	Fétido	Ausencia	330.48	1,876.51	976.67	-	-	15
10	Colonia ejidal	P1	27	7.26	3,440	Agua Clara	Fetidez baja	Ausencia	342.72	829.81	589.99	-	-	43
11	Colonia ejidal	P2	26	7.05	4,600	Agua Clara	Fetidez baja	Ausencia	338.64	1,169.28	707.23	-	-	9

No.	Location	Name of well	Total dissolved solid	Sulfates (SO4)	Residual chlorine	Turbidity	Nitrite (NO2)	Nitrate (NO3)	Ammonium nitrogen	In-org N	Phosphates	Fluoride (F)	Methylene blue active substance (MBAS)	Bicarbonates
			mg/L	mg/L	mg/L		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	WHO Guide Line		1000	250			3	50	1.5			1.50		
	Mexican Standard													
1	Carmen STP	P1	1,461.00	106.85	0.07	57	0.001	0.2	15.34	179.46	1.86	0.44	3.930	387.60
2	Carmen STP	P2	4,272.50	310.40	0.07	25	0.004	2.1	33.81	371.38	9.98	0.68	7.550	573.24
3	Carmen STP	P3	23,111.25	1,805.40	0.1	18	0.005	5.0	8.24	1836.75	3.11	1.43	3.120	300.90
4	Carmen STP	P4	23,541.00	1,794.30	0.17	5	0.003	3.4	13.64	1816.51	4.18	1.47	3.930	301.92
5	Carmen STP	Treated water	1,391.50	106.85	0.02	13	0.018	8.7	0	128.59	23.47	1.14	0.325	169.32
6	Carmen Landfill	P1	1,976.50	105.07	0.07	2	0.004	0.5	0	107.64	N.D	0.29	0.042	332.52
7	Carmen Landfill	P2	2,529.50	169.07	0.02	6	0.004	0.6	0	175.69	N.D	0.37	0.108	336.60
8	PDC reservoir	P1	1,318.00	108.18	0	2519	0.004	8.1	0	2635.28	N.D	4.00	0.088	273.36
9	PDC reservoir	P2	3,878.00	245.68	0	321	0.004	1.2	0	567.88	N.D	0.82	0.056	330.48
10	Colonia ejidal	P1	1,694.00	119.13	0.09	138	0.018	0.5	4.83	262.57	N.D	0.39	0.180	342.72
11	Colonia ejidal	P2	2,712.00	173.51	0.05	14	0.003	0.2	1.98	189.74	N.D	0.39	0.062	338.64

No.	Location	Name of well	Carbonates	Salmonella	Sptaphilococcos Aureus	Total coliform	Fecal coliform	Iron (Fe)	Zinc (Zn)	Lead (Pb)	Arsenic (As)	Total chromium (Cr)	Cadmium (Cd)	Magnesium (Mg)
			mg/L			NMP/100mL	NMP/100mL	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	WHO Guide Line							0.3	3	0.01	0.01		0.003	
	Mexican Standard													
1	Carmen STP	P1	0	Ausente	0	>2400	>2400	< L.D	< L.D	< L.D	< L.D	< L.D	< L.D	42.65
2	Carmen STP	P2	0	Ausente	0	<3	<3	10.85	< L.D	< L.D	< L.D	0.034	< L.D	249.18
3	Carmen STP	P3	0	Ausente	0	460	460	< L.D	0.093	< L.D	< L.D	0.034	< L.D	798.97
4	Carmen STP	P4	0	Ausente	0	240	93	0.07	< L.D	< L.D	< L.D	0.034	< L.D	709.58
5	Carmen STP	Treated water	0	Ausente	0	>2400	>2400	< L.D	0.097	< L.D	< L.D	0.013	< L.D	33.71
6	Carmen Landfill	P1	0	Ausente	0	43	9	< L.D	< L.D	< L.D	< L.D	0.013	< L.D	66.49
7	Carmen Landfill	P2	0	Ausente	0	460	75	< L.D	< L.D	< L.D	< L.D	< L.D	< L.D	103.73
8	PDC reservoir	P1	0	Ausente	0	9	<3	1.92	0.079	< L.D	< L.D	< L.D	< L.D	85.86
9	PDC reservoir	P2	0	Ausente	0	460	240	< L.D	< L.D	< L.D	< L.D	< L.D	0.011	132.04
10	Colonia ejidal	P1	0	Ausente	0	1100	1100	27.40	0.05	< L.D	< L.D	< L.D	< L.D	65.00
11	Colonia ejidal	P2	0	Ausente	0	240	93	< L.D	< L.D	< L.D	< L.D	0.013	< L.D	76.92

No.	Location	Name of well	Barium (Ba)	Copper (Cu)	Aluminum (Al)	Sodium (Na)	Calcium (Ca)	Potassium (K)	Manganese (Mn)	Silica (SiO2)	Phenol	Trichloroethylene (CHCL=CCl2)	Cyanides(CN)	Mercury (Hg)
			mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
	WHO Guide Line			2		200			0.1				0.01	0.001
	Mexican Standard													
1	Carmen STP	P1	< L.D	< L.D	< L.D	339.83	127.87	18.80	0.03	5.14	< L.D	N.D	< L.D	< L.D
2	Carmen STP	P2	< L.D	< L.D	< L.D	1303.62	158.99	42.35	0.112	7.05	< L.D	N.D	< L.D	< L.D
3	Carmen STP	P3	< L.D	< L.D	< L.D	6490.25	418.71	259.66	0.041	4.19	< L.D	N.D	< L.D	< L.D
4	Carmen STP	P4	< L.D	< L.D	< L.D	5654.60	346.76	213.49	< L.D	4.19	< L.D	N.D	< L.D	< L.D
5	Carmen STP	Treated water	< L.D	< L.D	< L.D	242.34	108.68	18.92	< L.D	9.91	< L.D	N.D	< L.D	< L.D
6	Carmen Landfill	P1	< L.D	< L.D	< L.D	459.61	97.03	12.24	< L.D	< L.D	< L.D	N.D	< L.D	< L.D
7	Carmen Landfill	P2	< L.D	< L.D	< L.D	576.60	108.68	18.31	< L.D	< L.D	< L.D	N.D	< L.D	< L.D
8	PDC reservoir	P1	0.162	< L.D	< L.D	417.83	122.11	21.84	< L.D	11.33	< L.D	N.D	< L.D	< L.D
9	PDC reservoir	P2	< L.D	< L.D	< L.D	885.79	126.91	34.11	0.03	< L.D	< L.D	N.D	< L.D	< L.D
10	Colonia ejidal	P1	< L.D	0.074	< L.D	420.61	105.80	17.10	0.041	< L.D	< L.D	N.D	< L.D	< L.D
11	Colonia ejidal	P2	< L.D	< L.D	< L.D	573.82	99.09	21.96	0.123	< L.D	< L.D	N.D	< L.D	< L.D

b. Comparison with WHO Guideline Value

Although Mexico has own drinking water standard, the results of the laboratory test were compared with the WHO guideline[2] value for drinking water. All of eleven (11) groundwater samples (one treated water) could not pass the WHO guideline values in terms of chloride (Cl), TDS, sodium (Na) and other several parameters.

(a) Na

The WHO guideline value of Na is 200 mg/L. No monitoring wells were below the guideline value.

(b) Fe

The WHO guideline value of Fe is 0.3 mg/L. There are 3 wells exceeding the guideline value. The maximum Fe concentration of 27.4 mg/L was detected at P1 well of Colonia Ejidal.

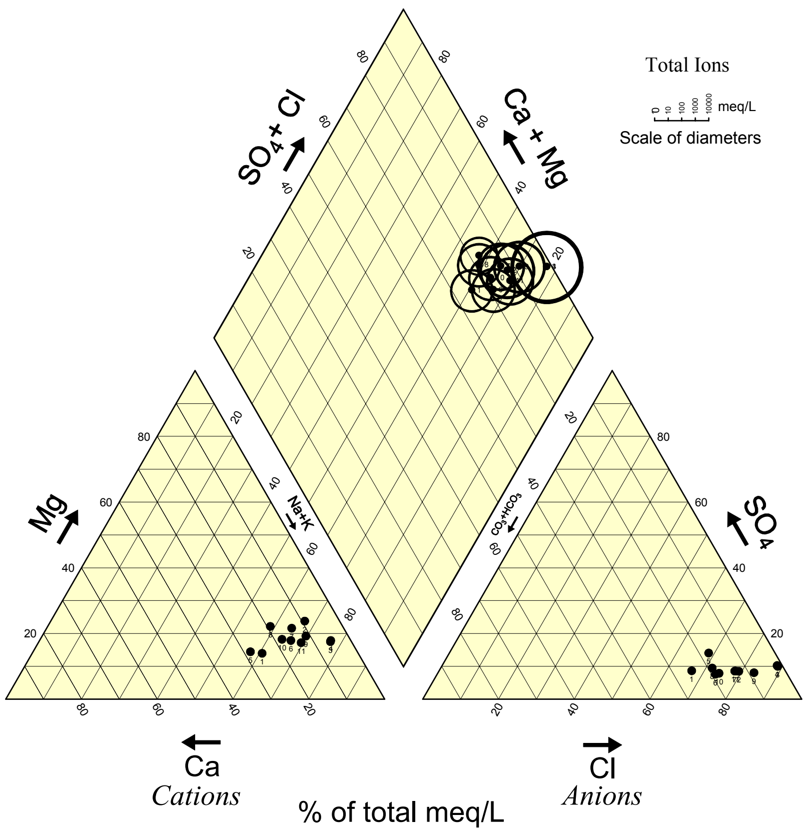


Figure K-19: Trilinear Diagram of Groundwater Samples

[2] WHO (1996): Guidelines for drinking-water quality, 2nd edition. Volume 2, Health criteria and other supporting information, WHO, Geneva

(c) Mn

The WHO guideline value of Mn is 0.1 mg/L. According to WHO (1996), the level of complaints about the taste, smell, and color from the users is set at 0.1 mg/L and the temporal guideline value from the health aspect is set at 0.5 mg/L. There are 2 wells having more than 0.1 mg/L in Mn concentration.

(d) As

The WHO guideline value of As is 0.01 mg/L. All samples are less than detective limit.

(e) Cl

The WHO guideline value of Cl is 250 mg/L. All wells are exceeding the guideline value.

(f) NO_3, NO_2

The WHO guideline value of NO_3 is 50 mg/L and NO_2 3 mg/L, respectively. No well exceeds the guideline value.

(g) F

The WHO guideline value of F is 1.5 mg/L. P1 of PDC reservoir is exceeding the guideline value.

(h) TDS

The WHO guideline value of TDS is 1,000 mg/L. All monitoring wells are exceeding the guideline value.

(i) NH_4 and SO_4

The WHO guideline values of NH_4 and SO_4 are 1.5 mg/L and 250 mg/L, respectively. All the monitoring wells in the wastewater treatment plant and Colonia Ejidal exceed NH_4 guideline value indicating man-made contamination. Concentration of SO_4 of all wells is below the guideline value except P2,P3 and P4 of the wastewater treatment plant. This contamination is caused by the raw wastewater injection in the compound of the wastewater treatment plant. The monitoring wells are located at a distance of about 100 m away from the injection well.

(j) Other parameters

Trichloroethylen, cyanide, cadmium, mercury and other heavy minerals are not detected or below the guideline value.

K.3.3.2 Analysis of Monitoring Parameters

El Table K-8 presents the results of analysis in February and April 2004 for comparison of 10 parameters. No significant changes happened between February and April although the increase and decrease of the ions can be observed. These changes should be examined in the long term. NH4 and other parameters which indicate man-made contamination should be monitored in May and June 2004.

Table K-8: Results of Water Quality Monitoring in February and April 2004

Location	Name of well	Water temperature		pH		EC		Chlorides		Total dissolved solid	
		° C				mS/cm		mg/L		mg/L	
		February	April	February	April	February	April	February	April	February	April
Carmen STP	P1	23	32	7.26	7.20	2,570	3,523	608	933	1,461	1,951
Carmen STP	P2	24	32	7.08	7.07	7,240	4,137	2,141	928	4,273	2,291
Carmen STP	P3	28	32	7.31	7.16	30,800	36,300	11,834	15410	23,111	30,742
Carmen STP	P4	27	32	6.82	6.94	24,300	27,467	11,457	10217	23,541	20,996
Carmen STP	Treated water	25		7.36		1,950		385		1,392	
Carmen Landfill	P1	20.5	31	7.23	7.03	3,150	3,120	750	785	1,977	1,959
Carmen Landfill	P2	20.8	31	6.96	6.93	4,420	2,930	1,141	730	2,530	1,890
PDC reservoir	P1	25.5	31	7.33	7.09	2,630	1,478	604	284	1,318	1,020
PDC reservoir	P2	25.5	31	7.18	7.15	6,930	4,420	1,877	1206	3,878	2,809
Colonia ejidal	P1	27	30	7.26	7.14	3,440	2,967	830	742	1,694	1,746
Colonia ejidal	P2	26	30	7.05	7.06	4,600	4,310	1,169	1103	2,712	2,637

Location	Name of well	Sulfates(SO4)		Nitrite (NO2)		Nitrate(NO3)		Total coliform		Fecal coliform	
		mg/L		mg/L		mg/L		NMP/100mL		NMP/100mL	
		February	April	February	April	February	April	February	April	February	April
Carmen STP	P1	107	168	0.001	<0.011	0.2	<0.078	>2400	240	>2400	<3
Carmen STP	P2	310	224	0.004	<0.011	2.1	<0.078	<3	>2400	<3	>2400
Carmen STP	P3	1,805	2,750	0.005	<0.011	5.0	<0.078	460	>2400	460	>2400
Carmen STP	P4	1,794	1,661	0.003	<0.011	3.4	<0.078	240	>2400	93	>2400
Carmen STP	Treated water	107		0.018		8.7		>2400		>2400	
Carmen Landfill	P1	105	73	0.004	0.02	0.5	1.25	43	9	9	9
Carmen Landfill	P2	169	347	0.004	<0.011	0.6	1.07	460	23	75	23
PDC reservoir	P1	108	150	0.004	<0.011	8.1	15.05	9	>2400	<3	1100
PDC reservoir	P2	246	156	0.004	0.02	1.2	6.6	460	<3	240	<3
Colonia ejidal	P1	119	140	0.018	0.02	0.5	0.82	1100	240	1100	43
Colonia ejidal	P2	174	278	0.003	<0.011	0.2	<0.078	240	93	93	21

K.4 Groundwater Simulation Studies

K.4.1 A Regional Flow Model

In accordance with the purpose of groundwater simulation, various sorts of models can be utilized. Three of them are usually used as 1) 2-D or 3-D regional model; 2) 2-D or 3-D section model; and 3) 3-D detailed model.

The first one, 3-D regional model is usually used to make clear in a comprehensive way the general characteristics of groundwater basin where the study area is located. Therefore, this kind of model is mostly applied as the first step of groundwater simulation, and the regional model covers not only the study area but also its surrounding area.

K.4.1.1 Modeling Concept

a. Purpose of Regional Flow Model

In accordance with the purpose of groundwater simulation, various sorts of models can be utilized. Three of them are usually used as 1) 2-D or 3-D regional model; 2) 2-D or 3-D section model; and 3) 3-D detailed model.

The first one, 3-D regional model is usually used to make clear in a comprehensive way the general characteristics of groundwater basin where the study area is located. Therefore, this kind of model is mostly applied as the first step of groundwater simulation, and the regional model covers not only the study area but also its surrounding area.

Essential result of regional model is distribution of water level or hydraulic head, and accordingly direction and amount of groundwater flow in each part of the model domain, so that the water budget could be calculated. Regional model can also be utilized in many cases for confirmation of groundwater basin structure and calibration of aquifer coefficient, to provide necessary information for creation of detailed model.

b. Method Selection

Groundwater simulation can be carried out by using several kinds of methods. In a simple case, groundwater flow can be calculated form formula manipulation, or measured form miniature like soil column. Rubber film and electrical model were also used for groundwater simulation about twenty to thirty years ago.

The computer based digital model, as the newest one of all the simulation methods, was developed in the past several decades, and has become the most popular approach with the rapid progress in computer technique. At the present moment, for almost all groundwater simulation in practical use level, especially in complicated groundwater basin condition, digital model has become indispensable method.

A lot of applications for computer simulation have been released, form simple one for 2-D groundwater flow modeling, to comprehensive one for all kinds of purposes involving groundwater flow, solute transport, soil compaction, and so on.

A comprehensive groundwater modeling application is composed of many modules. Most well-reputed applications use MODFLOW, as core module for groundwater flowing calculation. MODFLOW is a two- and three-dimensional finite-difference models created in 1970's and has been improved and used extensively by the U.S. Geological Survey and others for the computer simulation. Therefore, whatever application being used, there would not be a considerable difference in simulation results, if only the same simulation condition was set. The difference between those applications is mainly in its usability, capability of presentation and linkage to other kinds of software.

PMwin (Processing MODFLOW for Windows), one of the most popular applications, was adopted for creation of the regional model in this study. PMwin was developed in 1989, as one of the earliest applications to make the module of MODFLOW usable in windows environment, was the most popular program in earlier 1990's. However, rather than its history and share, PMwin is taken as a favorite software by many users because the adjustment of parameters can be specified as detail as every one cell by it.

c. Extension of the Regional Flow Model

A regional flow model was created in this work to involve the whole Quintana Roo State and its surrounding area. Figure K-20 shows the location and extension of the model.

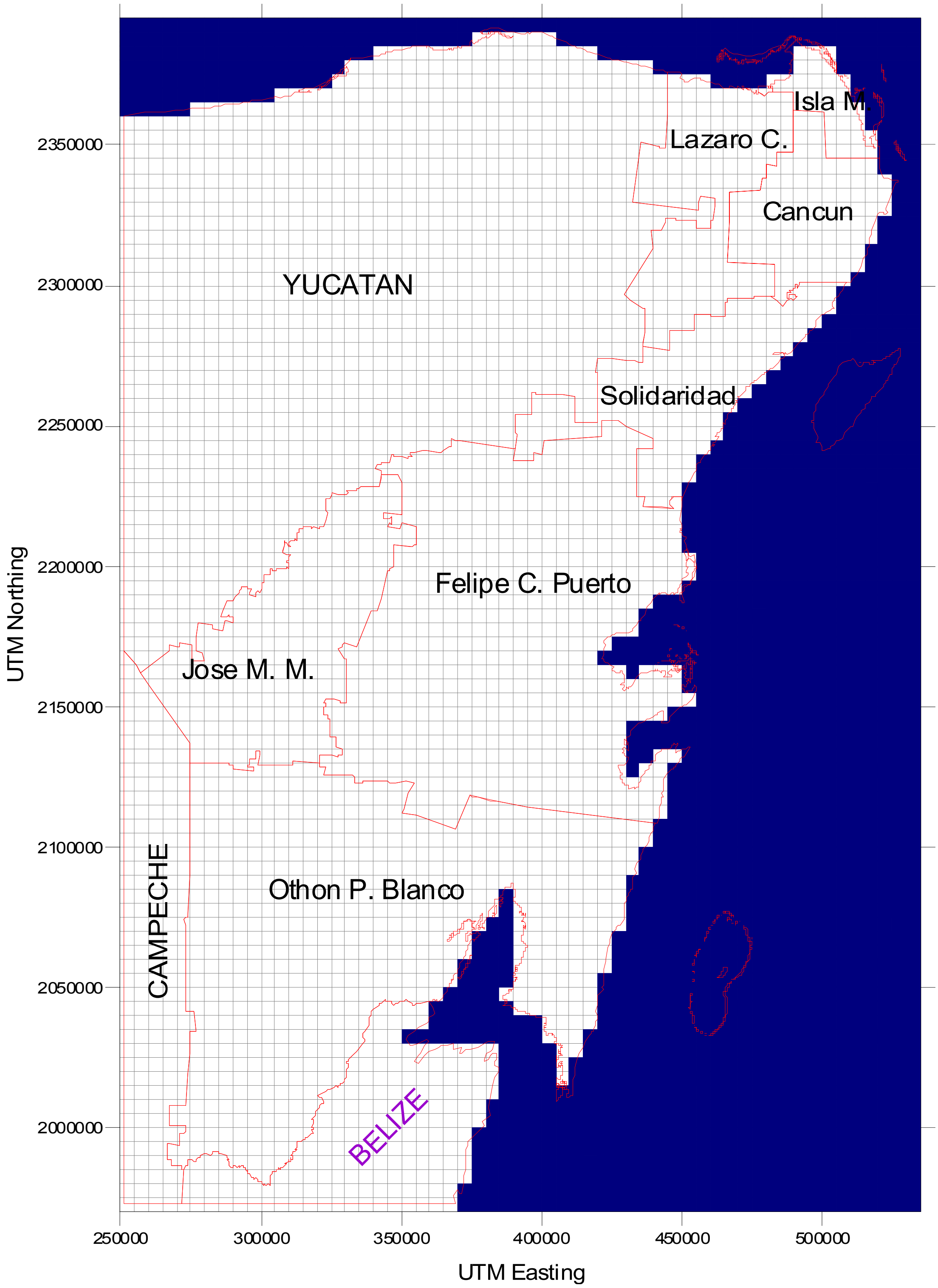


Figure K-20: Location and Extension of the Model

Coverage of the model is 285 km in west-east direction, form longitude west 89°21'30.3" to 86°39'42.2", corresponding to UTM Easting 250,000 to 535,000, and 425km in north-south direction, form latitude east 17°48'12" to 21°39'28.4", UTM Northing 1,970,000 to 2,395,000.

The model domain is divided into homogeneous 5 km X 5km square grid to hold 57 columns in longitude direction and 85 rows in latitude direction. Along north and east boundary of the model domain, cells are located in sea area including islands, which are as shown in blue color, set as constant hydraulic head cell, with the hydraulic head value of 0m.

In depth direction, the model was divided into 20 layers. The top layer has a top elevation larger than water table and bottom elevation of -3m amsl (above mean sea level). An uniform thickness, 5 m was given to all layers between top and bottom layers. Thickness of bottom layer was set as 7m, so that the model involves a depth up to -100m.

K.4.1.2 Parameter Specification

a. Aquifer Classification

Structure of groundwater basin is essential factor to restrict groundwater flow. So called structure of groundwater basin means mainly the division of aquifers including aquicludes, their characteristics and distribution. It has been clearly indicated by collected data that the groundwater basin is characterized by a thick limestone aquifer group in the study area. However, several well-taken logging data, such as the logging record in Chetumal, revealed the existence of clay layer or clayey limestone between limestone aquifers.

It is pointed out by several previous researches that these clay and/or clayey limestone layers can hardly be taken as a significant impermeable layer to separate aquifers upper and below them into different aquifer units. However, a very important indication can be acquired that limestone, as the main aquifer in the study area is not homogeneous in depth direction. Therefore, substantial consideration should be taken for different hydraulic conductivity in horizontal direction and depth direction.

Generally, the permeability in horizontal direction is set 10 times higher than that in depth direction for sedimentary rock area including Quaternary deposits, even though there is no special consideration of inhomogeneous in the two directions, and this kind of specification has been adopted as default setting for majority of groundwater modeling software. Therefore, it is considered reasonable to set the permeability in horizontal direction as lager as 100 times that in depth direction in the study area.

b. Hydraulic Conductivity

Hydraulic conductivity is the most important parameter in groundwater simulation and is generally obtained from pumping test. However, this kind of data is scarce in the simulation area. Two reasons might be taken into account of this scarcity; one is that pumping test is difficult to be conducted in the simulation area because drawdown caused by pumping discharge is usually too small to be measured due to very high permeability of limestone aquifer in horizontal direction, the other one is that there was little investigation the study area that took permeability of aquifer as object.

The most useful material for hydraulic conductivity setting is the summary of previous researches as shown in the following table form a CNA report. It gives relevant previous permeability test results in the whole Yucatan peninsular. According to previous studies, the limestone aquifer in the whole Yucatan peninsular including the study area is considered to have similar geological characteristic, therefore, the value within the table can be taken as the reference for hydraulic conductivity setting in this model.

Table K-9: Previous Permeability Test Results in the Yucatan Peninsula

Hydraulic Conductivity (m/s)	Reference	Place of Obtaining
1.5 e - 3	Buckley & Mcdonald (1994)	Acuífero de la ciudad de Mérida
6.4 e - 2	Méndez Ramos (1991)	Acuífero de la ciudad de Mérida
1.0 e - 1 to 1.0 e0	Marín Ponce (1990)	NW de la Península de Yucatán
5.0 e - 1 to 3.0 e - 4	Reeve & Perry (1990)	Norte de Mérida (Chuburná)
1.0 e- 2 to 1.0 e - 3	Martínez Guerra (1990)	Isla Cozumel
8.7 e - 3 to 3.2 e - 4	Villasuso Pino (1984,90)	Pozos pluviales ciudad de Mérida
5.0 e - 3 to 1.0 e - 6	González Herrera (1984)	Laboratorio ciudad de Mérida
1.0 e – 2	Back & Lesser (1981)	Balance Península de Yucatán

Data Source: CNA

Deviation in permeability can be found to be as big as million times, form minus 6th power (e10-6) to 1. However this kind of result is by no means skeptical in limestone area. It is well known that permeability of limestone aquifer is usually good and inhomogeneous as well. The permeability changes in not only depth directions but also horizontal direction. In accordance with these characteristics, the results given in the above table could be used to set the upper and lower limitations and average value of permeability of limestone aquifer during the adjustment of permeability is carried out for calibration.

K.4.1.3 Existing Condition

a. Water Level

a.1 Groundwater Monitoring

The distribution of water level or the shape of water table is necessary to be ascertained for initial hydraulic head specification in groundwater simulation model. On the other hand, it is indispensable in model creation to conduct calibration that is a process to make parameters and all kinds of specifications in the model really fit to the simulated groundwater basin. Normally, a long term groundwater observation result is used for the calibration. Within the modeling area, CNA has carried out groundwater monitoring for about 3 years, however, the CNA monitoring activity is concentrated in the northern part of the study area, around Playa

Del Carmen, and the vast southern area is still uncovered yet. Figure K-21 shows the distribution of CNA monitoring wells.

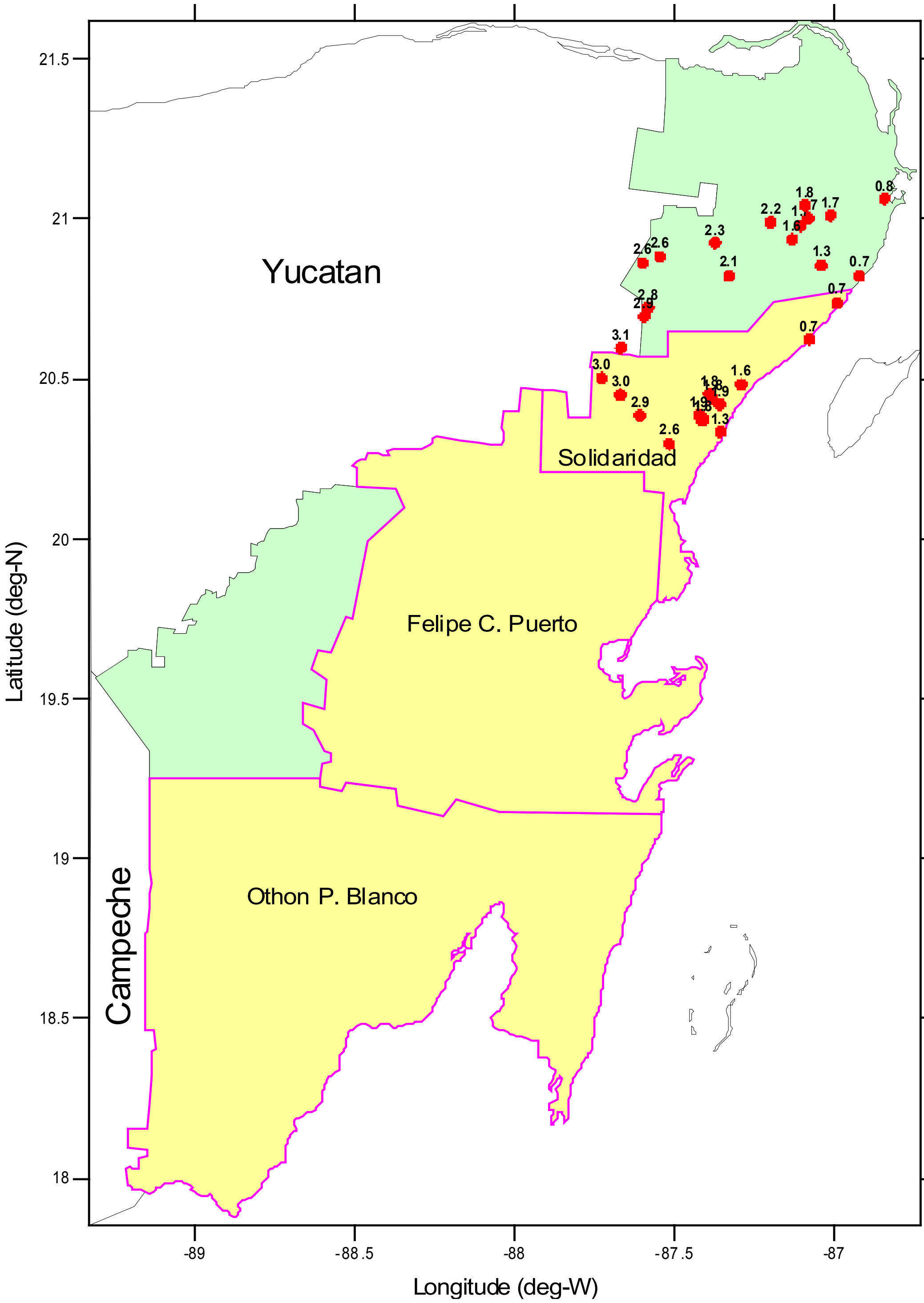


Figure K-21: Distribution of CNA Monitoring Wells

The importance to confirm the distribution of groundwater level in the modeling area, therefore, is much higher than the specification of initial water level. In the specification of hydraulic conductivity, which is the most essential parameter, the accuracy could hardly be improved due to the scarcity of relevant permeability test data. The previous researches gave only a very large range of hydraulic conductivity. There is not more data which could be used for set an adequate value to each model cell. So a method has to be applied to adjust the hydraulic conductivity, and water table is considered as the only material for this adjustment in the present situation.

a.2 Water Table Contour Map of SARH

A water table contour map is released in a SARH hydrogeological survey report. The map was created about 10 years ago and the original data for the map creation is very difficult to find. Therefore, data and the map could not be evaluated. However, the map is very valuable because there is no similar data newer than that. The SARH map only covers the whole modeling area.

Some defects were found when the SARH water table map was scrutinized. As shown in Figure K-22, the 1m and 2m contour lines of water table are verged to sea in area around Playa Del Carmen. It implies that along coast line groundwater level is higher than sea level by 1 or 2meters. In special cases of confined aquifer, rather that water level, hydraulic head is more suitable in groundwater flow analysis, because the head would be higher than the top of aquifer and sometimes higher than ground surface. However, as mentioned in previous section, no continuous impermeable layer can be identified significantly in the study area. So the implication of existence of confined aquifer could not be supported with reliable evidence. Accordingly, it becomes very difficult to explain why water level can be higher than ground surface.

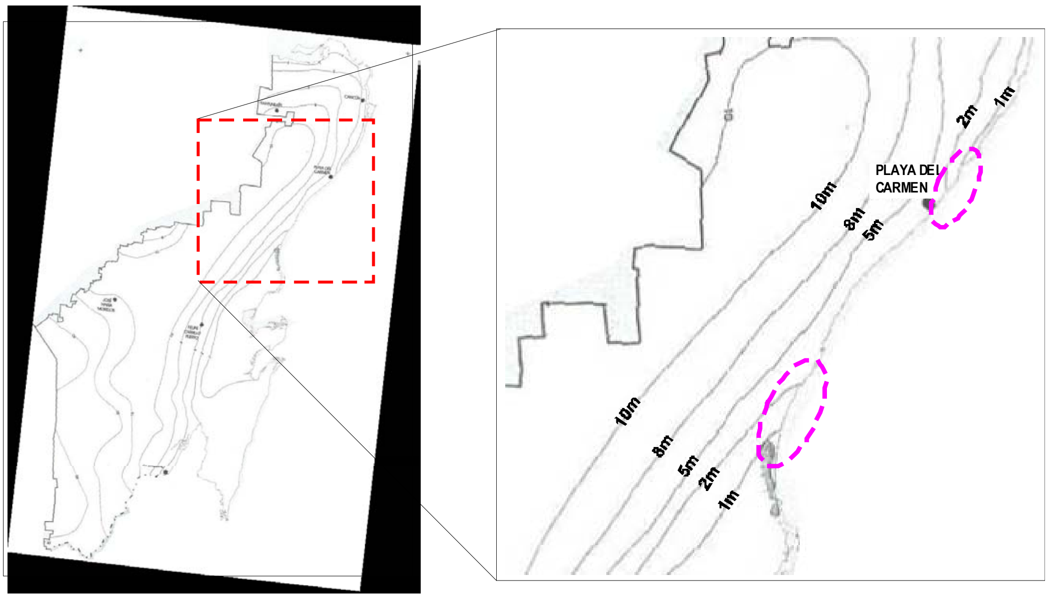


Figure K-22: Inconsistencies of SARH Map

On the other hand, when the SARH map is compared with CNA data, it can be found that water level in CNA's monitoring result is lower than that in SARH map. When contour lines of water level were drawn, no problem occurs on the controversial confined aquifer. The CNA data should be reputed quite accurate when it is evaluated from the view point of consistency. A clear tendency of groundwater level changing is shown from coast line toward to inland with CNA's monitoring wells, and dispersion within the observation wells is quite small to make the water level contour stretch smoothly. Therefore, the SARH water table map should be modified by using CNA water level monitoring result in the area covered by these two kinds of data.

a.3 Water Level Data from CAPA

Another source of water level data is the static water level records of CAPA's production wells in Chetumal and Felipe C. Puerto. However, the CAPA's water level data could not be used directly for water table creation, because the data is taken as the depth from ground surface and elevation data of the wells were not available. To use the CAPA's data for checking or rectifying SARH water table map, a processing is necessary to figure out elevation of wells. This processing was performed by using USGS 90m topography data, which was opened via INTERNET.

The CAPA's water level data were transferred to unit of AMSLM and shown in the following table.

Table K-10: Processed CAPA Water Level Data

Location	Well Depth(m)	Elevation of Tube Head	Level form Tube Head	Average Level (AMSLM)	SARH value
González Ortega	78.33	50.11	31.05	19.06	14
XUL-HA	55.2	52.54	37.99	14.55	10
Felipe C. Puerto	28	12.48	14.25	-1.77	5

About 20 well's distribute in 3 production well sites, but the deviation among wells is relatively large to make it difficult to draw a smooth contour by using these data. On the other hand, however, the distance between wells in the well site is too small in comparison with the scale of the model grid size, so the average of water level was taken for each production well site, and shown in the table.

For production wells sites in Chetumal, average water level is 19.06 and 14.55 m in González Ortega and XUL-HA, respectively. Both of them are higher than the value read from SARH map. In contrast, the result of Felipe Carrillo Puerto is not only lower than that of SARH map, but also lower than sea level. This kind of result is also quite skeptical. If it is true, it would lead a very high possibility of sea water intrusion, even in the situation without pumping extraction.

a.4 Water Level Specification

According to their availability, water level data in the modeling area were complied upon the following 3 points: First, as the newest and most reliable data, CNA data should be used in the highest priority.

Second, for areas where CNA has not conducted groundwater monitoring, SARH data has to be used.

Last, data from CAPA of Chetumal and Felipe Carrillo Puerto show different value from SARH map, but it is difficult to judge which one is more credible, so the simple average value could be taken.

A new water level contour map was created by this way, and shown in Figure K-23. The recreated contour is considerably different from SARH map in the CNA monitoring area, a little different from the SARH map in the vicinity of Chetumal and Felipe Carrillo Puerto CAPA production well site, and just equivalent to SARH map in other area.

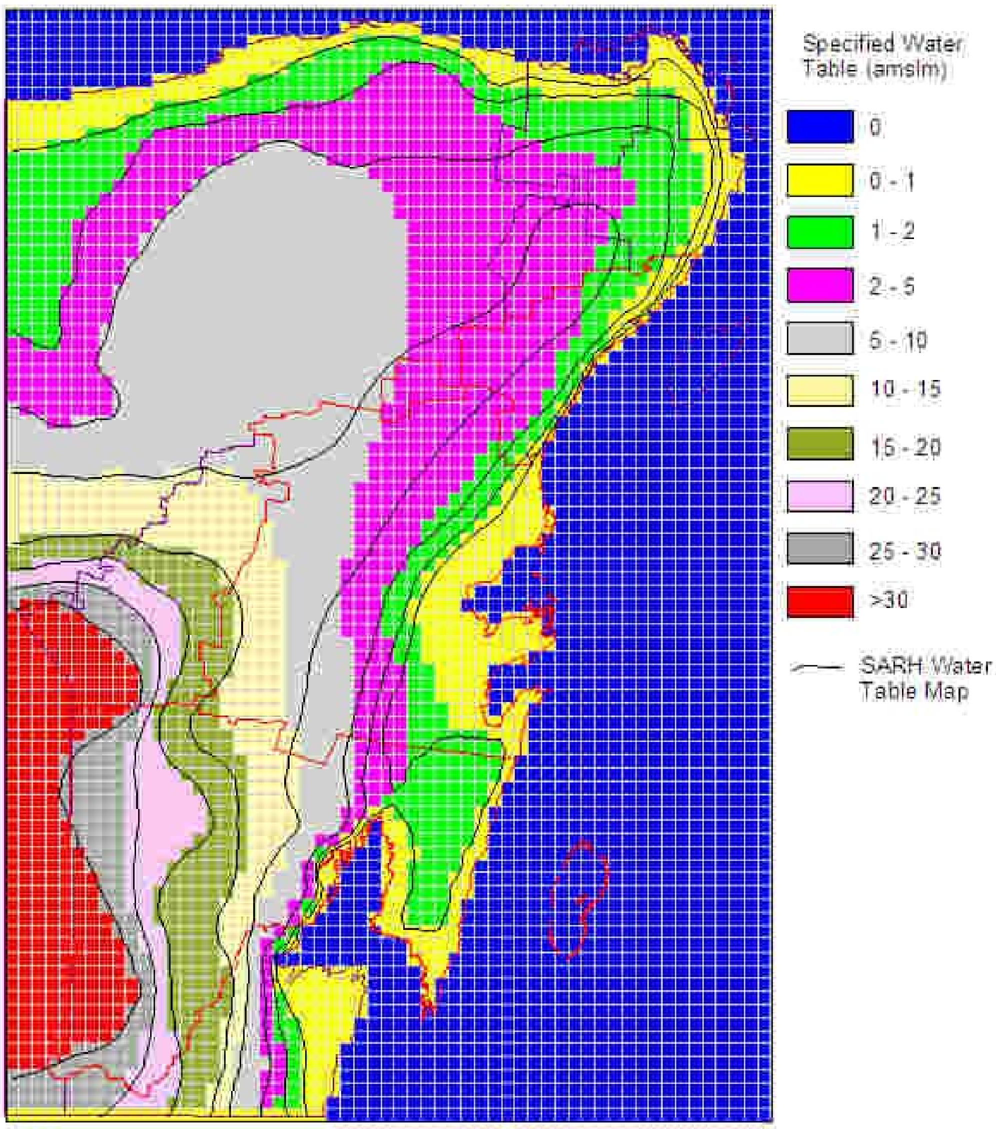


Figure K-23: New Water Level Map Created by S/T

b. Rainfall

Precipitation is the essentially recharge source for groundwater in the study area. Rainfall data of 30 meteorological stations within Quintana Roo State was provided as long term average values in the newest hydrogeology report released by INEGI(2002). For other part in vicinity of Quintana Roo state, the data was downloaded from World Climate home page via Internet.

Table K-11: Average Rainfall in and around the Modeling Area

Location	Easting	Northing	Rainfall	Country	Data_period
Adolfo Lopez Mateos	323041	2171745	1366.0	MEXICO	1983-1998
Agua Blanca	306987	1991964	1364.0	MEXICO	1984-1998
Alvaro Obregon	326479	2023425	1338.0	MEXICO	1964-1998
Andres Q. Roo	384009	2118989	1461.7	MEXICO	1987-1998
Becanchen, Yucatan	251512	2186451	1074.0	MEXICO	1949-1982
Cancun - Capa	518661	2339509	1333.0	MEXICO	1988-1998
Chetumal Observatorio	359867	2046084	1295.0	MEXICO	1952-1998
Chetumal Tec	361867	2048065	1333.2	MEXICO	1984-1998
Coba	423095	2265719	1180.4	MEXICO	1987-1998
Cozumel	505615	2267920	1326.5	MEXICO	1951-1980
Dzitas, Yucatan	337241	2297185	1261.0	MEXICO	1948-1985
Dziuche	310324	2201571	1186.9	MEXICO	1983-1998
Felipe Carrillo Puerto Obs.	390404	2164835	1397.0	MEXICO	1952-1998
Ideal (Nuevo Xcan)	443180	2309221	1449.1	MEXICO	1989-1998
Izamal, Yucatan	282768	2307901	1096.0	MEXICO	1949-1982
Kantunilkin	449574	2332824	1450.1	MEXICO	1952-1996
La Presumida	316219	2190542	1419.9	MEXICO	1965-1998
Lazaro Cardenas	372261	2098931	1350.9	MEXICO	1972-1998
Leona Vicario	478747	2320857	968.1	MEXICO	1961-1996
Limones	383239	2103470	1480.7	MEXICO	1983-1998
Nicolas Bravo	295952	2041892	1225.5	MEXICO	1961-1998
Pedro A. Santos	377460	2096160	1518.0	MEXICO	1983-1996
Playa del Carmen	491902	2281705	1445.6	MEXICO	1988-2002
Pucte	323903	2016629	1364.5	MEXICO	1972-1998
Saban	338842	2216219	1125.1	MEXICO	1985-1998
Senor	380876	2194967	1304.3	MEXICO	1972-1998
Sergio Butron Casas	334406	2047331	1310.8	MEXICO	1983-1998
Solferino	455399	2360489	1248.0	MEXICO	1967-1998
Sotuta, Yucatan	272052	2274860	1162.0	MEXICO	1945-1987
Tekax, Yucatan	250619	2229316	1103.0	MEXICO	1948-1983
Telchaquillo, Yucatan	249726	2285576	1120.0	MEXICO	1950-1985
Tihosuco	357262	2233460	1179.0	MEXICO	1966-1998
Tulum	452152	2236504	1025.2	MEXICO	1972-1998
Valladolid	367604	2287362	1131.0	MEXICO	1969-1980
Vallehermoso	339780	2122415	1095.2	MEXICO	1972-1998
Victoria	470812	2298999	1417.3	MEXICO	1965-1998
X-Pichil	355763	2178068	1039.6	MEXICO	1961-1998
Belize/Int.Airport	364925	1936408	1890.0	BELIZE	1941-2000
Big Falls Ranch	331883	1935515	1934.0	BELIZE	1965-1978
Libertad_ Santa Cruz	352423	2023030	1449.0	BELIZE	1937-1977

Figure K-24 shows the rainfall contour created by data from 40 stations within and around Quintana Roo State.

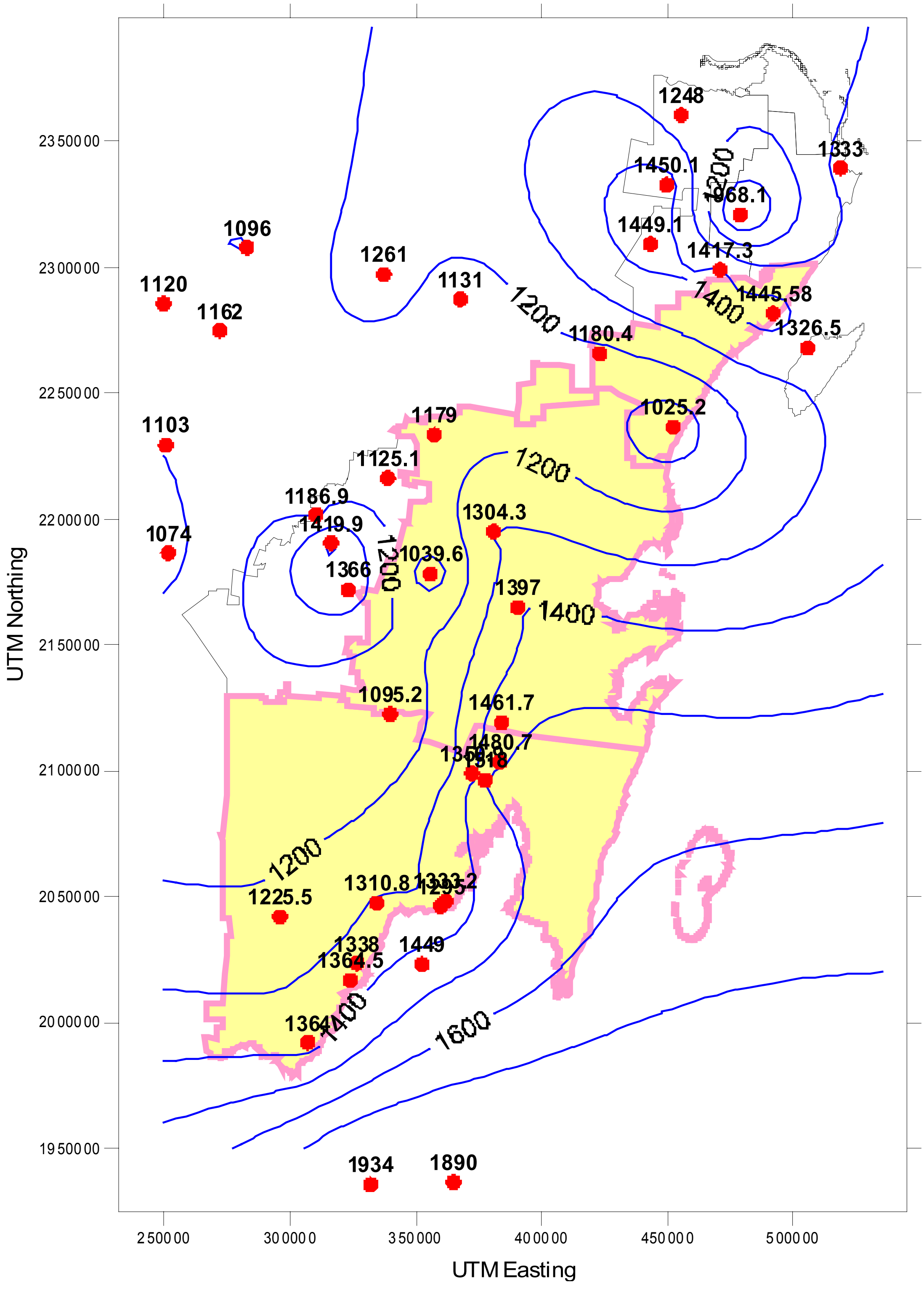


Figure K-24: Rainfall contour Map

c. Evaporation

Evaporation is as important as precipitation, because it accounts for a substantial portion of groundwater consumption. However, evaporation from groundwater is one of the most difficult factors to be measured. Generally the evaporation amount for a model is specified by empirical value. Within the materials collected in this study, evaporation coefficient was reported in range between 77 % and 95 % of rainfall as shown in the following table.

Table K-12: Evaporation Rate

Evaporation rate	Source
0.777	INEGI,2002
0.88	SARH,1990
0.90 to 0.95	Anonymous,1983
0.91	Cruz-Cetina,1978
0.76	Gobierno,1984
0.85	Average

It is difficult to evaluate which one would be more credible, so the average of previous reported value, 85 % was set as the initial value of evaporation rate in the modeling area.

d. Groundwater Extraction

d.1 CNA Well Inventory

Pumping extraction is also one of the most important factors related to groundwater consumption. The amount of groundwater extraction is often difficult to be estimated, because of existence of many non-registered private wells. But in the study area, it is believed that almost all wells have been taken into the well inventory of CNA. Consequently, a high accurate estimation of pumping extraction can be expected.

When the CNA well inventory was scrutinized, however, some defects in well coordinate were found. About 10% of wells have coordinates out of Quintana Roo State, and some of them were located as far as several dozen kilometers apart from the location indicated by the name of town or municipality.

A dBASE file, "Centro_poblados.dbf ", was used to modifying those impertinent coordinate of wells. Those wells were matched to the dBASE file by the name of well location and then the coordinate was substituted by the corresponding data in the dBASE file. The original well location and their modified results are shown in Figure K-25**.** The accuracy of this kind of modification is limited in the extent of town or village level. Considering the model grid size, 5km X 5 km, however, the deviation of coordinate is considered to be within an acceptable level.

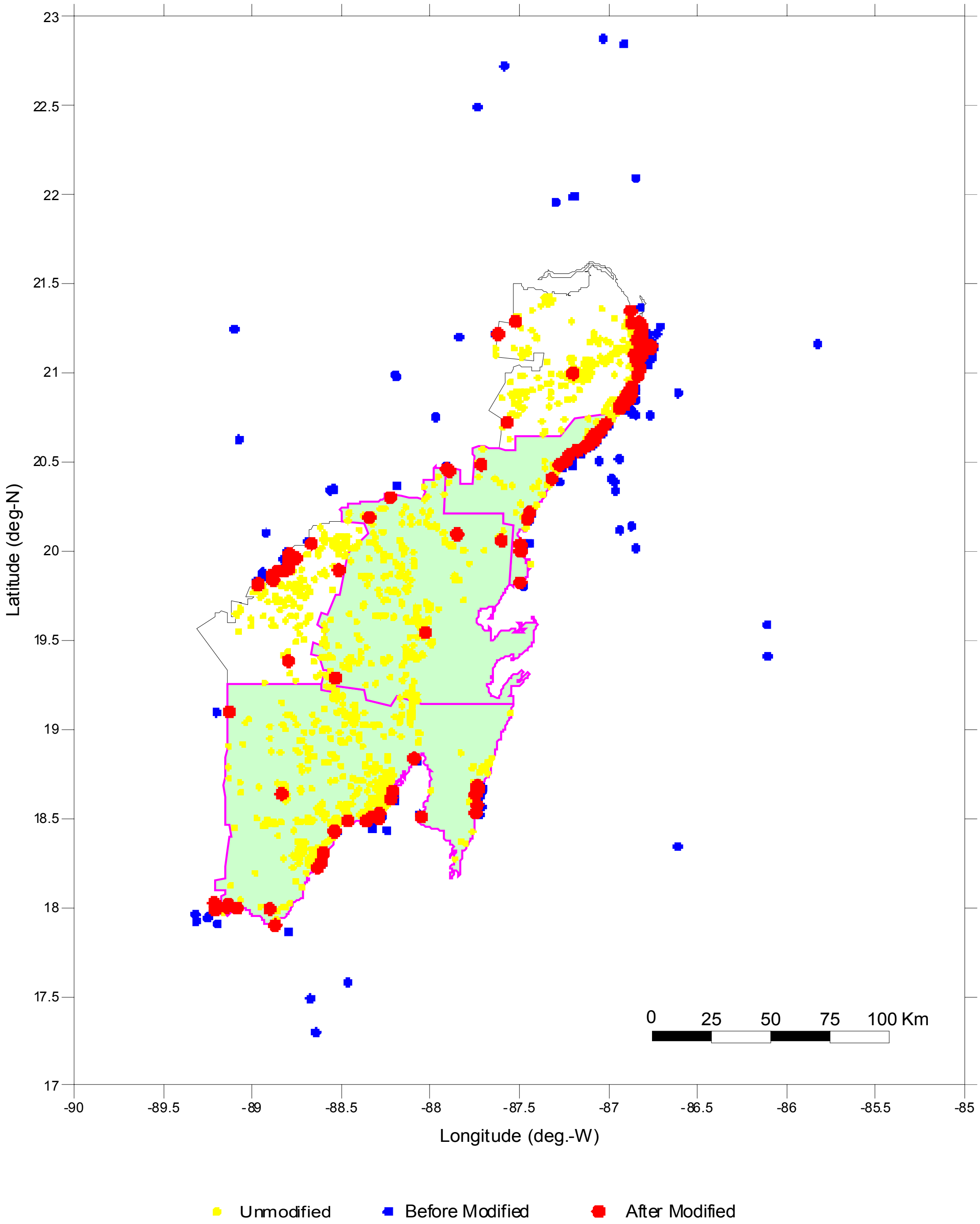


Figure K-25: Original and Modified Well Location

d.2 Pumping Discharge Distribution

According to the requirement of PMwin, pumping discharge was compiled in the unit of cell as shown in Figure K-26. In several cells where CAPA production wells are located, pumping discharge are found as high as over 5 million m^3/year, these kind of cells are mainly around Cancun and Chetumal.

However, pumping discharge is small in other cells, generally less than 4,000 m^3/year, even though there could be many wells within one cell.

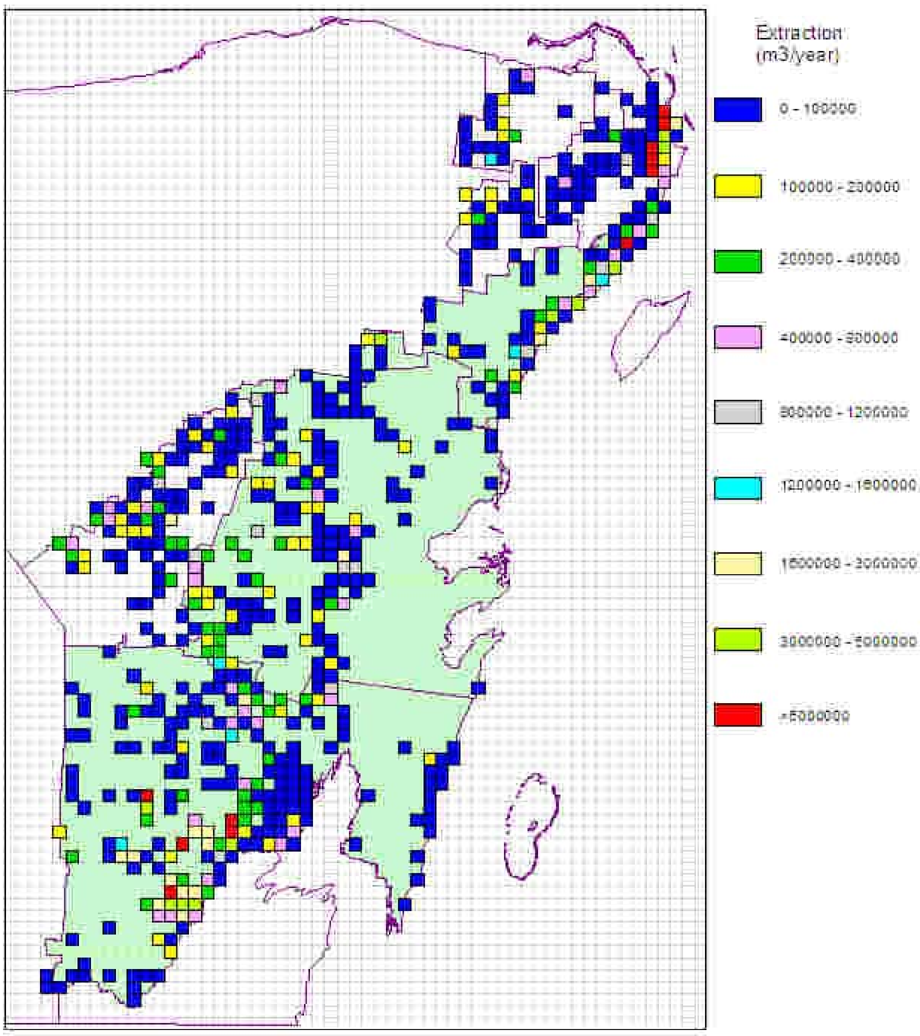


Figure K-26: Pumping Discharge by Cell of the Model

K.4.1.4 Simulation Result

a. Water Table

As mentioned above, limestone aquifer is inhomogeneous, and the existing permeability test result is not sufficient to specify hydraulic conductivity throughout the modeling area. The modified water level data, therefore, become the only available material for hydraulic conductivity specification.

As the most essential principle of groundwater flowing, velocity and/or amount of groundwater flow is in proportion to hydraulic conductivity and hydraulic gradient. The relation can be expressed in Darcy's Law:

$V = Ki$ or $Q = Aki$

where, V and Q represent velocity and amount of groundwater flow, respectively;

K is hydraulic conductivity in unit of (length/time)

i is hydraulic gradient (=(difference of hydraulic head)/(distance in groundwater flow direction))

A is the section area of groundwater flow

Consequently, in same layer or same aquifer, hydraulic conductivity is inversely to hydraulic gradient. That is, within water level contour map, hydraulic gradient is larger in the area where interval between adjacent water level contour lines is small, and accordingly hydraulic conductivity should be smaller.

The result of the calibration is shown in Figure K-27.

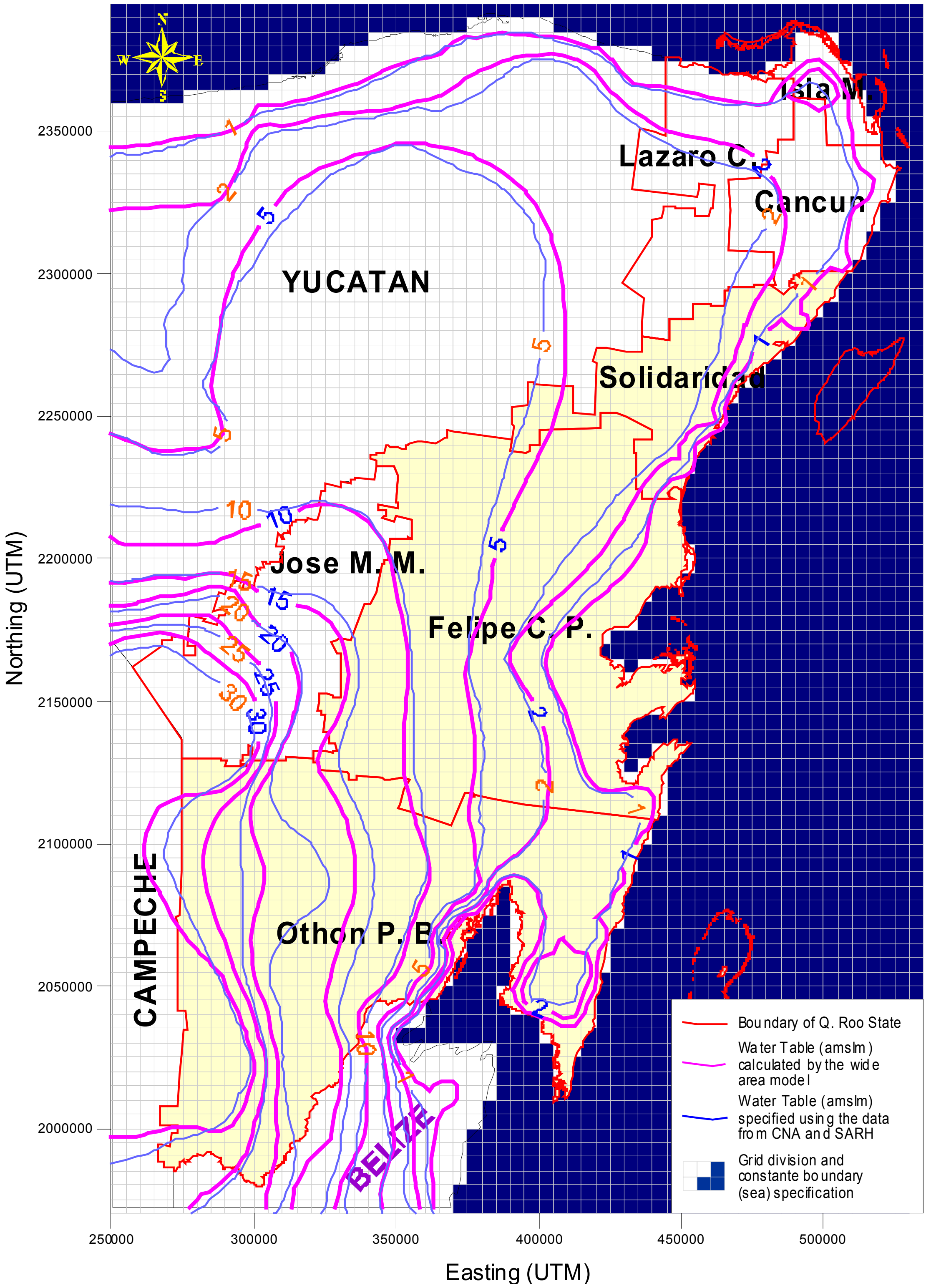


Figure K-27: Simulated Hydraulic Head

b. Groundwater Flow

Figure K-28 shows distribution of groundwater flow direction and schematic of the flow velocity in the modeling area.

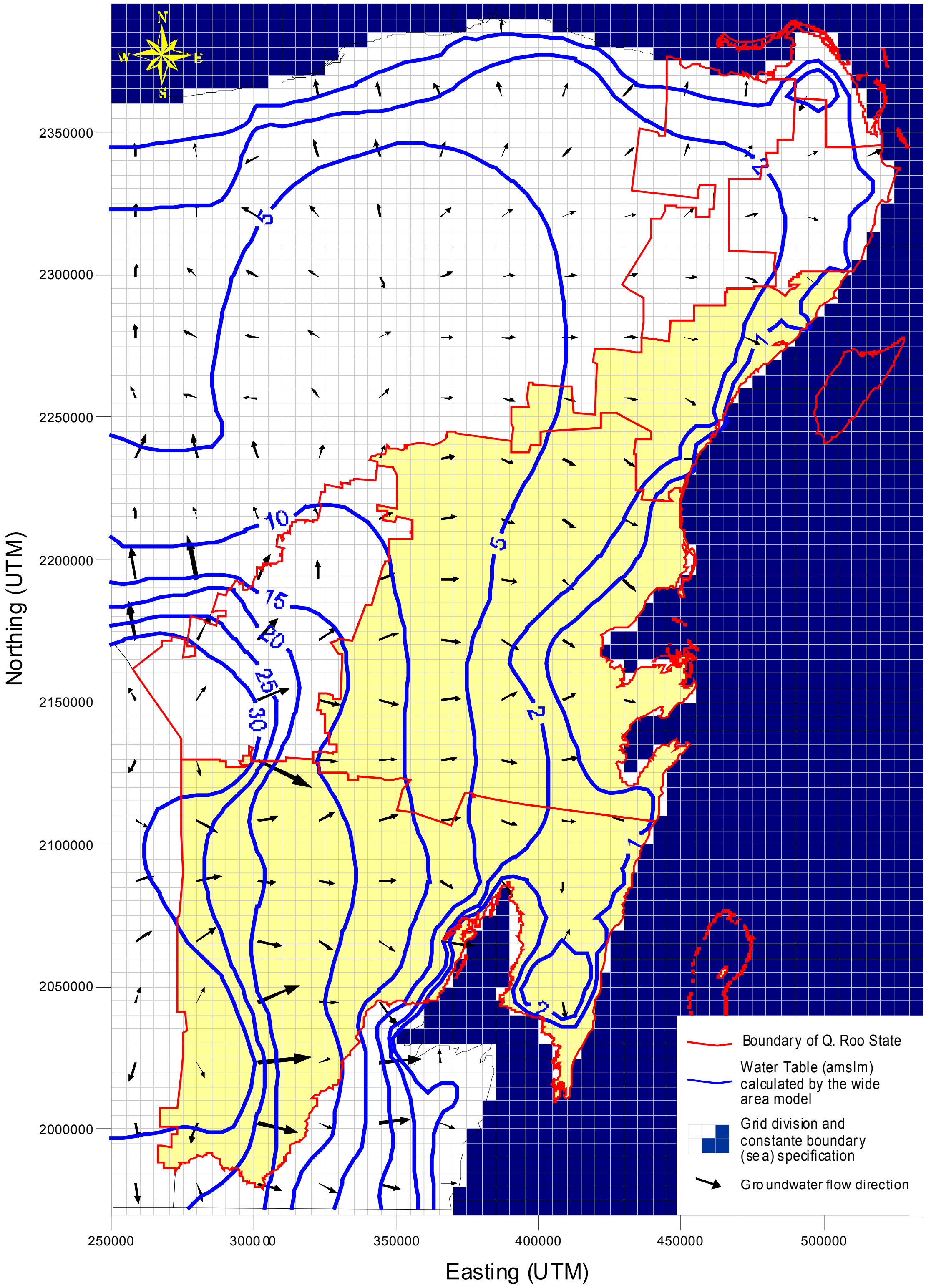


Figure K-28: Simulated Groundwater Flow Direction and Velocity

c. Water Budget

Table K-13 and Table K-14 show the water budget in Quintana Roo State and the three municipalities in the study area. In Quintana Roo State, the main source for groundwater recharge is rainfall, and the main consumption is evaporation. The total annual average rainfall in Quintana Roo State, 56,449 Mm^3 , can be divided into three portions:

Corresponding to evaporation from ground surface, one portion of rainfall return back to atmosphere before infiltrate into ground;

Another portion is corresponding to the evaporation or evapotranspiration form groundwater, after the rainfall's infiltration;

The last portion could be taken as net recharge amount form precipitation, which is the amount of groundwater discharged to area out of Quintana Roo State. The amount of this portion is a little more tan 5,000 million cubic meters, about 78% of total recharge amount in Quintana Roo State.

Another recharge source is flow in from adjacent area to Quintana Roo State. Total amount of flow in is about 1,433 million cubic meters, about 22% of the total recharge amount and one forth of rainfall recharge.

Main discharge is flowing toward the sea, 5,035 million cubic meters, about 78% of the whole discharge. Pumping discharge is about 270 million cubic meters only about 4% of the total discharge.

Table K-13: Water Budget in Quintana Roo State

Unit:Mm^3/year

Study Area	Othon P. Blanco	Felipe C. Puerto	Solidad_ ridad	Others	Total
Rainfall Recharge	1,801.3	1,611.0	346.0	1,265.9	5,024.1
Flow in	366.6	211.3	124.1	731.3	1,433.2
Sub total	2,167.8	1,822.3	470.1	1,997.1	6,457.3
To sea	-927.8	-2,428.6	-862.6	-815.6	-5,035
Pumping Discharge	-124.0	-21.2	-30.0	-94.7	-270
Flow out	-811.8	-31.0	0.0	-310.0	-1,153
Sub total	-1,863.6	-2,480.8	-892.6	-1,220.3	-6,457.3

Table K-14: Water Budget of Municipalities in the Study Area

Othon P. Blanco						unit: m3
Recharge	Rain fall	(Flow in)				
		Belize	Campeche	Felipe C.P.	Others(N)	Sub Total
	1,801,261,350	6,635,269	359,936,743	141,590,009	46,452,032	2,355,875,403
Consumption	To sea	(Flow out)	(Extraction)	(Flow out)		
		Belize		Felipe C.P.	Others(N)	Sub Total
	-927,837,776	-811,771,379	-123,977,440	-481,786,978	-10,501,830	-2,355,875,403
Felipe C. Puerto						
Recharge	Recharge	(Flow in)				
		Yucatan	Othon P.B.	Solidaridad	Others(W)	Sub Total
	1,610,991,604	211,264,170	481,786,978	213,610,567	225,206,455	2,742,859,774
Consumption	To sea	(Flow out)	(Extraction)	(Flow out)		
		Yucatan		Solidaridad	Others(W)	Sub Total
	-2,428,581,014	-30,986,790	-21,230,411	-253,959,433	-8,102,127	-2,742,859,774
Solidaridad						
Recharge	Recharge	(Flow in)				
		Yucatan		Felipe C.P.	Others(N)	Sub Total
	345,952,623	124,132,185		253,959,433	384,361,957	1,108,406,197
Consumption	To sea	(Flow out)	(Extraction)	(Flow out)		
		Yucatan		Felipe C.P.	Others(N)	Sub Total
	-862,624,899	0	-29,973,482	-213,610,567	-2,197,249	-1,108,406,197

K.4.1.5 Boundary Between Fresh Water and Sea Water

Groundwater extraction is generally considered safe when extraction amount is less than recharge, and the pumping discharge is much less than recharge in the study area and the whole Quintana Roo State. However, as shown in Figure K-26, pumping discharge does not distributes homogeneously, so it is necessary to check the safety of extraction in the area where groundwater extraction is obviously larger than average value. The checking is especially important in coast area, where vulnerability of aquifer is high because of the high risk of saline (sea water) intrusion.

Saline water usually exists under fresh water because of its high density. In ideal static condition, if the influence of dispersion between fresh water and sea water could be neglected, the depth of the boundary between fresh water and sea water can be calculated as nearly 40 times of groundwater level in AMSLM. However, this is just a kind of conceptual situation. Actually the depth of the boundary changes due to various factors.

In the study area, there is not yet the report of damage resulted from sea water intrusion. However, some researches have revealed that in some area the influence of sea water on groundwater use has been so high as to restrict groundwater extraction, because the depth of the boundary is as small as about 20m. In this work, change of the boundary was not simulated by the regional model, because there is no data available for both confirming the change and calibration for necessary parameters like dispersivity and effective molecular diffusion coefficient. However the boundary was estimated.

a. CNA´s Groundwater Quality Monitoring

When the problem of sea water intrusion is taken into consideration, its occurrence can only be confirmed by the examination whether or not the boundary between fresh water and sea water moved upwards. The examination is generally carried out by the method of checking if groundwater quality changed worse during a given period. Therefore, groundwater quality monitoring is indispensable for comprehension of sea water intrusion.

CNA has carried out groundwater quality monitoring for about 3 years. Even though the duration of the CNA’s water quality monitoring is not long enough for the calibration of parameters on sea water intrusion, and the coverage of the monitoring area has not encompass the whole study area or at least coastal area, the monitoring data is quite valuable for estimation of the present boundary between fresh water and sea water, and will surely fulfill a great role in groundwater management in the future.

The distribution of CNA’s water quality monitoring wells is just similar with that of the water level monitoring wells as shown in Figure K-29. TDS(total dissolved solids) level from most monitoring wells is under 1,000mg/l, to indicate that groundwater extracted from a depth less than that of monitoring wells is good enough for drinking water supply in the view point of salinity. However, TDS level form one well near coast line is 37,309 mg/l, that is a value as high as sea water to indicate that the bottom of the well has penetrated into sea water zone.

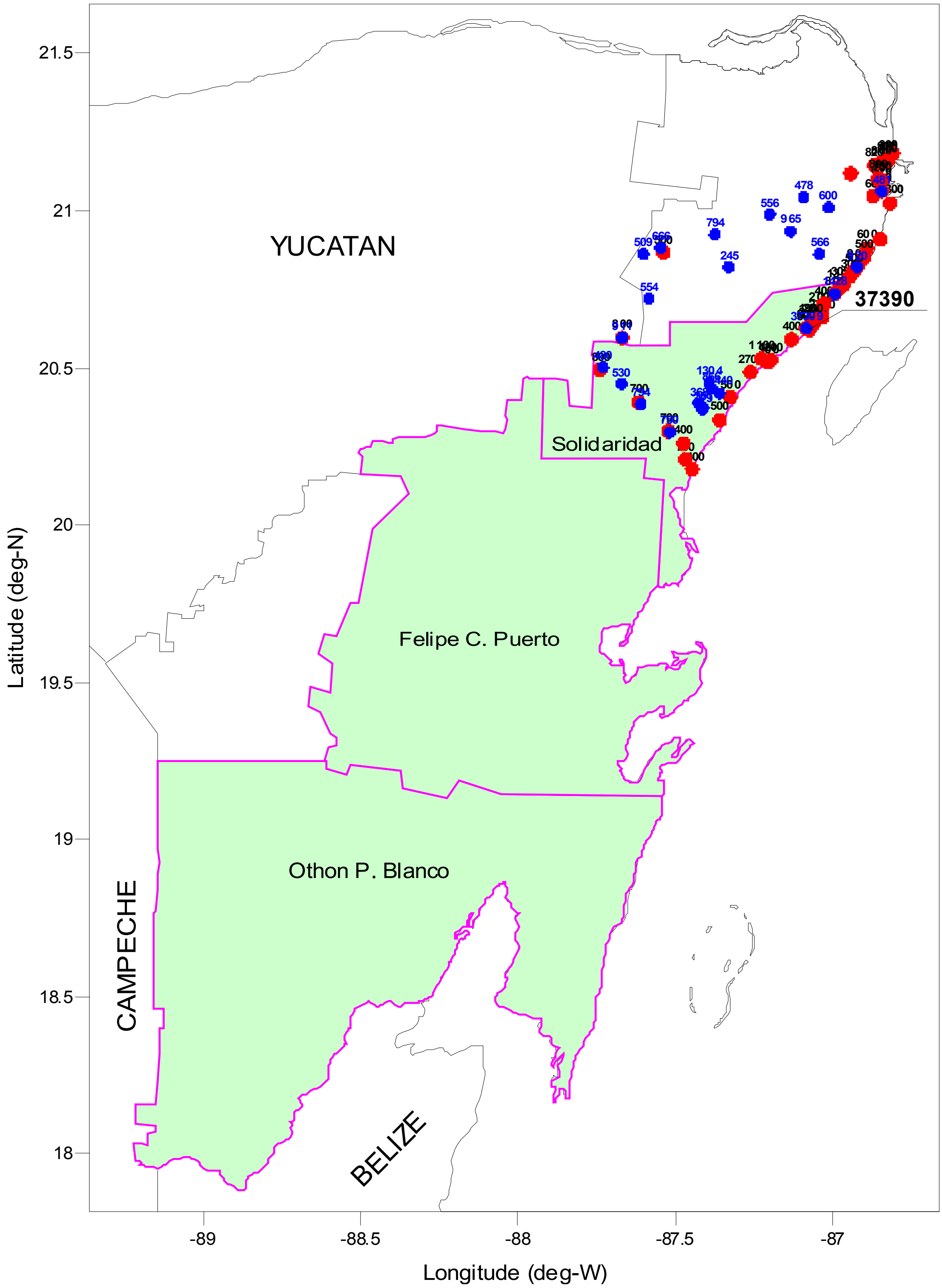


Figure K-29: CNA Water Quality Monitoring Wells

b. Well Depth Distribution

Due to CNA's water quality monitoring wells, which are most reliable data in the study area, has not covered the whole study area, wells form CNA well inventory were used as reference to estimate the boundary.

It is supposed that fresh water can be extracted from all wells in CNA well inventory, consequently the sea water boundary has to be below the bottom of those wells. Then by working out the bottom elevation of the deepest well in every cell, it will be at least possible to confirm that the sea water boundary should be lower than the elevation.

Because the elevation data is not included in the well inventory, USGS 90m mesh topography data was used to proximately calculate the elevation like the process in working out the elevation of CAPA production wells. Figure K-30 shows the general state of the USGS topography data.

Figure K-31 shows maximum depth of wells in each cell of model grid. In accordance with topography, deep wells are concentrated in the mountainous area in southwest part of Quintana Roo state, and in other part of Quintana Roo, well depth changes mainly in a range from 5m to 60m. Figure K-32 shows the bottom elevation of the deepest wells in each cell of model.

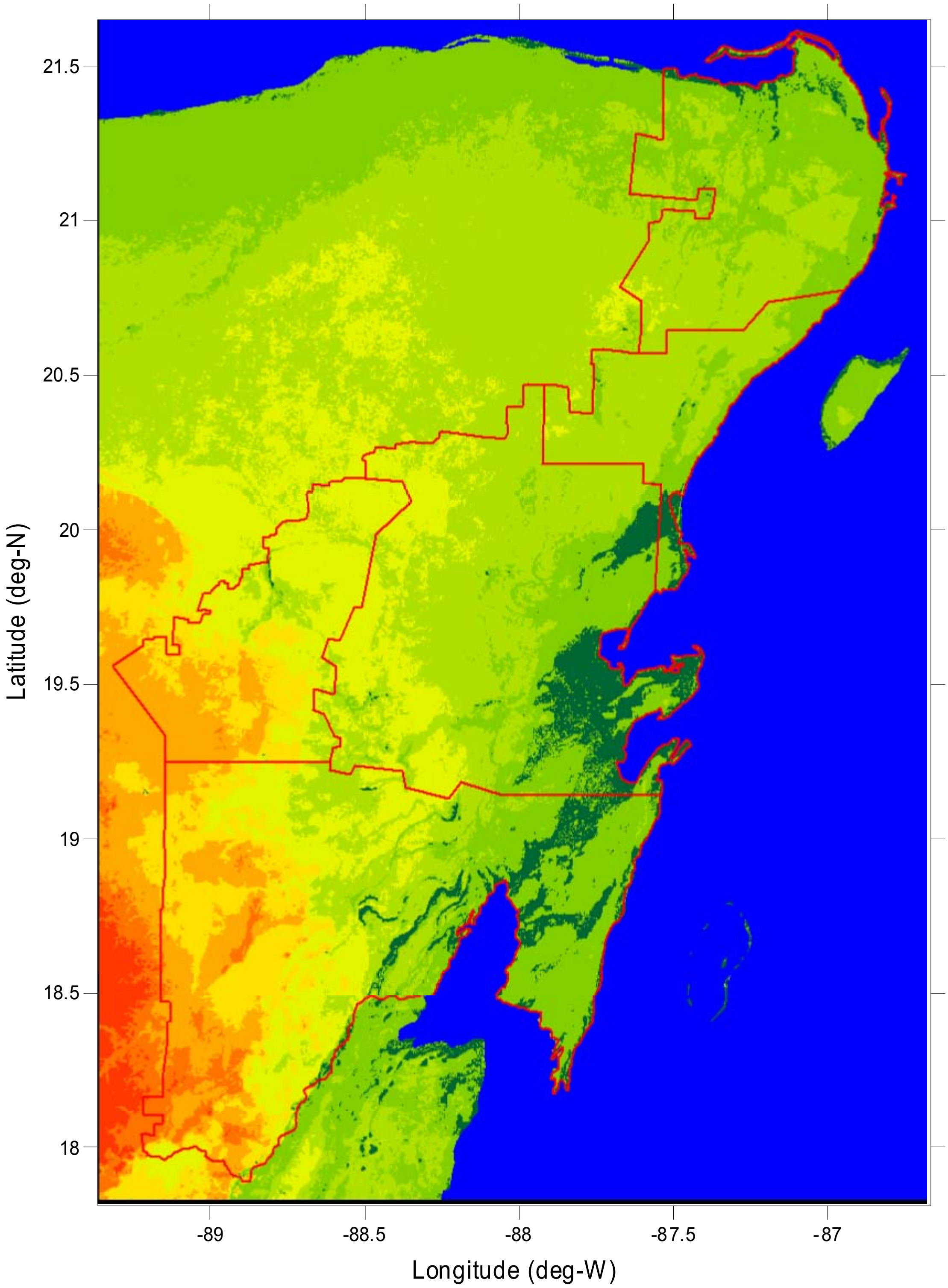


Figure K-30: General State of USGS Topography Data

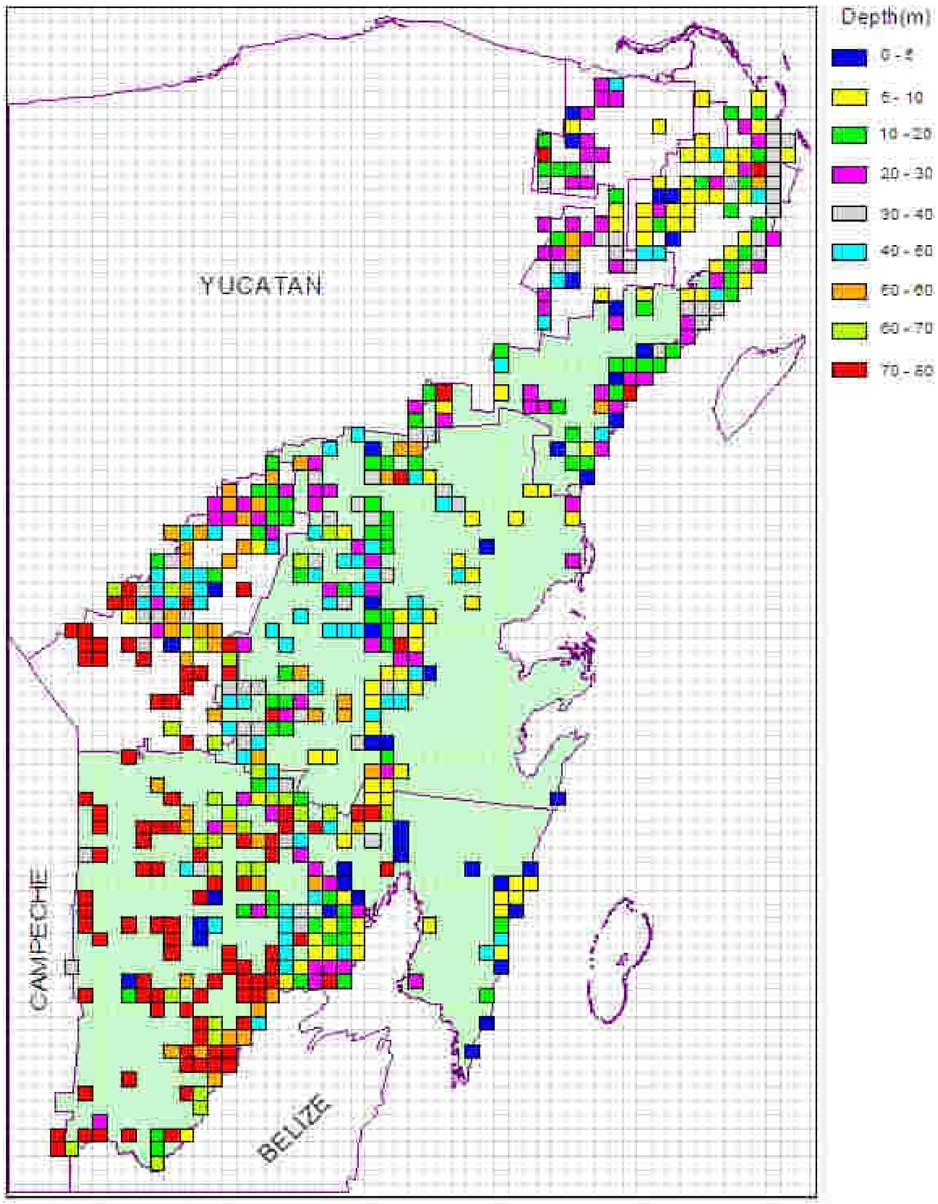


Figure K-31: Maximum Depth of Wells in Each Cell

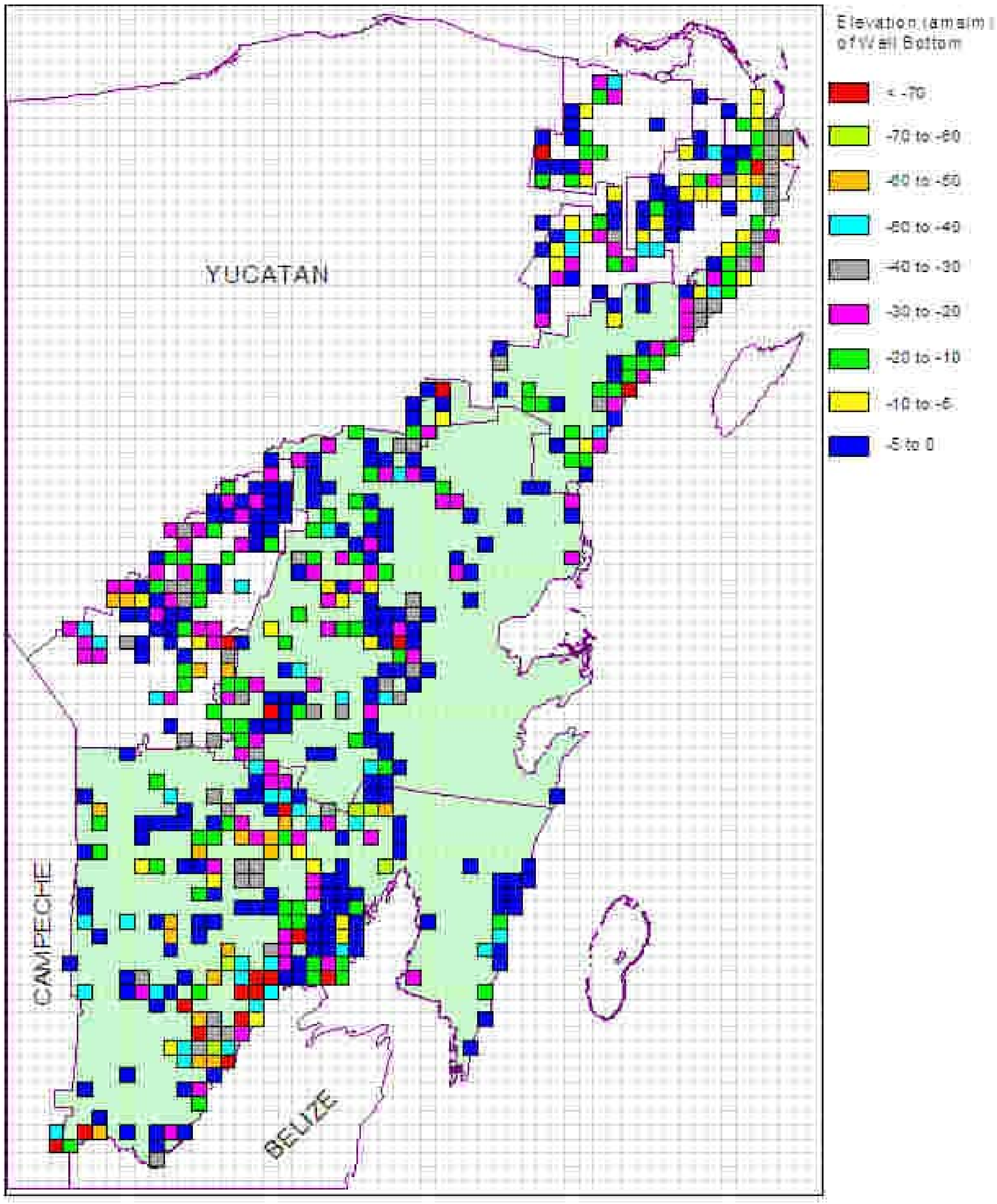


Figure K-32: Bottom Elevation of Deepest Wells in Each Cell

c. Specification of the Boundary Between Fresh Water and Sea Water

Figure K-33 shows the estimated distribution of the boundary between fresh water and sea water. The boundary gets deeper from coast line towards inland. Within a distance of about 10 km form coast line, the boundary might be as high as within -20m (AMSLM). Considering the elevation of ground surface, it could be presumed that wells within the 10km zone along coastal line might penetrate into saline water if the well depth is over 30m.

Figure K-34 and Figure K-35 show two sections to give the distribution of the boundary between fresh water and sea water. Rather than an accurate indicator of sea water zone's depth, the sections should be taken as a reference like a schematic due to the insufficiency and uncertainty of data for its creation as mentioned above.

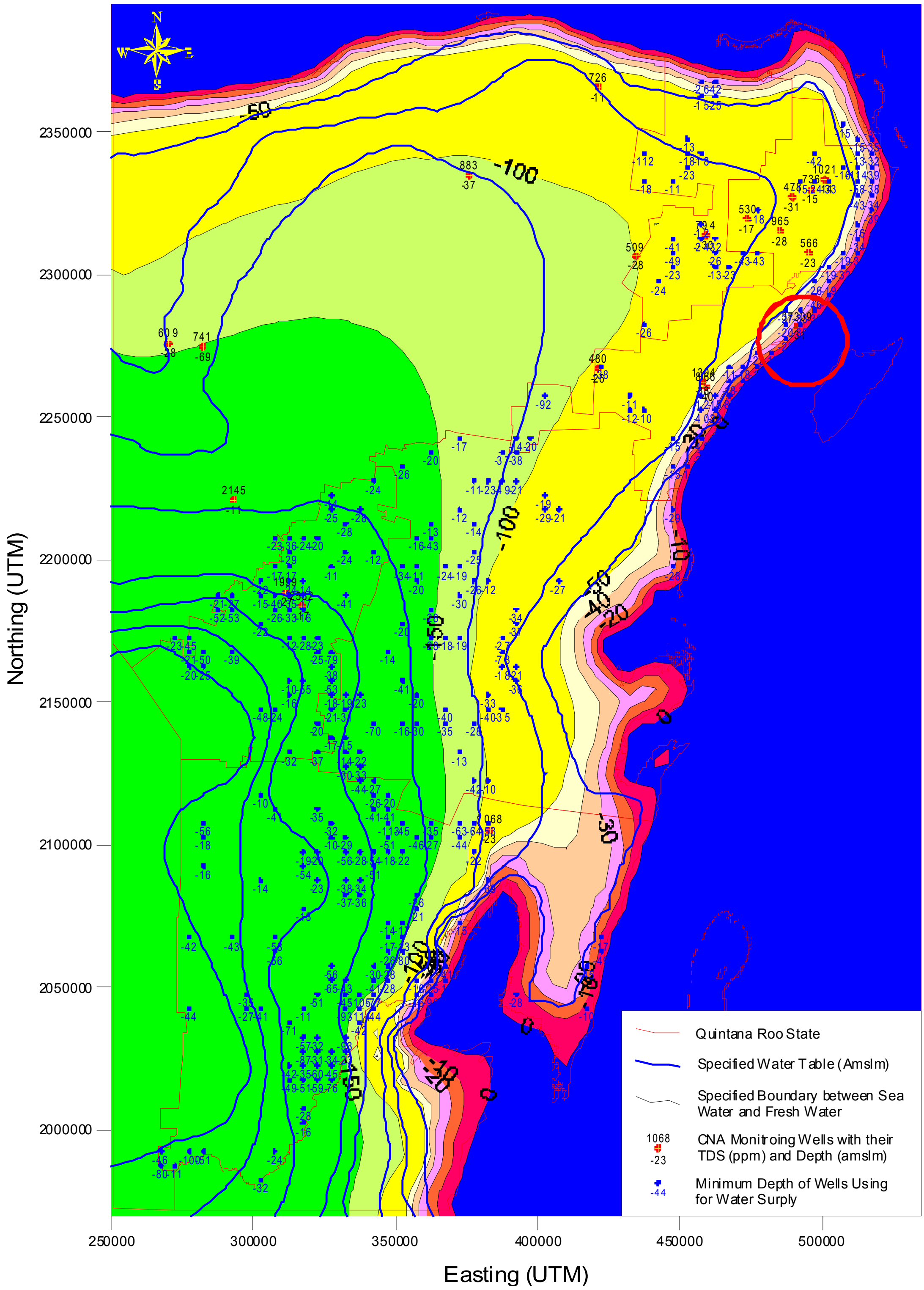


Figure K-33: Estimated Boundary between Fresh Water and Sea Water

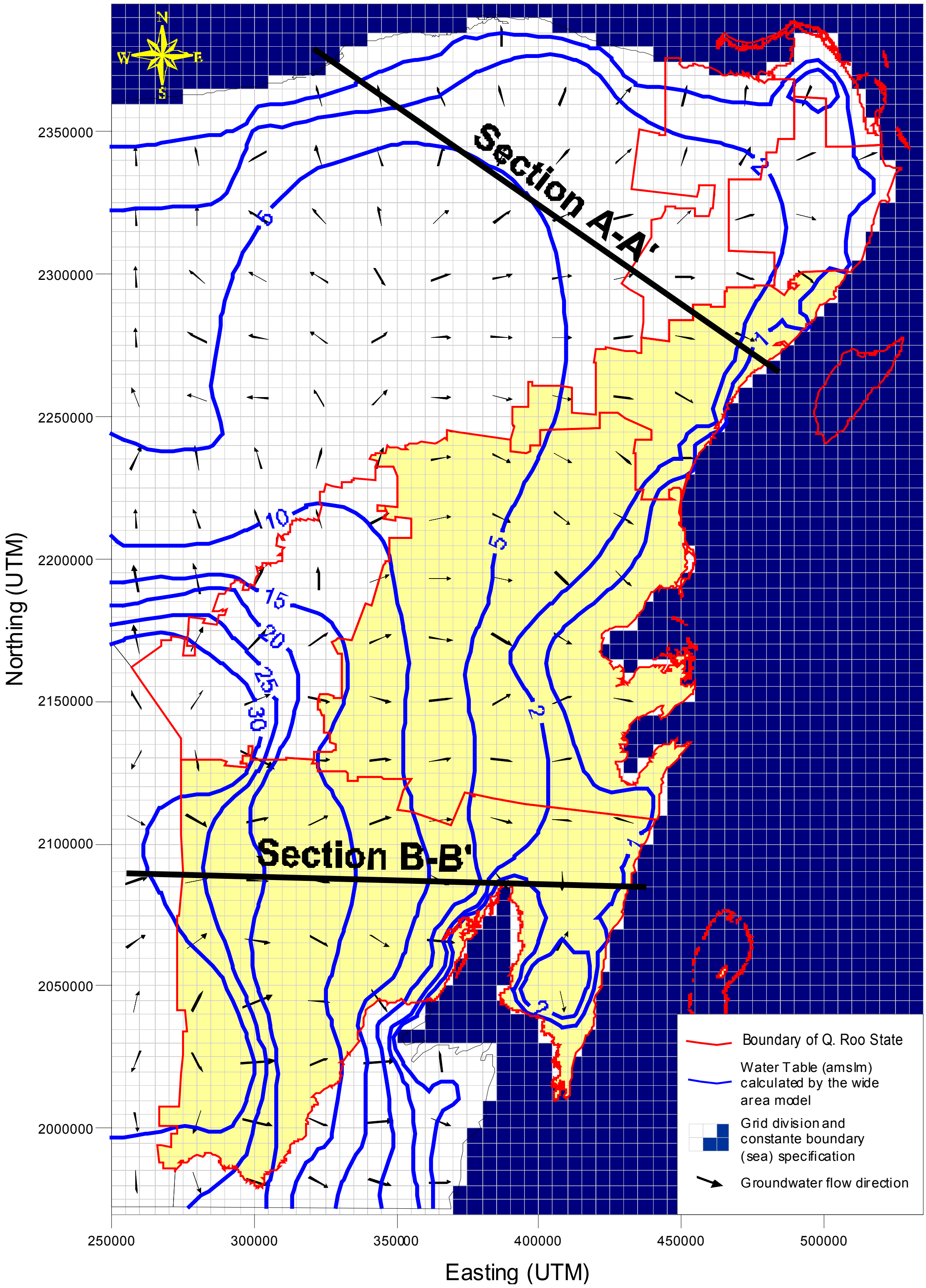
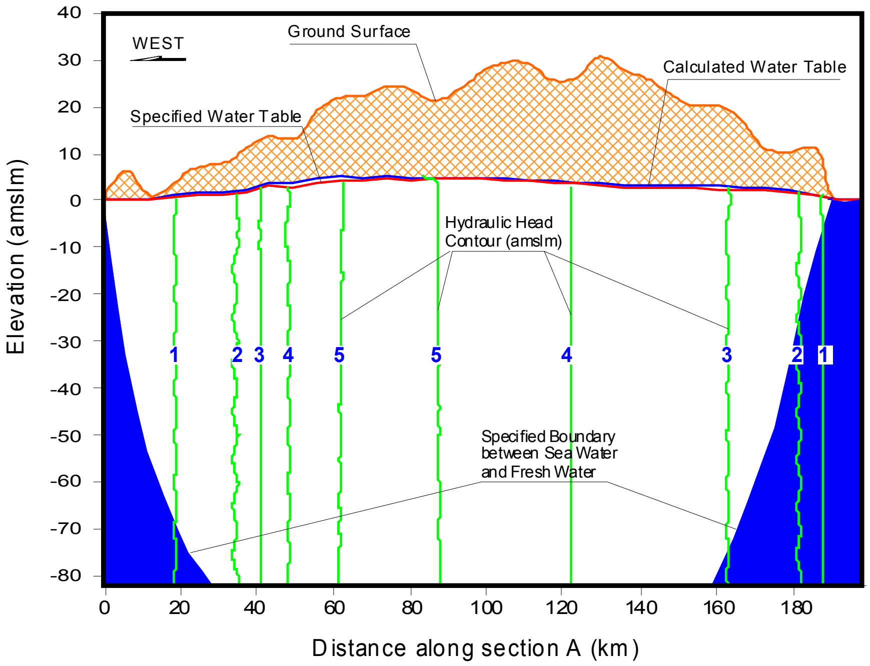


Figure K-34: Location of Sections



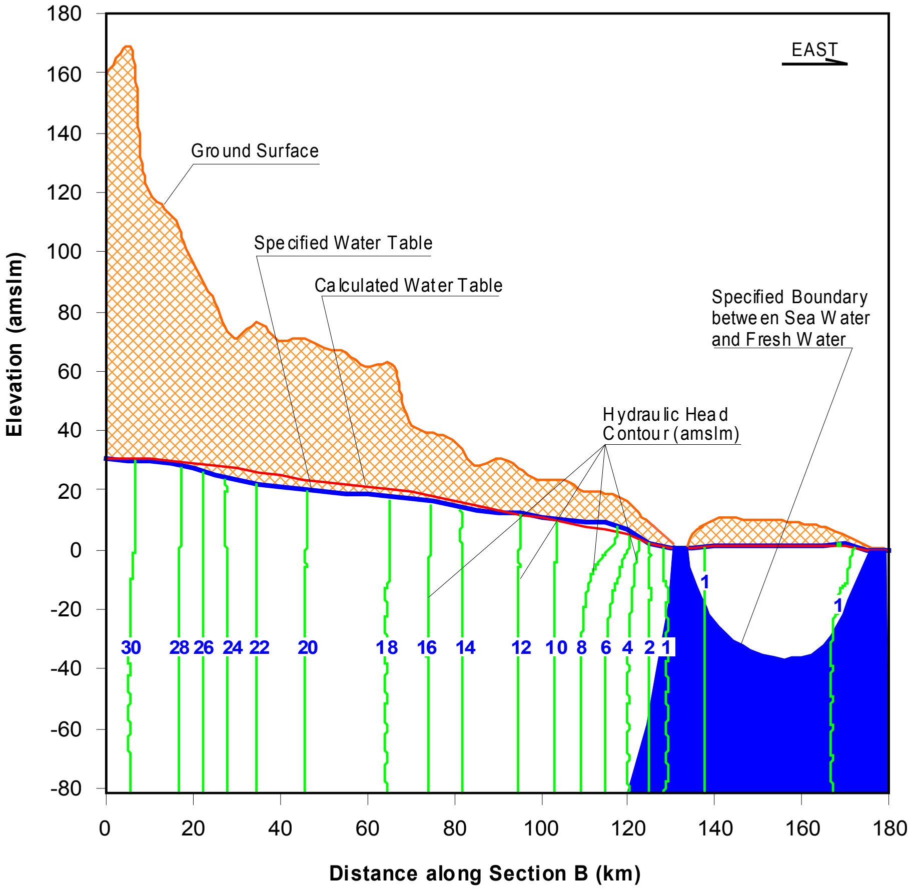


Figure K-35: Scheme of the Boundary between the Sea Water and Fresh Water