THE REPUBLIC OF THE PHILIPPINES
METROPOLITAN CEBU WATER DISTRICT (MCWD)

THE STUDY FOR IMPROVEMENT OF WATER SUPPLY AND SANITATION IN METRO CEBU IN THE REPUBLIC OF THE PHILIPPINES

FINAL REPORT
VOLUME-III: SUPPORTING REPORT

AUGUST 2010

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NJS CONSULTANTS CO., LTD. (NJS)

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Composition of the Final Report

Volume-I Executive Summary contains the study results, while Volume-II Main Report includes contents of the action plan with major examinations and recommendations for its realization. Volume-III Supporting Report describes examination methods and study results in water supply sector, and contents of the technical transfer. Volume-IV Data CD installs the electronic files of primary data/ information, presentation materials and cost estimation for effective use in future.

Currency Exchange Rates Adopted for the Study: March 2010

US$1.00 = PHP46.148, PHP1.00 = JP¥1.934

Table of Contents

Chapter-I: Field Report
Part-A: Socio-economy and Poverty Analysis
Section-I: Outline

I-1 General Information

Socio-economic Survey has been conducting for collecting basic data and analysis to be reflected and referred to this study. Outline of the survey is described below.

(1) Objectives

Objectives of the socioeconomic survey are to clarify the followings;

- socioeconomic situation including household budget and ability to pay,
- current situation of water use,
- current situation of sanitation, and
- possibility for establishment of water users association for lower income households.

The result of the survey will be utilized for the following works of the study;

- water demand (including MCWD demand) forecast,
- review of water tariff,
- suggestion for improvement of water supply for lower income households, and
- basic planning for sanitation.

(2) Target Area

Target area is four (4) Cities and four (4) Municipalities, in total eight (8) local government units as franchise areas of MCWD water supply.

(3) Schedule and Progress

The contract with local consultant was made on February 18, 2009 through tendering. Then the preliminary survey had conducted from February 20 to 26. The full scale survey has been conducting now and will be completed by mid. June, 2009.

I-2 Scope of Survey

(1) Phasing

The survey is divided into preliminary survey and full scale survey.

(2) Survey Number

< Preliminary Survey >

Preliminary survey includes interview surveys with 5 samples of barangay captains and 20 samples of existing and potential users (domestic and business purpose). Based on the preliminary survey result, two types of questionnaire have been finalized.

< Full-scale Survey >

Full-scale survey includes interview with 800 samples.

Section-II: Methodology

II-1 Preliminary Survey

Based on the result of preliminary survey and the discussion with the C/Ps, sampling methodology was considered

(1) Proportion of Sampling Number

The total number of sampling, which is 800, was divided into 700 for households and 100 for business establishment.

(2) Target Barangay

There are in total 223 barangays among eight (8) cities and municipalities. In total 136 barangays out of 223 are being served by MCWD while additional 65 barangays are identified as potential areas for extra water demand (see Figure A.I-01). Therefore the target barangay for the full scale survey has been set as 201 barangays

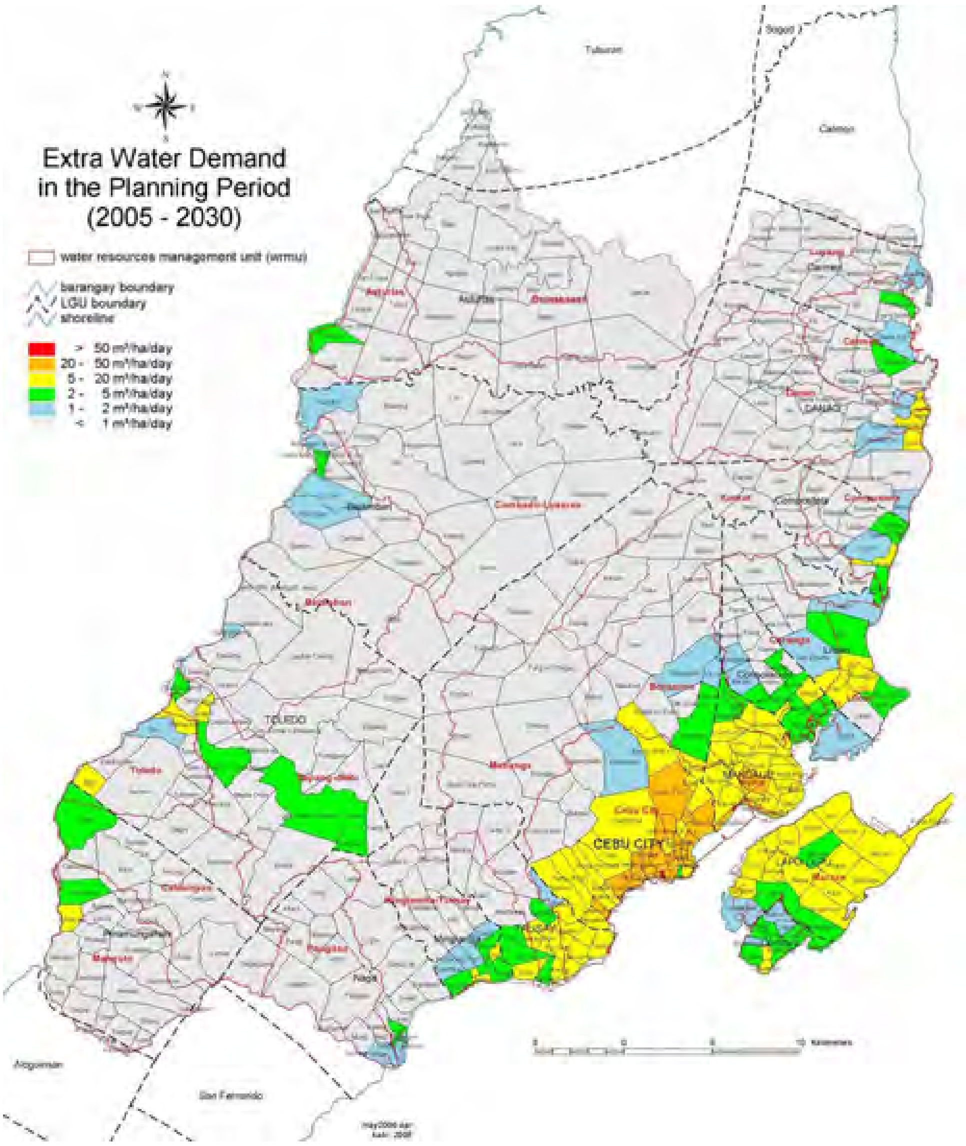

Figure A.I-01 Extra Water Demand (2005-2030), Water REMIND Project

Currently, there are 104,141 HHs served by MCWD while 235,452 HHs in the expansion barangays are identified as potential users. The Scope of Work has set a total sample of 700 HHs and 100 establishments to be covered in the study.

The sample barangays were chosen in random and the allocated number of household-respondents in each city/municipality was divided equally among the identified sample barangays. For fractions, the value was rounded-up to the next number. For example, Cebu City was allocated 132 MCWD-user HHs to be taken from 10 barangays or 13.2 HH per barangay. The resulting fraction was converted into an absolute number. Thus, in the same example, 14 HHs will be interviewed in each MCWD served barangay of Cebu City bringing the total respondents to 140. From the computations, the total number of household-respondents in the entire study area reached 746, which is actually higher than the targeted sample of 700 HHs.

The first stage of the sampling will involve determining the sample barangays in each city/ municipality, as described in the following steps:

1. For each city/municipality, determine the number of barangays that are (a) currently being served by MCWD (refer to Column C of Table A.I-01); and (b) potential areas for expansion (Column D).
2. For each city/municipality, compute for the proportion of served barangays over the total number of served and potential barangays (Column F).
3. For each city/municipality, determine the number of households served by MCWD (Column G) and total number of households in the potential barangays (Column H).
4. Compute for the distribution of served and potential households by dividing the number of households in each city/municipalities by the total served and potential households in the eight cities/municipalities (Column J).
5. For each city/municipality, determine the number of sample barangays by computing for 20% of the total number of served and potential barangays (Column K of Table A.I-02).
6. For each city/municipality, determine the number of sample barangays served by MCWD by multiplying the proportion of served barangays (from Step 2) with the number of sample barangays (from Step 5). (Column L).
7. Based on the number of samples allocated for MCWD and non-MCWD barangays (potential barangays) in each city/municipality, select the sample barangays randomly from the list of barangays served by MCWD and list of potential barangays.

The second stage of the sampling will involve selecting the sample households, as follows:

1. Allocate to the eight cities/municipalities the 700 sample households based on the proportion of served and potential households in a particular city/municipality to the total served and potential household for the eight cities/municipalities (Column N).
2. For each city/municipality, compute for the number of sample households to be taken from the barangays served by MCWD by (a) determining the proportion of served households (Column G) over the served and potential households (Column I), then (b) applying said proportion to the sample households allocated to the city/municipality (Columns O and P).
3. For each city/municipality, compute for the number of sample households to be taken from potential barangays (non-MCWD) by (a) determining the proportion of potential households (Column H) over the served and potential households (Column I), then (b) applying said proportion to the sample households allocated to the city/municipality (Column Q and R).
4. Distribute the number of sample households allocated to barangays served by MCWD

equally to the MCWD-served barangays.

5. Distribute the number of sample households allocated to potential barangays (non-MCWD) equally to non-MCWD barangays.
6. Based on the number of sample households allocated for each barangay, select the sample household-respondents randomly from the list provided by the Barangay Chairman or Secretary.

Table A.I-01 Sampling Methodology (1)

LGUs	Census 2007		No. of Barangay				No. of HHs			
	Barangay	HHs	Served by MCWD	Non-MCWD (Potential)	Total (C+D)	Coverage (C/E %)	Served by MCWD	Non-MCWD (Potential)	Total (G+H)	Distribution (I/I-total %)
	A	B	C	D	E	F	G	H	I	J
1. Compostela	17	6,892	4	12	16	25%	787	5,885	6,672	2.0%
2. Consolacion	20	14,052	10	10	20	50%	3,416	10,636	14,052	4.1%
3. Cordova	13	7,137	7	6	13	54%	620	6,517	7,137	2.1%
4. Talisay City	22	31,472	12	8	20	60%	6,330	24,439	30,769	9.1%
5. Cebu City	80	161,567	51	15	66	77%	64,037	89,140	153,177	45.2%
6. Lapu-lapu City	30	48,644	18	12	30	60%	7,243	41,401	48,644	14.3%
7. Lilo-an	14	14,647	8	1	9	89%	4,143	9,120	13,263	3.9%
8. Mandaue City	27	65,309	26	1	27	96%	17,565	47,744	65,309	19.3%
Total	223	349,720	136	65	201	68%	104,141	234,882	339,023	100.0%

Note: column "J" is distribution rate of total HHs combined with served and potential.

Table A.I-02 Sampling Methodology (2)

LGUs	Distribution of Sample Barangays			Distribution of Sample HHs				
	Sample Brgy (20% of E)	Served by MCWD	Non-service MCWD	Sample HHs	Served by MCWD No.	Served by MCWD G/I %	Non service MCWD No.	Non service MCWD H/I %
	K	L	M	N	O	P	Q	R
1. Compostela	3	1	2	14	2	12%	12	88%
2. Consolacion	4	2	2	29	7	24%	22	76%
3. Cordova*[1]	3	2	1	15	1	9%	13	91%
4. Talisay City	4	2	2	64	13	21%	50	79%
5. Cebu City	13	10	3	316	132	42%	184	58%
6. Lapu-lapu City	6	4	2	100	15	15%	85	85%
7. Lilo-an	2	2	0	27	9	31%	19	69%
8. Mandaue City	5	5	0	135	36	27%	99	73%
Total	40	28	12	700	215	31%	485	69%

Note*[1]: Figures were adjusted because Column K to M and N to R do not totally due to rounding.

(3) Sampling for Business Establishment

Business establishments were randomly selected from the list of entire registered business establishments.

II-2 Full Scale Survey

Full scale survey is planned to be conducted in April, 2009 with above 800 samples. The result of the survey will be prepared by the middle of May. Detailed raw data is shown in Data CD.

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Part-B: Water Sources Management
Section-I: General Information

I-1 Introduction

This "Part B" of the supporting report was prepared to supplement the main report in the field of water source management. This part includes all kinds of water source as an input to the MCWD water supply system. However, most of water source to survive the harsh water crisis depends on the groundwater availability at the moment. Therefore, this study put emphasis on groundwater examination for preparation of action plan. Nevertheless, improvement plan on the existing surface water intake was prepared in rough-and-ready manner.

Individuality of this study was to built a calibrated groundwater model in MCWD with due consideration of saltwater intrusion. Several groundwater investigations were implemented in this study to supplement the available information and data. It is eagerly recommended that the groundwater model has to be improved continuously by MCWD using accurate and verified information, because there were still many input assumptions in the said initial model. Additionally, groundwater monitoring technologies shall be strengthened since the model precision reaches an advanced level.

The groundwater model, hereinafter called as "the Cebu-GWM-09", is used for not only groundwater development and conservation technically but also regulatory operation institutionally as a part of technical guideline. Therefore, it would be anticipated that institutional setting regarding operation system of groundwater regulation shall be set up and well functioned among the stakeholders. It would be the first operation case of groundwater regulation in the Philippines, if the stakeholders will participate in the social activity without barrier of national and local governments, regulatory and developer sides, public and private sectors, and any other intervention forces.

I-2 Objectives

The study on water sources management has following objectives:

1) To built a calibrated groundwater model with due consideration of saltwater intrusion for monitoring and evaluation purposes, including an improvement plan on the Cebu-GWM-09.
2) To formulate an action plan for groundwater development and conservation for sustainable groundwater use, and

I-3 Scope of Study

I-3.1 Groundwater Study Area

The study covers the service area of MCWD water supply for the WATSAN planning. Surroundings of the study area were included for the planning of water sources development. Figure I-01 shows the maps on relative information.

MCWD has franchise LGUs for the water supply services, administrative areas of where consist of 4 cities and 4 municipalities. Because of topographical features in the Metropolitan Cebu, most of residents are concentrated along the coastal plain area of Cebu Island and the north-west side of Mactan Island. Accordingly, MCWD service covers the same area of the high population density.

Exploitable and feasible groundwater in the study area is distributed in aquifers composed of limestone and alluvial formations. Location of these formations and MCWD service area is almost overlapped. Groundwater model domain was selected by the WRMUs, because water balance information in such units is available in MCWD obtaining from the Water Remind Project and hydrogeology of the said aquifers.

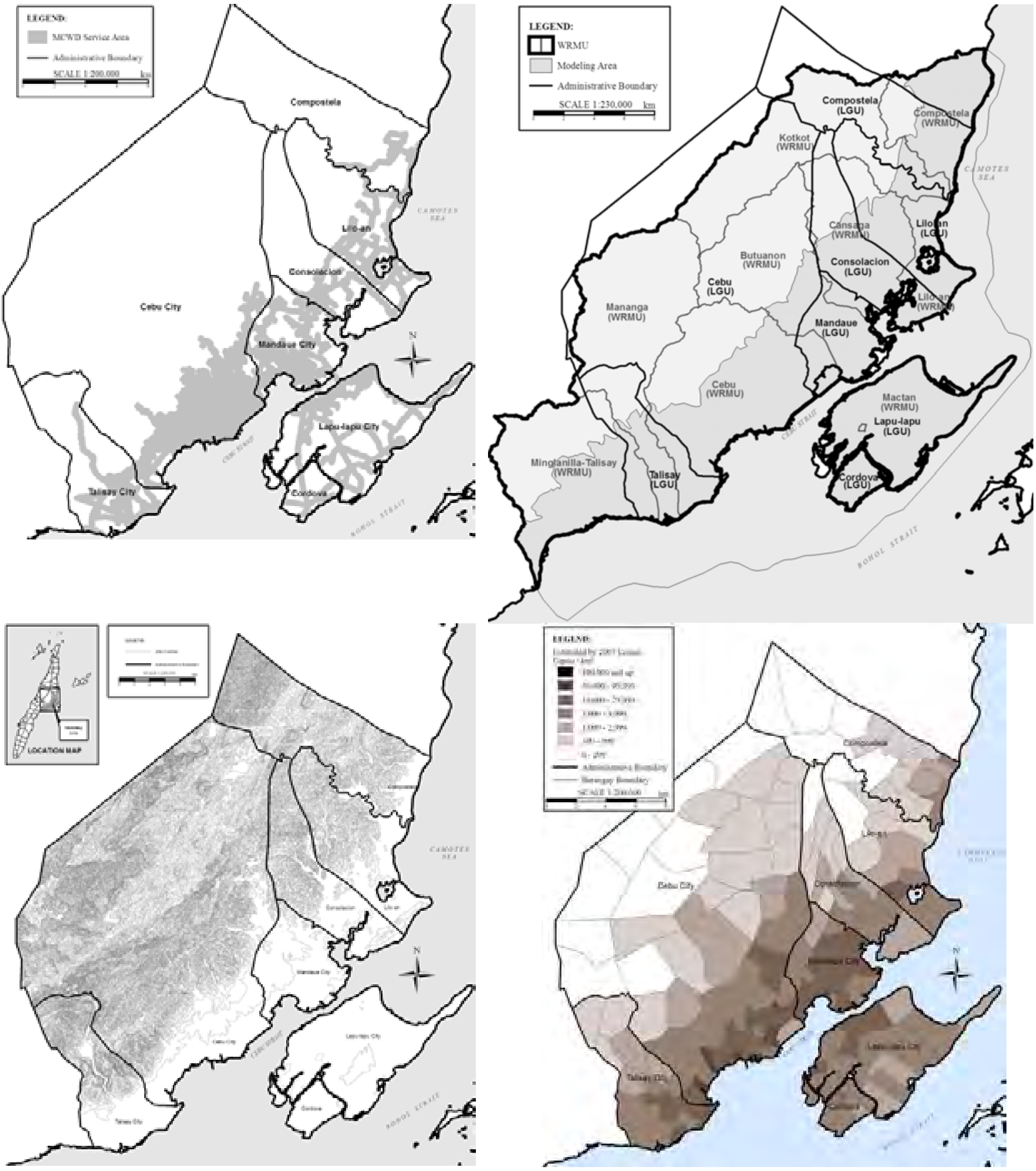

Figure B.I-01 Comparison Maps of
LGUs, MCWD Service Area, WRMUs, Topography, Population Density & Model Domain

I-3.2 Implementing Agencies and Phasing Approach

Field of water sources management includes three (3) plans namely; groundwater development, groundwater conservation and improvement of the Cebu-GWM-09, respectively. Following Table BI-01 shows implementing agency and phase of the groundwater plans.

Table B.I-01 Agency and Phase for Groundwater Plans

Plan		Agency	Phase	Objectively Verifiable Indicators
Development		**MCWD**, LGUs, NWRB	Annual Execution until 2015	Increasing of Revenue Water, Improvement of Service Level and Reduction of Development Risks
Conservation	Monitoring			
	Environment	**MCWD**, LGUs, DENR	Requirements at Target Year 2015	
The Cebu-GWM-09 Improvement		**MCWD**, NWRB, LWUA, UP, USC		Up-grading of Model Accuracy and Simulation Sensitivity

Note: These plans relate to the water supply system improvement and effectiveness of sanitation improvement.

I-4 Technical Concept and Methodology of the Study

About 71% of provincial population occupies only 12% of provincial jurisdiction area according to the Census 2007. Water demand was projected as much larger amount than groundwater potential. Since long-year back and until now, the several plans on surface water development by dam construction were proposed repeatedly for MCWD service improvement. However, all of such plans were ignored, because such plan is not measure with cost effectiveness due to natural characteristics of Cebu Island, and is also troublesomeness consisting of political and administrative interventions.

As urgent and realistic measures, water deficit in the action plan was fallen on the de-salination of brackish water or sea water. On the other hand, water shortage in the long-term plan was merely supposed to be imported under the scheme of bulk water supply from the outside of MCWD franchise area, such as Carmen Water Supply Project in private sector.

For achievement of the objectives, following technical procedures were adopted as shown in Figure BI-02 with indication of reporting assignment.

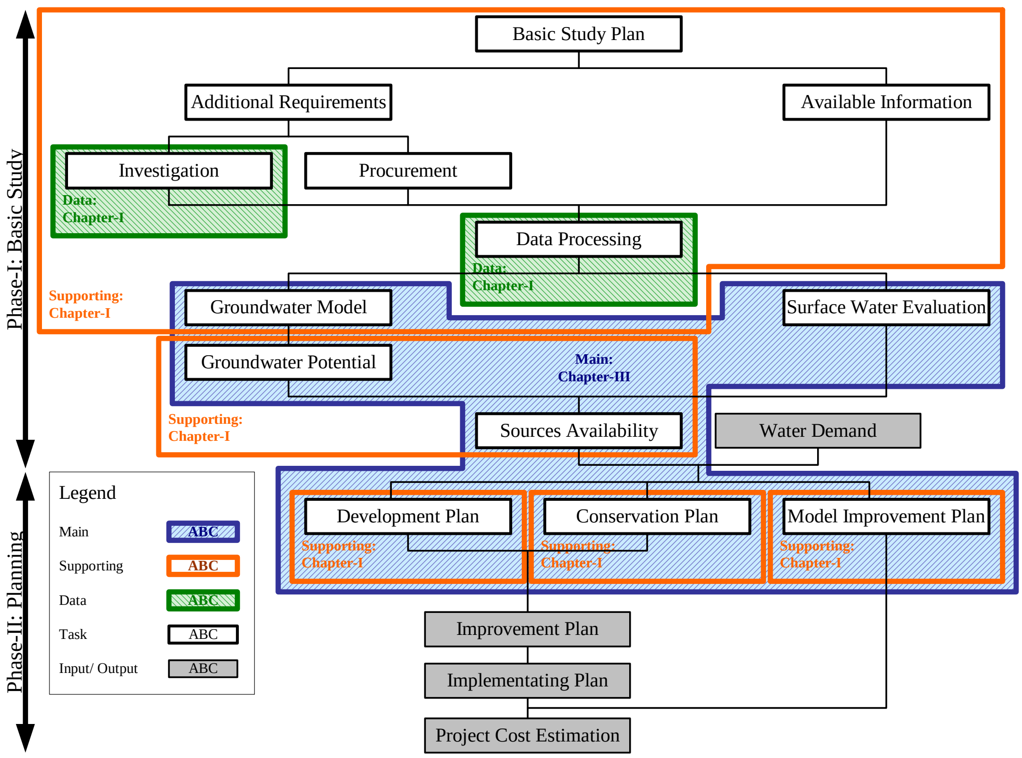

Figure B.I-02 Workflow and Reporting Assignment

Pre-condition to this task is amount of projected water demand and outputs were transferred to the improvement plan on the MCWD water supply system. This system improvement plan is composed of action plan and project cost estimation for annual execution.

Key groups of the study methodology were briefly described below.

(1) Groundwater Modeling

The Cebu-GWM-09 was built in the semi-workstation computer in MCWD using available information and data in the Philippines including supplemental results of field investigation being conducted by the study scheme. The Cebu-GWM-09 is a basis of planning. Therefore, it is recommended that both sides of regulator and developer maintain the same model.

(2) Groundwater Development

Groundwater development plan has target of well field allocation. The first priority of action was given to the screening of existing well fields and individual production wells for allocation and improvement. Therefore, technical guideline consisting of standardization, monitoring and evaluation (M&E), and performance indicators (PI) was prepared for smooth project execution.

(3) Groundwater Conservation

Groundwater conservation plan includes control of over extraction and M&E activities in terms of water level and water quality. Rigorous operation of groundwater regulation and promotion of groundwater recharge were also included in this report. Concerned national government agencies and local government units are required to institutionalize the conservation activities with project design matrix (PDM) and plan of operation (PO).

(4) Groundwater Model Improvement

Formulation of improvement plan on the Cebu-GWM-09 was added during the basic study period for technical support to the MCWD experts with referential cost estimation. This plan was prepared with due consideration of model limitations and simulation weak points including contractor capability in the Philippines.

I-5 Study Organization

Study organizational was set up between MCWD and the study team for smooth implementing of the study tasks on water sources management at the beginning of the study period. Figure 1-03 (next page) shows the said organizational structures including decision making group and external relations.

The joint task force team for "groundwater modeling" was set up for the planning of procurement and investigation, and the technical transfer of modeling works. Groundwater modeling seminar was conducted with target participants of MCWD experts.

On the other hand, experts from the study team supervised the investigation contractors and controlled the procurement suppliers with corporation of MCWD experts. Workshops were held two times in the study period at the social hole in MCWD with coordination of MCWD experts.

(1) Joint Task Force Team

Joint task force team (JTFT) was organized by MCWD and the study team as shown in Figure I-03 consisting of following members that was confirmed in the M/M (minutes of meeting) of the IC/R (inception report). GM of MCWD and study team leader managed the overall decision. Mr. Lasaro P. Salvacion was nominated as leader of the JTFT.

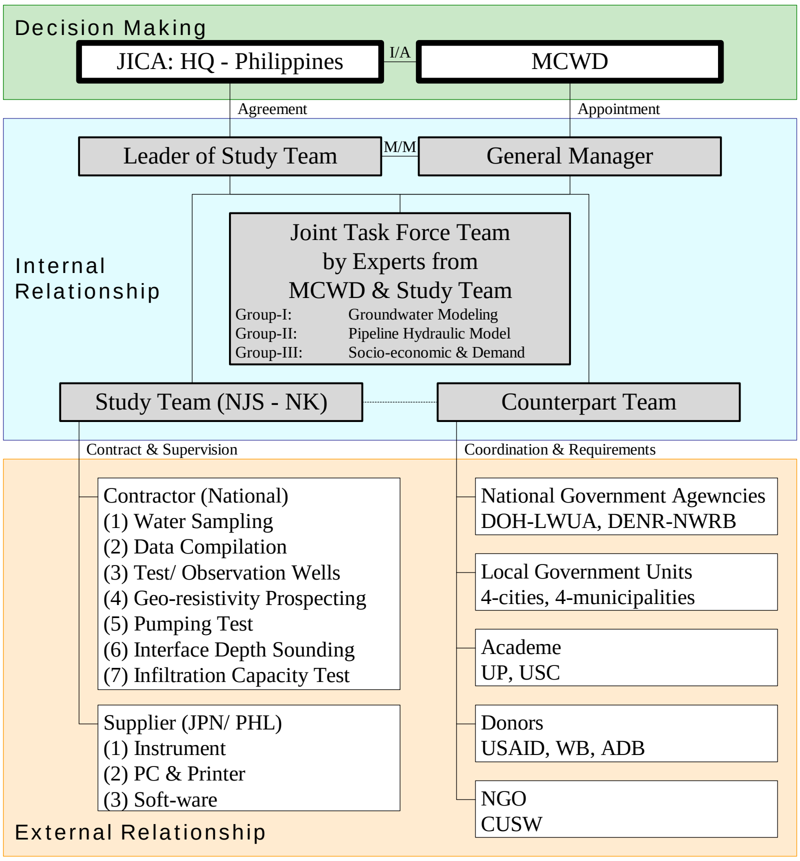

Figure B.I-03 Task Organization

< MCWD >

Mr. Lasaro P. Salvacion	Manager, EWRKC (Environment & Water Resources Knowledge Center)
Mr. Ronnel Y. Magalso	OIC, Groundwater Division, EWRKC
Mr. Lemuel A. Canastra	OIC, Surface Water Division, EWRKC
Mr. Roel A. Panebio	Manager, Environment Division, EWRKC

< Study Team >

Mr. Nobukatsu Sakiyama	Hydrogeologist
Mr. Keiji Ishii	Groundwater Modeler

(2) Stakeholders

Relative organizations were set up for the “Stakeholders Committee” for this study with following concepts.

Purposes:
(a) Integration of Planning Information
(b) Confirmation of Work Sharing & Action to be taken

Activities:
(a) Aggressive Participation to implement their roles in the Action Plans
(b) Decision Making for Critical Issues & Measures

Organization:
(a) Chair: MCWD
(b) Members: National Government Agencies, LGUs
(c) Observers: Academe, Donors (including JICA), NGO

According to the concepts mentioned above, following stakeholders were nominated by MCWD:

< National Government Agencies >

LWUA, NWRB, (Regional DENR/ DPWH: relating to the sanitation sector)

< Local Government Units >

Cebu Province, Cebu City, Talisay City, Mandaue City, Lapu-lapu City, Cordova Municipality, Consolacion Municipality, Lilo-an Municipality, Compostela Municipality

< Academe >

University of the Philippines, University of San Carlos

< Donors >

USAID, WB (IBRD), JICA

< NGOs >

CUSW (Cebu Uniting Sustainable Water Foundation Incorporated)

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Section-II
Groundwater Modeling

II-1 Modeling Workflow

The Cebu-GWM-09 is recognized as major planning tool for groundwater development and conservation. Following Figure B.II-01 shows adopted workflow of groundwater modeling in this study including groundwater planning with interrelationships of each study item.

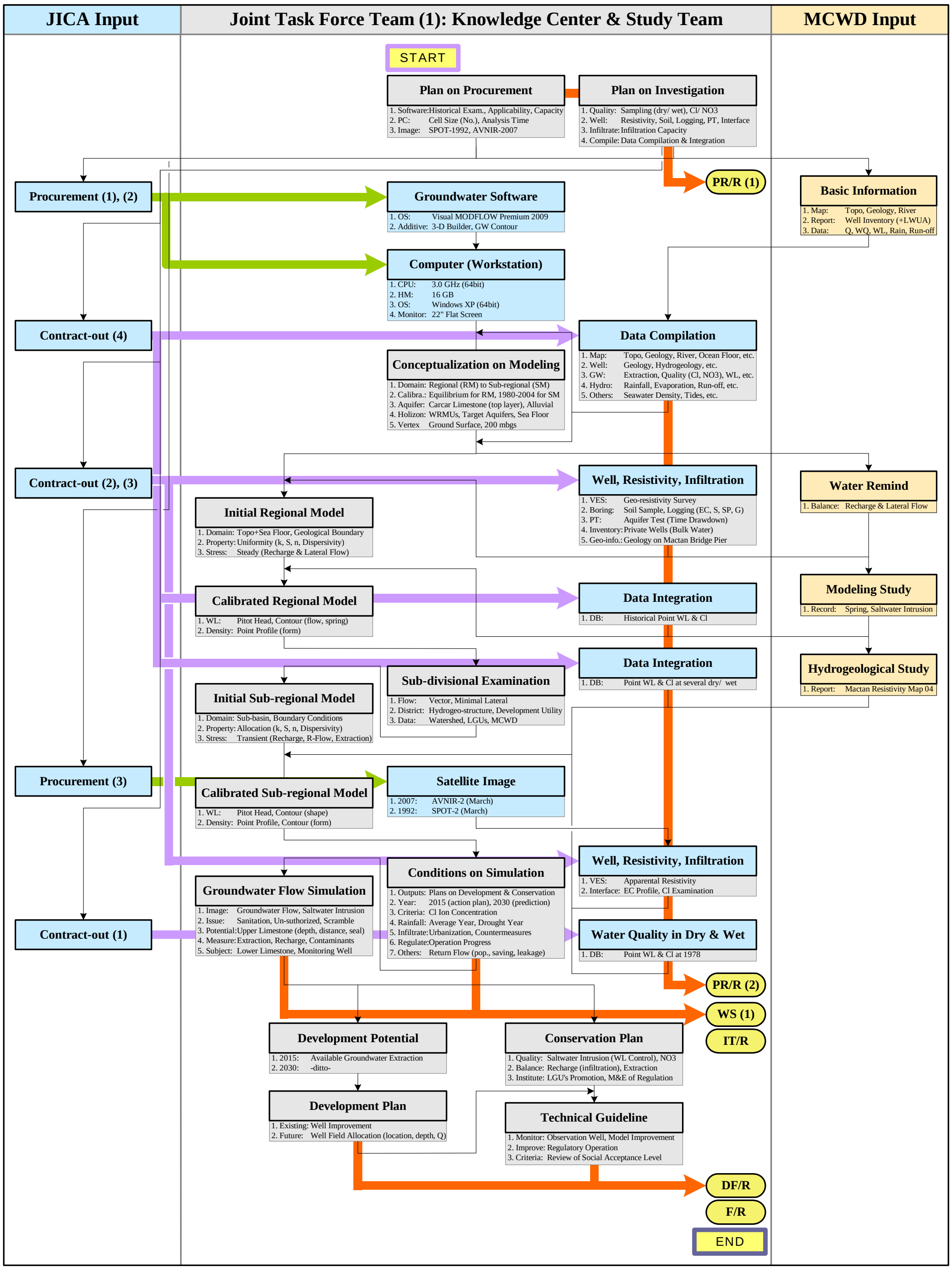


Figure B.II-01 Workflow of Groundwater Modeling and Plans

II-2 Preparatory Works

As the first step of the study on water sources management, plans on procurement and investigation were finalized for execution within the study period that was based on following original items to be procured and investigated in this study scheme. Following indicate the initial plans and scopes.

(1) Procurement

- Soft-ware with Supporting Modules on Groundwater Modeling using Density Flow Simulation
- Computer for Model Building, Calibration and Predictive Simulation including Printer
- Satellite Images for Prediction of Infiltration Capacity
- Instruments for Field Survey and Supervision of Hydrogeological Investigation
  - ✓ Water Sampler for Well: 1 set
  - ✓ Potable pH and EC Meters: each 2 units
  - ✓ Manual Water Level Indicator: 2 set
  - ✓ Water Level Meter and Data Logger with Calibrator: 1 unit (5 meters per unit)

(2) Investigation

- Field Survey for Geological Boundaries
- Core-boring for Permeability Column Tests
- Interval Permeability Tests
- Infiltration Capacity Tests
- Water Quality Examination

II-2.1 Procurement Items

(1) Requirements with due consideration of Current Situation

The joint task force team (JTFT) members prepared following procurement plan based on the past experiences.

< Problems Requiring to Groundwater Modeling >

The JTFT expects to have solution of following problems using groundwater modeling.

- ✓ Evaluation at the current coastal aquifer status as to sustainable yield or seawater intrusion
- ✓ Assessment on the extent of pollution/ contamination affecting groundwater quality
- ✓ Analysis on the urbanization effects (rapidly changing of land-use) on groundwater potential
- ✓ Forecasting on the seawater intrusion under the climate change scenarios (long droughts)
- ✓ Management on the groundwater yield (monitoring/ regulation)
- ✓ Grasp on the interaction of surface water and groundwater
- ✓ Optimization on the groundwater development (potential new well-fields/ existing wells)

< Model Effectiveness in Problems >

Basic features of a groundwater model can be interpretative and predictive use for groundwater regulation and management.

- ✓ Assessment of groundwater flow, fate and transport of domestic and common contaminants as wells as other advance pollution threats from heavy metals and volatile organic compounds in the future.
- ✓ Simulation of local (large) regional hydrologic setting/ interactions, and also capable of modeling sub-regional water budgets and flow processes in small subset areas.
- ✓ Can simulate un-saturated flow to account conditions at the portion above the aquifer.

- ✓ Can handle chemical modeling to address chemical mixing processes.
- ✓ Can define geographically the extent and effects of multiple pumping wells under varying time and spatial conditions.

< Data Issues for Modeling Works >

Available local data (monthly time series) from MCWD and local agencies as inputs to the model are:

- ✓ Hydrologic data (rainfall, evaporation data, river flows: 1977-2009), Central Cebu area
- ✓ Static water level data (1989-2009), MCWD area/ Central Cebu area.
- ✓ Monthly pumping water level data/ extraction volumes/ water quality i.e. salinity, nitrate, turbidity. Well efficiency records (annual, 2007)
- ✓ Well survey reports showing penetrated well lithology and construction, complete chemical analysis, pumping tests and hydrogeological parameters (transmissitivity, storage, etc.) borehole resistivity and conductivity profiles and selected geo-resistivity surveys.
- ✓ Water resources assessment reports; analytical model in 1978, analytical model in 1981, analytical model for north area in 1983, digital mainframe model in 1986 (model construction and schematization report).
- ✓ NWRB/ CEST 2004 model report, construction, runs and documentation
- ✓ Private well data spontaneous location/ random water quality analysis, pumping test records.

Following aspects are foreseen data problems concerning to build a groundwater model.

- ✓ Well/ geologic data from MCWD concentrated on well-fields far from the shoreline. Data between this location and the shoreline are sparse and few. Interpolation was applied in 1986 to give a good data distribution and representation, if available private well data are not correctly analyzed or interpreted.
- ✓ Position of saltwater interface is technically debatable. Current understanding is based on water quality survey base on the salinity value of 50 ppm.
- ✓ Data on river conductance and the river/ groundwater interaction is still subject to verification.
- ✓ Input flow from surface runoff in the volcanic layers to the limestone area is suspected to provide additional recharge aside from rainfall. No specific study as to this phenomenon is made.
- ✓ Very few information is available on the hydrogeological parameters in the volcanic layers.
- ✓ Effective infiltration to the limestone aquifer is not very well defined.
- ✓ Local clay cover in the seaward front of the aquifer renders this part in artesian condition. Accurate geographic delineation of this part of the aquifer provides good representation (characterization and conceptualization) of the real aquifer condition.
- ✓ In some specific areas with karst topography, the aquifer is highly channelized making porous media flow analysis impossible.
- ✓ Hydraulic properties of the soil are not so well defined and studied making data difficulties in the unsaturated flow modeling.

< Previous Groundwater Modeling Study >

Following Table B.II-01 shows the previous groundwater study projects.

Table B.II-01 Past Groundwater Study in MCWD

Title / Year	Investigator	Coverage	Type	Purpose
Water Resources Investigation (1978)	DKK (LI)	MCWD Franchise	Analytical	For verification of drawdown and extents
Interim Report (1981)	Cebu Consultants	MCWD Franchise		For Verification of last study
Water Resource Assessment (1983)		MCWD North Area		Design of new wells
Groundwater Model Study (1986)		MCWD Franchise	Digital, Solute transport	Groundwater Investigation/ Prediction
Groundwater Modeling of MCWD area (2000)	Olaff Scholze UH Germany	MCWD Franchise	FEM: Digital, Solute transport, SHEMAT/ FEFLOW	Groundwater Investigation relative to seawater level rise
Groundwater Modeling Study by NWRB/ ADB (2004)	NHRC (CEST)	Central Cebu	Digital Flow Model /MODFLOW FDM no solute transport	Update Assessment of current GW situation
WATER REMIND: Holland (2006)	WRC/ Delft Hydraulics	Central Cebu	Analytical tank models	Water Availability Modeling (Tank type Water balance)

Source: EWRKC, MCWD

< Required Capabilities and Features on the Groundwater Modeling Software >

- ✓ To have an operational and calibrated groundwater flow model for MCWD to cover a fairly large area with limited aquifer data
- ✓ The groundwater model must have the capabilities as follows;
  a. Un-saturated/ saturated variable-density flow modeling coupled flow and solute-transport
  b. Regional/ sub-regional groundwater flow and groundwater availability modeling
  c. Surface water/ river physical processes and interactions with groundwater
  d. Full GIS interface (Arc-view)
  e. Porous/ karst flow
  f. Advance geo-statistical package
  g. User friendly and easily manageable/ modifiable and upgradeable
  h. Dynamic 3-D visualization and graphical outputs
  i. Technical training package and support for MCWD model users
  j. Extensive documentation with after sales technical support
  k. Automatic calibration capabilities

Requirements for the groundwater modeling mentioned above are understandable according to the groundwater situations in the study area. However, any national agencies and donors did not remain the groundwater model in MCWD for calibration, updating and improvement of the groundwater model by MCWD.

(2) Procurement Plan

Procurement plan on three items of modeling soft-ware, computer and satellite image was approved by JICA, details of which are described below.

a. Modeling Soft-ware

The features of different softwares being well-used for groundwater modeling were examined as shown in Table B.II-02. Key considerable items of soft-ware selection are to have higher applicability such as operability, expandability, comparability and defensibility.

Table B.II-02 Comparison Table on Well-used Groundwater Modeling Softwares

	Product Name	PM-Win 5.3	GW Vistas 5	V-MOD 4.3*3	GMS 6.5	FEFLOW 5.4
Numerical Analysis Method		FDM	FDM	FDM	FDM and FEM	FEM
Main Feature	Saturated Flow	YES	YES	YES	YES	YES
Main Feature	Un-saturated Flow	**NO**	*	*	**FEM only**	YES
Main Feature	Mass Transport	YES	YES	YES	YES	YES
Main Feature	Variable-density Flow	**NO**	YES	YES	**FEM only**	YES
Main Feature	Local Water Budget	YES	YES	YES	YES	YES
Main Feature	Particle Tracking	YES	YES	YES	YES	YES
Usability*1	Operability		Usual	Excellent	Good	
Usability*1	Stability		Stable	Stable	**Possible un-stable in FEM**	
Size Limitation*2		Grid Size: 250,000 x 80 layers		Grid Size: 250,000 x 60 layers		
Manufacturer		W_H. Chiang and W. Kinzelbach	ModelCAD-TM	SWS (WHI)	Aqua-VEO (EMS-I)	DHI-WASY (GmbH)
Integrated Major Program	< FEM: have the advantage in regard to flexible boundaries, variable scale meshing >					
Integrated Major Program	FEFLOW	**NO**	**NO**	**NO**	**NO**	YES
Integrated Major Program	FEMWATER	**NO**	**NO**	**NO**	YES	**NO**
Integrated Major Program	< Flow simulation by FDM >					
Integrated Major Program	MODFLOW-1996	YES	YES	YES	**NO**	**NO**
Integrated Major Program	MODFLOW-2000	YES	YES	YES	YES	**NO**
Integrated Major Program	MODFLOW-2005	**NO**	YES	YES	**NO**	**NO**
Integrated Major Program	< Particle Tracking based on MODFLOW >					
Integrated Major Program	MODPATH	PMPATH	YES	YES	YES	**NO**
Integrated Major Program	< Local water budget based on MODFLOW >					
Integrated Major Program	Zone Budget	Similar	YES	YES	Similar	**NO**
Integrated Major Program	< Mass transfer based on MODFLOW >					
Integrated Major Program	MT3DMS	YES	YES	YES	YES	**NO**
Integrated Major Program	RT3D	YES	YES	YES	YES	**NO**
Integrated Major Program	MT3D99	YES	**NO**	YES	**NO**	**NO**
Integrated Major Program	PHT3D	**NO**	**NO**	YES	SEAM3D	**NO**
Integrated Major Program	< Variable Density Flow simulation coupling with MODFLOW and MT3DMS >					
Integrated Major Program	SEAWAT	**NO**	YES	YES	**NO**	**NO**
Integrated Major Program	< Optimization for hydrologic parameter (PEST) or well pumping rate (GMO) >					
Integrated Major Program	MGO	**NO**	BRUTE FORCE	YES	**NO**	**NO**
Integrated Major Program	PEST	Yes	YES	YES	YES	YES
Integrated Major Program	< Coupling with Un-saturated flow FDM model (SURFACT) or Surface Water Model (MIKE11)-river network simulation >					
Integrated Major Program	SURFACT	**NO**	enable	enable	**NO**	**NO**
Integrated Major Program	MIKE11	**NO**	**NO**	enable	**NO**	enable

Note: All above applications equipped with pre and post processing feature can utilize GIS common file such as DXF or SHP format. Envisioned computer is supposed to satisfy all requirements of above candidate applications for installation. However, it should be confirmed to have a compatible OS with PMWIN and GW Vistas. Five models, SUTRA/ SEAWAT/ CODESA3D/ GEO_SWIM/ FEFLOW are introduced as "Most popular and recent model for seawater intrusion" by Professor Lalabi at G-WADI Workshop in 2007.
FDM: Finite Difference Method, FEM: Finite Element Method

*1: Usability is evaluated relatively in the SWS internal report by creating a model with three applications.

*2: Size limitation will be modified by requesting to manufacturer.

*3: The new version of V-MOD will be released within April 2009 according to un-official information.
Also, V-MOD can utilize V-MOD 3D Builder specialized for building a conceptual model separately.

Additional information according to the capabilities mentioned above and (1) operability of softwares, (2) possibility of future interface to other softwares; ArcGIS, etc. for 3-softwares on the right side: V-MOD, GMS and FEFLOW, were studied.

For the marketability of software suppliers, the JTFT prepared the following comparison table of candidate softwares as a reference material as shown in Table B.II-03.

Table B.II-03 Hearing Result on Expected Capabilities of Groundwater Modeling Software

Hearing Item	Hearing Result from Manufacturer or Information obtaining from their Web-site		
	V-MOD 4.3 (SWS-WHI)	GMS 6.5[*1] (AQUA-VEO/ EMS-I)	FEFLOW 5.4 (DHI-WASY GmbH)
1. Can I build un-saturated/ saturated flow variable density coupling with mass transport flow model?	Saturated only unless MOD-FLOW SURFACT is integrated separately.	When using FDM, it is limited for saturated flow and transport simulation without coupling both.	Yes
2. How can I regional/ sub-regional groundwater modeling?	On conceptual modeling using V-MOD 3D Builder, both modeling are operated at a time. But numerical modeling must be done separately.	No clarified answer (but maybe numerical modeling will be done separately)	
3. How can I model surface water/ river physical processes and interactions with groundwater?	1) RIVER Package 2) STR (stream flow routing) Package 3) coupling with MIKE11 river modeling soft-ware	No clarified answer (but maybe RIVER package or STR package will be applied in FDM)	1) 1D finite elements using Manning-strickler equation 2) coupling with MIKE11 river modeling software
4. Can I model karst flow in limestone aquifer without assuming porous media?	Porous media only	No clarifies answer (but maybe porous media only)	The flux the fracture represented as 1D or 2D is calculated by Hagen Poiseuille law or Darcy's law.
5. Does it include advanced geo-statistical package or something like that?	No	T-PROGS, which performs transition probably geo-statistics on borehole data, is available in conjunction with MODFLOW.	No
6. Does it include dynamic 3D visualization and graphical output?	Yes		
7. How support can I take including seminar after purchasing it?	Technical support via e-mail or phone is free access. Training seminar need extra fee.		Technical and engineering support via e-mail or phone is free access (limited to the first year after purchasing). Training seminar need extra fee.
8. How does it work in conjunction with GIS interface (ArcGIS)?	Many types of file including ArcGIS format are available for; - import data for model setup and - export data from modeling results.		
9. What type of data format is it needed to define geological structure?	- grid data (.grd, .dem) or - points data (.shp, .xls).	No clarified answer.	- bird-eye-view geometry as GS data - 3D elevation data for the geological layers as Point Shape files
10. Can we apply auto calibration program, PEST with variable density simulation?	Possible to use PEST with SEAWAT. Adjustable parameters are limited to Conductivity, Storage and Recharge.	No clarified answer (but PEST is implemented to this software).	That is difficult, however not impossible. But manual calibration is usually preferred in variable-density simulation.

Also the following matters are manifested through several meetings.

- ✓ Problems on groundwater in Cebu has been put emphasis on sustainable freshwater development under controlling seawater intrusion in saturated porous aquifer.
- ✓ Currently, JTFT-MCWD team members have apprehension of tricky operation on groundwater software using FEM (finite element method) referred to some experience.

For the stated above, V-MOD based on FDM (finite difference method) was selected as prime candidate beyond the advantage of FEM such as un-saturated flow, flexible boundary geometry, variable scale meshing and so on. Then, the software of V-MOD mentioned above was operated as trial on the personal computer of the EWRKC for well understanding of their operability and visual command performances (see Figure B.II-02 in next page).

Finally, the JTFT decided to select the "V-MOD Premium (latest version)" to be used for groundwater modeling in Metropolitan Cebu. And also, for making full use of V-MOD capability, "V-MOD 3D Builder" which is specialized in building a conceptual model independent of grid structure was selected. Additionally, for digitizing or interpolating input/ output data of groundwater modeling, "GW-contour" is added.

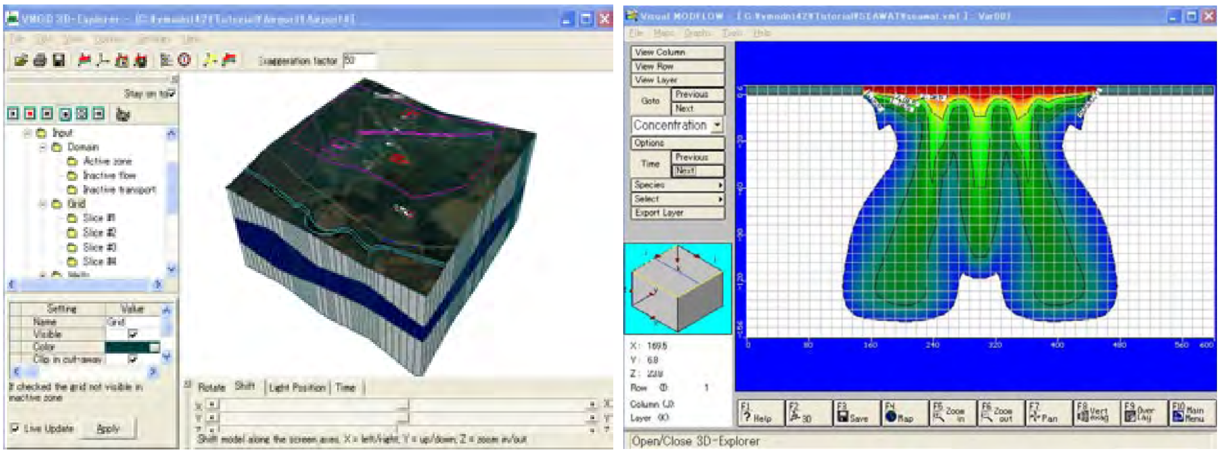


Figure B.II-02　Visual Images of V-MOD Operation

- ✓ Visual MODFLOW Premium (latest version, Schlumberger Water Services)
- ✓ Visual MODFLOW 3D-Builder (latest version, Schlumberger Water Services)
- ✓ GW-Contour (latest version, Schlumberger Water Services)

b. Computer

Groundwater modeling area covering MCWD franchise LGUs is composed of nine (9) watersheds and is estimated at approximately 590 km^2. Three dimensions (3D) area with numerical analysis of 1.5 billion cells as the maximum (X: 5,000 cells, Y: 5,000 cells and Z: 60 cells) can be visualized using candidate software.

Member of the JTFT expected that this groundwater model may have a cell size as smaller as possible comparing with NWRB-Model-04; X-500m, Y-500m and Z-25m. On the other hand, the technical specifications of computer must be capable to operate smoothly because increasing of cell number affects operation time directly.

The design criteria for the technical specifications on computer to be used for the modeling works were examined. With due consideration of power supply sustainability in Cebu and air conditioning in the MCWD office, time period of computer operation was estimated at the daytime limitation. In this regard, a computer shall have the operation capacity of calibration and simulation within three to five hours. Following technical specifications were proposed.

✓ CPU	3.0 GHz
✓ OS	XP Professional 64bit
✓ Memory	16 GB DDR2
✓ Hard Drive	320 GB SATA 3.0 GB/s
✓ Monitor	22” Ultra Sharp WFP

Additionally, the computer may be used for WaterCAD operation during the study period. It was confirmed that the above technical specification of computer is applicable to operate WaterCAD also.

c. Satellite Image

Satellite images will be used to estimate the infiltration capacity on the flat land in Metropolitan Cebu for building of the Cebu-GWM-09. Available data are;

- ✓ Monthly recharges in the WRMUs for tank modeling with periods between January 1980 December 2004 (25 years: 300 months) can be obtained from the Water REMIND Project

✓ Infiltration capacity tests in alluvial area were conducted in the study scheme.

Table B.II-04 shows candidate satellite images which are available in the market. Among these candidates in the market, following images were selected.

✓ Past Image: SPOT 2 (12-March 1992), 10m mono
✓ Late Image: ALOS Daichi (31-March 2007), 10m color

Table B.II-04 Candidate Satellite Images

Shooting	Satellite	Sensor	Precision	Unit	Q'ty	Price	Amount
1973-1989	LANDSAT 1-5	MSS	80 m	Scene	1	Free	-
1988	SPOT 1	SPOT1	Color 20 m	Scene	1	472,500	472,500
1989-1990	LANDSAT 4-5	TM	30 m	Scene	1	free	-
30-Jan 1991	SPOT 2	SPOT2	Color 20 m	Scene	1	472,500	472,500
21-Mar 1992	SPOT 2	SPOT2	Mono 10 m	Scene	1	472,500	472,500
22-Jun 1996	JERS-1	VNIR	18.3 m × 24.2 m	Scene	1	2,520	2,520
1999-2003	LANDSAT 7	ETM+	Color 30 m Mono 15 m	Scene	1	free	-
2000-2008	Terra	ASTER	15 m	Scene	1	19,600	19,600
25-Mar 2000	IKONOS	IKONOS	1 m, 4 m	km^2	600	9,000	5,400,000
2003-2005	Quick Bird	Quick Bird	Color 2.4 m Mono 0.6 m	km^2	600	4,900	2,940,000
31-Mar 2007	ALOS (Daichi)	AVNIR-2	Color 10 m	Scene	1	55,000	55,000
2-Apr 2007	SPOT 4	SPOT4	Color 20 m Mono 10 m	Scene	1	472,500	472,500
2002-2008	SPOT 5	SPOT5	Color 5 m Mono 2.5 m	Scene	2	1,662,570	3,325,140
6-Feb 2008	IKONOS	IKONOS	1 m	km^2	600	9,000	5,400,000
18-Nov 2008	Alos (Daichi)	PROSM	Mono 2.5 m	Scene	2	31,500	63,000

Note: Screening criteria are (1) Precision < 100m and (2) clearness < 50%. Unit of price and amount is in Yen.

(3) Procurement Items

Following Tables B.II-05 and B.II-06 show the lists of instruments and equipment, items of which were approved and procured for this study.

Table B.II-05 List of Procured Instrument/ Equipment in Japan

No.	Description	Type	Specifications		Unit	Q'ty
1	pH/ Temp Meter	HM-20P	method range	2-electrods pH: 0-14 Temp: 0-99.9 celsius	set	2
2	EC Meter	CM-21P	method range	glass electrodes EC: 0.1-10,000 mS/m	set	2
3	Water Level Meter	WL-50BT-1	depth	50 m	set	2
4	Water Sampler Rope Reel	CMR-200SUS CMR-201SUS	diameter length rope	43 mm 310 mm 100 m	unit	1
5	Water Level Logger Calibrator	CO-U20-001-01TI CO-U-DTW-1	Atmospheric pressure	21.7k data, maximum depth 9 m	set unit	5 1
6	Modeling Soft-ware	V-MODFLOW Premium Module	FDM, Mass Transport, Density Flow Visual MODFLOW 3D-Builder GW-contour		lot	1
7	Satellite Images	ALOS-2 SPOT-2	Shooting on 31-Mar 2007, 10m Shooting on 21-Mar 1992, 10m		shot shot	1 1

Note: Satellite images were installed into the computer.

Table B.II-06 List of Procured Instrument/ Equipment in the Philippines

No.	Description	Type	Specifications		Unit	Q'ty
1	GPS	Garmin GPS-Map 76CSx Battery Re-charger (NJS)	receiver waypoints routes	Parallel 12 channels 1,000 50	set	2
2	Computer	Dell Precision T7400 Back-up Battery (MCWD)	OS CPU HD RAM Monitor	XP Professional 64bit 3.0GHz, 1.6GHz FSB 640 GB SATA HDD 32 GB 22" WFP	unit	1
3	Printer	Hp K 7100, Wireless (NJS)	Printer	A3 Ink Color (#95/ 98)	unit	1

Note: Accessories of battery and wireless connection are optionally procured.

II-2.2 Hydrogeological Investigation

(1) Data Requirements for Groundwater Modeling Work

Table B.II-07 shows a summary of requirements for smooth groundwater modeling.

Table B.II-07 Data Requirements for Calibrated Groundwater Modeling

Item	Reliable Data and Information
1. Static Water Level	monthly data (mean/ position), monthly contour (Alluvial/ Limestone)
2. Cl Concentration	monthly content (mean/ position), monthly contour (Alluvial/ Limestone)
3. Meteorological Data	monthly precipitation (total/ position), monthly run-off (total/ watershed)
4. Mapping Info.	topography, geology (structures), watershed, land-use, administration
5. Aquifer Properties	Conductivity (K), Storage Coefficient (S), Porosity (n), Diffusivity (D)
6. Extraction Data	monthly (total/ position)

Note: Detailed information of requirements shall be referred to the work plan on the groundwater modeling.

(2) Current Situations relating to the Investigation Planning

Following current conditions relating to the investigation plan were confirmed.

- Boundary information on surface geology and water body are available in the Bureau of Mines.
- Descriptive reports of sinkhole can be provided from the San Carlos University in Cebu City.
- Core soil samples in alluvial formation may not be taken due to its un-consolidation.
- Core soil samples in limestone formation may not be examined due to its karstic flow direction.
- Permeameter (column tester) is available in the San Carlos University but it is mal-functioned.
- There is no available existing well for "interval permeability tests" due to frequent operation.
- Water REMIND report on infiltration capacity of each watershed is available in the MCWD.
- The ratio of infiltration capacity values between alluvial and limestone is still un-known.
- Annual water quality examination results with parameters of Cl and NO_3 are available.
- MCWD has examined E-coliform at all production wells twice a month.
- Daily capacity of water quality examination in the MCWD Laboratory shall be confirmed.

(3) Emphasized Data for Accurate Modeling in Cebu

Along the said situations, it was studied that what kinds of data would be critical information for preparation of an accurate groundwater modeling/ simulating in terms of "salt water intrusion". It was concluded that following data (see FigureB.II-03) would be important information.

- Geological Boundaries in depth of Alluvial and Limestone
- Aquifer Properties of Alluvial
- Groundwater Interface between Fresh and Brackish

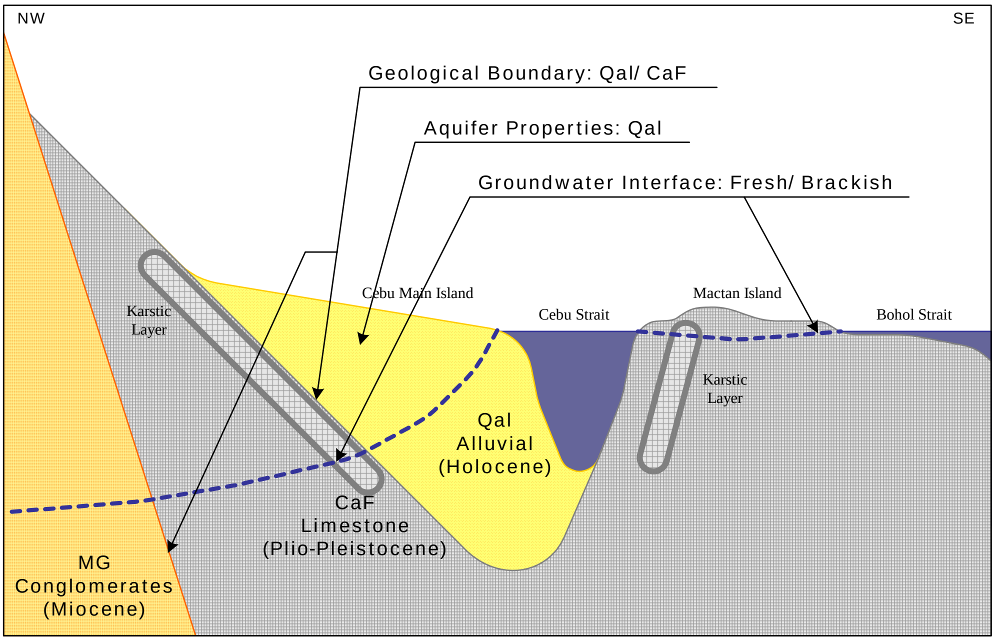


Figure B.II-03 Data/ Information to be emphasized in the Groundwater Modeling

(4) Investigation Plan and Brief Technical Specifications

Following technical specifications were proposed to supplement the data lacking for an accurate groundwater modeling.

< Water Quality >

Replacement of Nitrogenous parameter was judged by examination results obtaining from the MCWD Laboratory. According to such data, Nitrate concentration (NO_3) has a clear increasing trend instead of Nitrite concentration (NO_2). Probably, the cause of this trend is an oxidization of groundwater during underground flow as shown in Figure B.II-04.

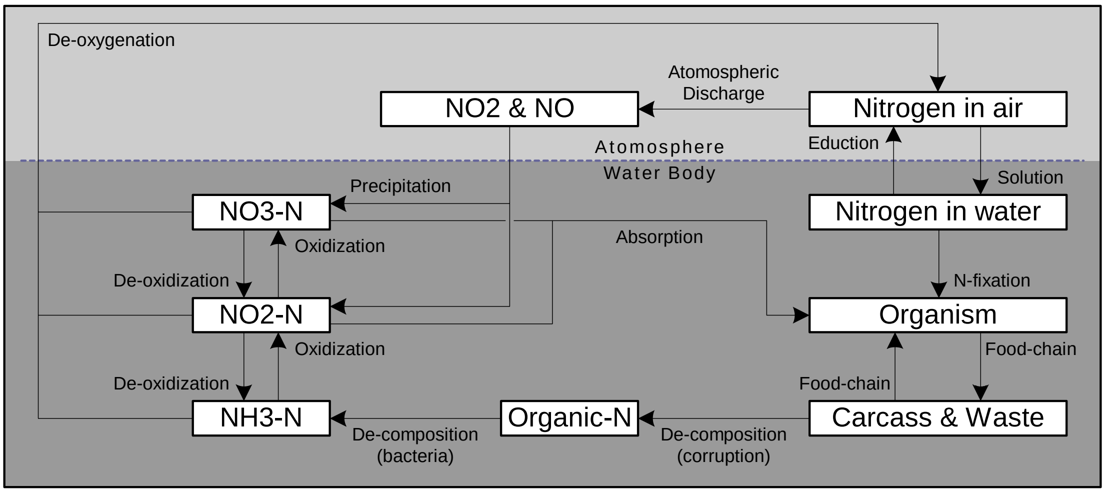


Figure B.II-04 Natural Cycle of Nitrogenous Compound

Following specifications were planned.

- ✓ Duration: Wet and Dry seasons (April and July)
- ✓ Sampling No.: 50 wells (to be nominated from MCWD 109 wells)
- ✓ On-site: EC, pH and Temp.
- ✓ Laboratory: TH, Cl, Ca, Mn, NO_3

< (1) Geological Prospecting >

This was conducted to estimate distributional thickness of alluvial formation.

✓ Sounding Sites: 30 sites (20 along coastal belt, 5 for cross section with 2-lines)
✓ Configuration: Wenner Method with 300 m in sounding depth

< (2) Test/ Observation Well Construction including Geo-physical Logging >

These were constructed according to specifications below, the aims of which are to take soil samples and to investigate geo-physical logging for judgment of alluvial formation thickness. Secondary purposes of well construction are to estimate alluvial properties and to examine groundwater quality characteristics in terms of seawater intrusion and nitrate contamination.

✓ Well Sites:	Observation Well:	100 A×	100 m×	3 wells (NO_3)	CaF (Cebu Island)
	Test Well:	100 A×	50 m×	5 wells (Cl)	Qal (Cebu Island)
	Observation Well:	100 mm×	50 m×	2 wells (Cl)	Mactan
✓ Logging:	Resistivity (long and short), SP, Natural Gamma, EC Profile				

< (3) Pumping Test >

This test was investigated to estimate alluvial properties.

✓ Testing Sites: 5 test wells (mentioned in the above table)
✓ Test Method: Time Drawdown Test including observation well sounding if available
Preliminary Step Drawdown Test was conducted to design the test above.

< (4) Interface Depth Sounding and Water Quality Examination>

Following tests were investigated for interface depth analysis.

✓ Sounding Site: depth sampling for 7 wells (5 test wells and 2 observation wells)
✓ Sampling Method: each 5 m unto the well bottom (7 wells) or pumping water (3 wells)
✓ On-site Test: EC and pH (for all samples)
✓ Laboratory: Cl (3-samples per well at different depths)
NO_3 (1-sample per well while pumping)

Items of (1) to (4) mentioned above were packaged for contract-out because data and information were interrelated each other. Table B.II-08 shows the scope of works including investigation quantities.

Table B.II-08 Scope and Results of Test/ Observation Well Construction

<table>
<tr><th colspan="2" rowspan="2">Site Identification</th><th colspan="4" rowspan="2">Scope of Tests</th><th colspan="3">Construction</th></tr>
<tr><th>Borehole</th><th>Well Depth</th><th>Screen Length</th></tr>
<tr><td>1.</td><td>Pooc, Talisay</td><td rowspan="10">Logging (EC, R, SP, G)</td><td rowspan="5">Pumping Test</td><td rowspan="7">Interface Depth Sounding</td><td rowspan="10">Water Quality Examine</td><td>100 m</td><td>56 m</td><td>21 m</td></tr>
<tr><td>2.</td><td>San Roque, Talisay</td><td>100 m</td><td>50 m</td><td>24 m</td></tr>
<tr><td>3.</td><td>Subangdaku, Mandaue</td><td>100 m</td><td>72 m</td><td>36 m</td></tr>
<tr><td>4.</td><td>Pakna-an, Mandaue</td><td>100 m</td><td>66 m</td><td>36 m</td></tr>
<tr><td>5.</td><td>Kot-kot, Lilo-an</td><td>100 m</td><td>66 m</td><td>36 m</td></tr>
<tr><td>6.</td><td>Marigondon, Lapu-lapu</td><td rowspan="5"></td><td>51 m</td><td colspan="2" rowspan="2">Borehole
non collapsible formation</td></tr>
<tr><td>7.</td><td>Buaya, Lapu-lapu</td><td>53 m</td></tr>
<tr><td>8.</td><td>Tisa WTP, Cebu</td><td rowspan="3"></td><td>100 m</td><td>100 m</td><td>24 m</td></tr>
<tr><td>9.</td><td>Lahug, Cebu</td><td>100 m</td><td>94 m</td><td>24 m</td></tr>
<tr><td>10.</td><td>Tawason, Mandaue</td><td>100 m</td><td>94 m</td><td>24 m</td></tr>
</table>

< Infiltration Capacity Test >

Test area was subjected on the area with Alluvial and Limestone formation in mainly Cebu Island. The study team appreciates the study results of infiltration capacity on each watershed mentioned in the report of Water REMAIND (watershed tank model). However, ratio of limestone and alluvial would be classified by the following Infiltration Test.

- ✓ Test Site: Alluvial Formation area in 3-cities and 3-municipalities
- ✓ Test Method: Water Injection

< Preparation for Modeling Works >

Additional contract-out for "Data Compilation for Groundwater Modeling Works" to be used for the modeling works with the following TOR was proposed.

- ✓ Period of Data Processing: May until middle of July (2.5 months) for Data Compilation
  middle of July to August (1.5 months) for Data Integration
- ✓ Number of Modeler: at least 3-modelers for first 2.5 months (7.5 MM)
  at least 2-modelers for next 1.5 months (3.0 MM)
- ✓ Qualification of Modeler: having an experience of MODFLOW operation
  (any type of FDM software)
- ✓ Outputs: filling-up data into the spread sheets and
  Mapping indicates analysis information
- ✓ Work Conditions: MCWD provides Data/ Information,
  the Contractor shall prepare the database/ mapping in his PC,
  final database will be transferred to work-station computer

(5) Scope of Works

The following investigations were planned for modeling works by contract-out scheme as shown in Table B.II-09.

Table B.II-09 Final Plan on Hydrogeological Investigations

Description (by packages of contracted-out)	Specifications	Quantity
1. Data Compilation	Compilation and Integration	LS
2. Geo-resistivity Prospecting,	Wenner Configuration, Sounding depth of 300m	30 points
Test/ Observation Well Construction,	Soil Sampling and Logging (resistivity, SP, gamma)	10 sites
Pumping Test,	Step and Time-drawdown Test with observation	5 wells
Interface Depth Sounding (Cl), and	EC profiling with EC, pH and T	7 wells
Water Quality Examination (NO_3)	Water Sampling for Cl, NO_3, TH, Ca, Mn	3 wells
3. Infiltration Capacity Test (Alluvial)	Direct Injection Method, 3-tests per site	300 sites
4. Water Sampling (Dry and Wet Seasons)	Laboratory: Cl, NO_3, TH, Ca, Mn	50 wells

Note: Contract-outs of water sampling in dry and wet seasons were simply combined.

II-3 Conceptualization

It is very important to set up the model conceptualization with modeling purpose and simulation target. Conceptual models are to represent site hydrogeology, flow direction, gradient, etc. Models can be classified into 2 types; (1) physical models such as sand columns and lysimeters, and (2) mathematical models such as analytical solutions and numerical models. The Cebu-GWM-09 is grouped in the numerical model.

A groundwater model is a simplified representation of the real groundwater flow system. However, a model can never represent the true complexity found in nature. In this regard, modeling works shall have clear milestones such as:

- What? Numerical analysis of the model reflects natural phenomena of groundwater system that affect environment and social activities.
- Why? The model represents a "living" planning tool that allows us to assess the groundwater system, and update it as new information becomes available.
- Where? Groundwater modeling is a science-based process that develops tools to predict the behavior of the hydrogeologic environment.
- When? This helps developers and regulators make defensible decisions about the potential impacts that might occur to the system.
- How? The model can be built as simple or as complex as the study objectives require.

A numerical model uses the principle of fluid mass conservation and the governing equation of groundwater flow to develop a description of the groundwater flow system. It incorporates the physical feature of the natural system as mathematical expressions: hydraulic properties and model layers, boundary conditions, and calibration parameters. Therefore, model predictions are based on real-world observations of the site. To achieve effective modeling, following requirements are commonly shared among the stakeholders.

- define the purpose and scope of the model before starting,
- define important processes in the conceptual model (scale defines the detail necessary, and geology/ hydrogeology define properties and boundary conditions),
- select the appropriate modeling code (know the limitations of the selected code, choose a code that is suitable for the problem and understand practical "tricks of the trade" for effective use of the chosen modeling software),
- construct the numerical model to reflect the conceptual hydrogeologic model, and
- calibrate the numerical model to ensure that the model represents field conditions, prior to making predictions.

A sensitivity analysis is the evaluation of model input parameters to see how much they affect model output. The objective of sensitivity analysis is to answer the following questions:

- Do small variations in the input data cause large changes in the model results?
- Is the input data reasonable?
- Is the model defensible?
- Are the model assumptions valid?

Tips of modeling works before modeling works are shown in Table B.II-10 below. Figure B.II-05 indicates standard modeling process.

Table B.II-10 Standardized Modeling Works

The best approach to modeling is:	The most important concepts are:
• start simply and refine as it is calibrated, • collect more data if necessary, • scenario analysis uncertainty in input parameters leads to a range of possible output results, and • revise model and present most up-to-date results.	• choose model boundaries carefully (use natural boundaries whenever possible), • calibrate and validate a model; run model for "static" and "stressed" conditions, • conduct a sensitivity analysis, and • predict/ interpret results conservatively.

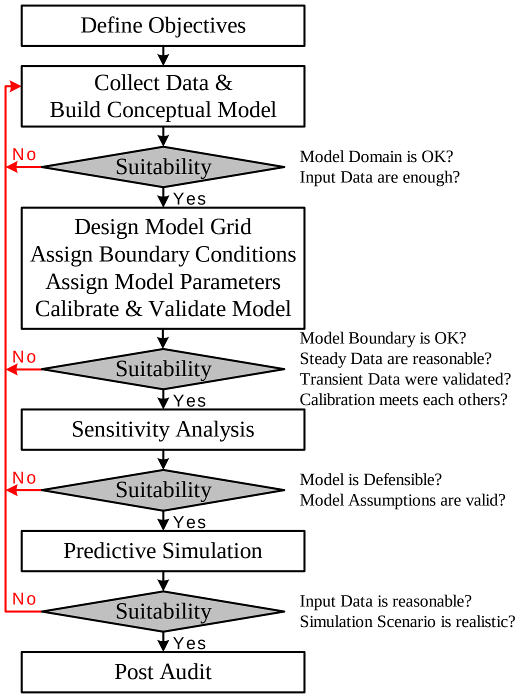


Figure B.II-05 Standard Modeling Process with major Judgment Items

II-3.1 Hydrogeology and Model Domain

There are major aquifers in the groundwater investigation area as identified following.

- Carcar Limestone: This formation is most important aquifer in the Metropolitan Cebu area.
- Fluvial Deposits: This formation is made of river deposits and has potential of river-bed water. MCWD has Jaclupan well field at Mananga WRMU.
- Alluvial Deposits: This formation exists along the coastal belt of Cebu Island. There are many un-registered wells constructed and used for domestic, commercial and industrial water.
- Cebu Limestone: This aquifer distributes on the highland area with low value of hydraulic conductivity. Only spring development is available.
- Sandstone: Locally, it is called as Malbog Formation along the Kot-kot valley. Specific yield of this formation may be low however, hydrogeological investigation of this formation has been not conducted sufficiently yet.

Important issue of groundwater problems in Metropolitan Cebu is seawater intrusion. Within these available formations in the study area, Carcar Limestone and Alluvial Deposits were selected for groundwater simulation. Figure B.II-06 shows the site locations of MCWD wells on the geological map. Target aquifers are located along the coast and inland in Cebu Island, and entire Mactan Island. In this regard, Cebu-GWM-09 was built under the following hydrogeologic conditions as shown in FigureB.II-07 (at next page).

- Target Aquifer: Coastal Un-consolidated and Limestone Formations
- Un-consolidated Formation: Alluvial Formation along the coastal line and Fluvial Formation along the major rivers
- Limestone Formation: Karstic Limestone Formation at the upper-northern portion and Massive Limestone Formation at the lower-southern portion

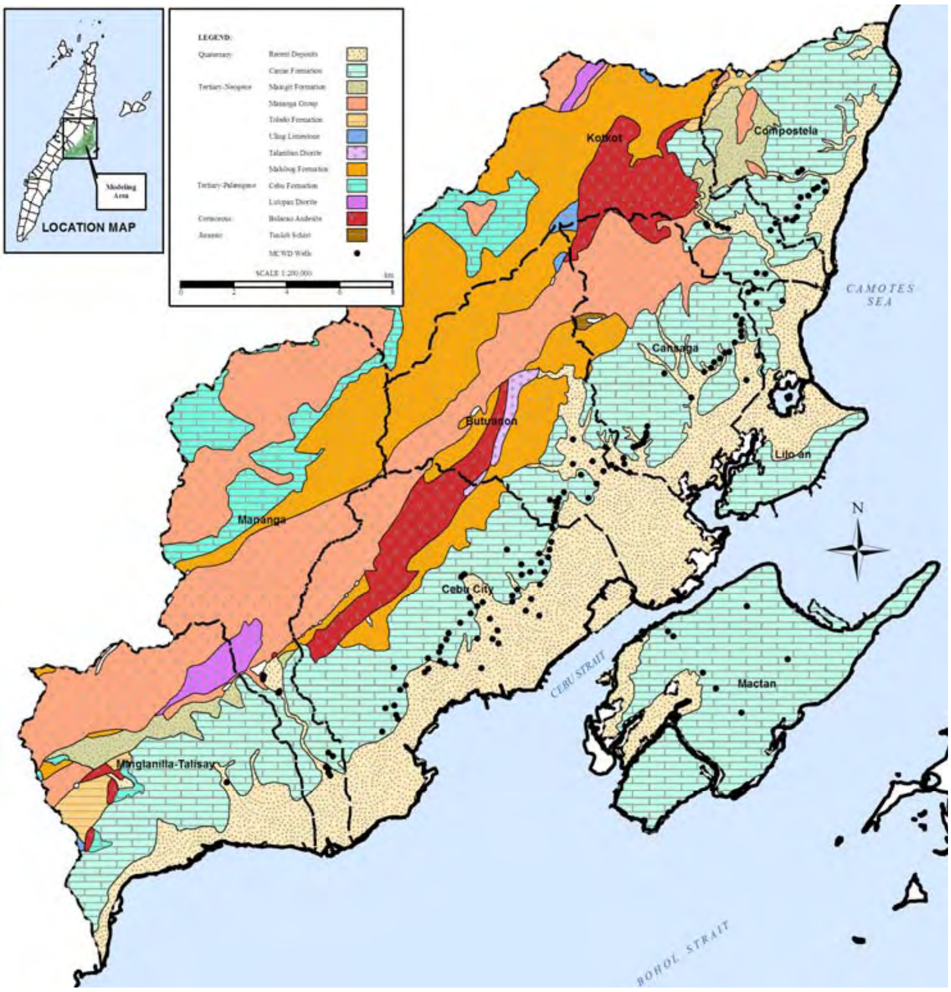


Figure B.II-06 MCWD Wells on Geological Map in the 9-WRMUs

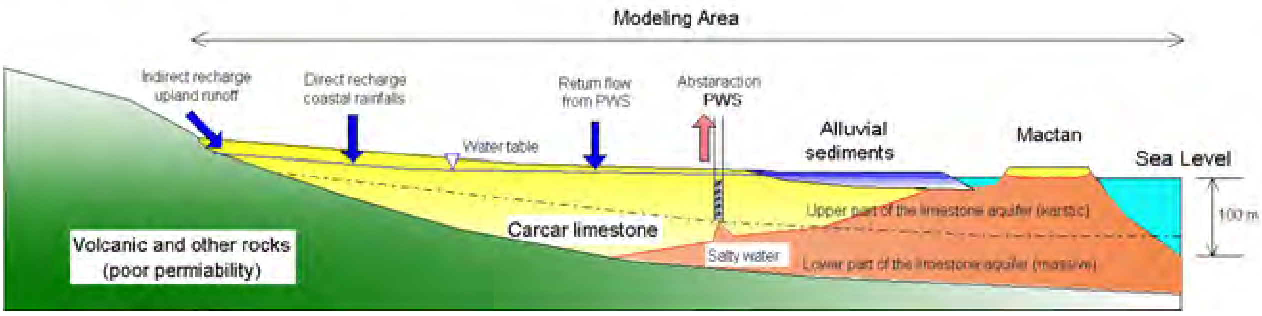


Figure B.II-07 Conceptual Model including major Water Components

(1) Modeling Districts

Regional model with steady stresses and equilibrium statement was built at the first to research the groundwater flow directions for sub-regional modeling to simplify the model features. The regional model was divided into 4 districts for time saving of calibration using boundary of WRMUs as shown in Table BII-11 and Figure BII-08 with due consideration of following criteria.

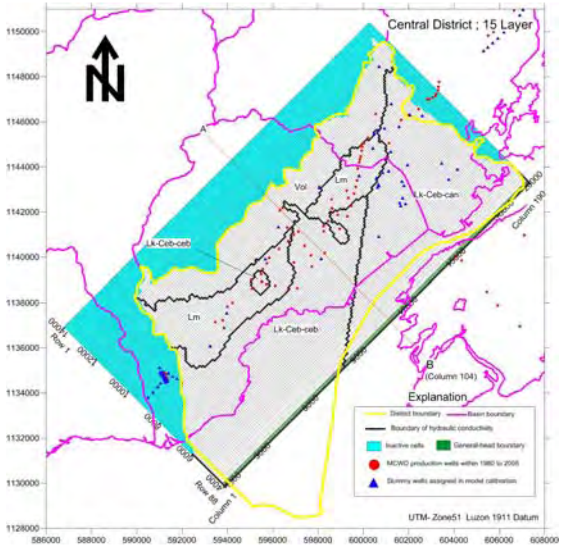
Sub-regional domains shall;

- be bounded along the groundwater flow direction of regional model as much as possible to avoid thoughtless disturbance of groundwater environment,
- have similar conditions of hydrogeology, development status and usage, statistical data and information such as recharge, return flow, extraction, water supply, population, etc.

Table B.II-11 Modeling Districts with Hydrogeological Features

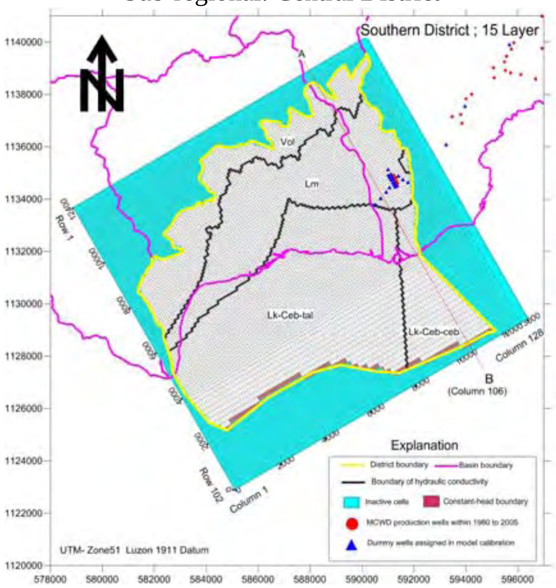
District	WRMUs	Features
Northern	4: Compostela, Kot-kot, Lilo-an, Cansaga	narrow alluvial and karstic limestone in shallow depth
Central	2: Butuanon, Cebu	wide alluvial and assumed fault line with large extraction
Southern	2: Mananga, Minglanilla-Talisay	narrow alluvial and thick massive limestone
Mactan	1: Mactan	island composed of limestone (karstic and massive)

Entire
Modeling Domain

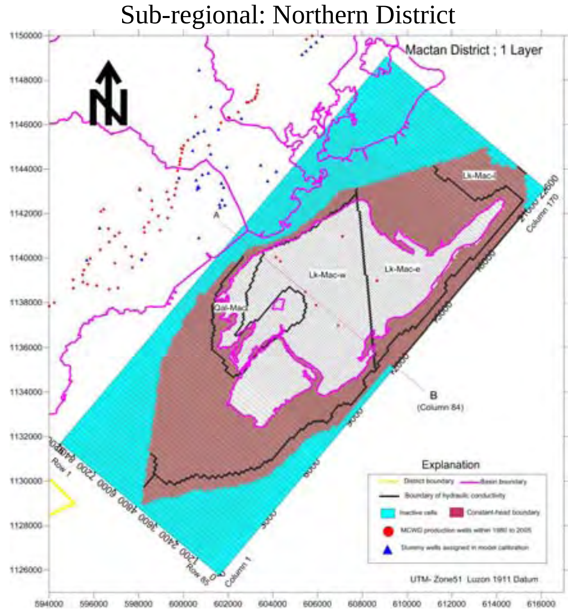


Sub-regional: Central District

Sub-regional: Northern District



Sub-regional: Southern District



Sub-regional: Mactan District

Figure B.II-08 Location Maps of Regional and Sub-regional Model Domains

(2) Horizontal and Vertical Extent

Area surrounded limestone boundary and the line of seabed elevation corresponding to 100 mbsl. Model basement is set to 200 mbsl under the assumption that is less affection from pumping of any production wells in the model districts.

II-3.2 Water Component

(1) Water Remind Project

This project was supported by Netherlands. The aim of this project is to formulate water resources development plan until the year 2030 including water supply scheme of MCWD as a social service sector. Study area of this project is shown in Figure B.II-09. Water balancing study was done using tank model especially in the Metropolitan Cebu area. Portion with light brown color in the map is same to this study area for groundwater modeling.

Figure B.II-09 Study Area of Water Remind Project

Water components were selected as inflow to and outflow from the target aquifers. Lateral flow was adopted among the water components, because of WRMUs division. Interaction between groundwater and surface water was included into natural recharge.

- Inflow to Aquifer: natural recharge, return flow and lateral flow
- Outflow from Aquifer: abstraction and flow to the sea

(2) Appropriation of Water Components

As an output from this project, water component at each WRMU was estimated during the period from January 1980 until December 2004 (25 years/ 300 months). Table B.II-12 shows the differences between the tank model in Water Remind Project and the flow model in this study.

Table B.II-12 Domain Comparison between Tank Model and Flow Model

Water Balance Domain	Management Basin		Domain	
	Boundary	No.	Boundary	No.
Tank Model*	WRMUs	21	Elevation of 100m: Coastal and Highland	2
Numerical Model*		9	Geology: Alluvial and Limestone	2

Note*: "Tank Model" was built by the Water REMIND Project, while "Numerical Model" was built by this study.

Items of water components in the tank model were applied for building and calibration of the sub-regional Cebu-GWM-09. Such water component items are:

- Recharge: Direct Recharge to groundwater by rainfall
  In-direct Recharge to groundwater by surface run-off from up-stream
- Lateral Flow: Under-ground recharge from adjoin basins
- Abstraction: Spring Yield (to be neglected by this modeling)
  MCWD Well Intake
  Non-MCWD Well Intake
- Return Flow: Recharge from Waste Water
  Recharge from NRW of the Water Supply System

Other items are: rainfall, evapotranspiration, surface run-off, drainage to sea, etc. Figure B.II-10 indicates typical water flow in each WRMU with due consideration of localities. Within these WRMUs, Lilo-an basin has no highland area (left-upper below), while Mactan is independent basin (left-lower below).

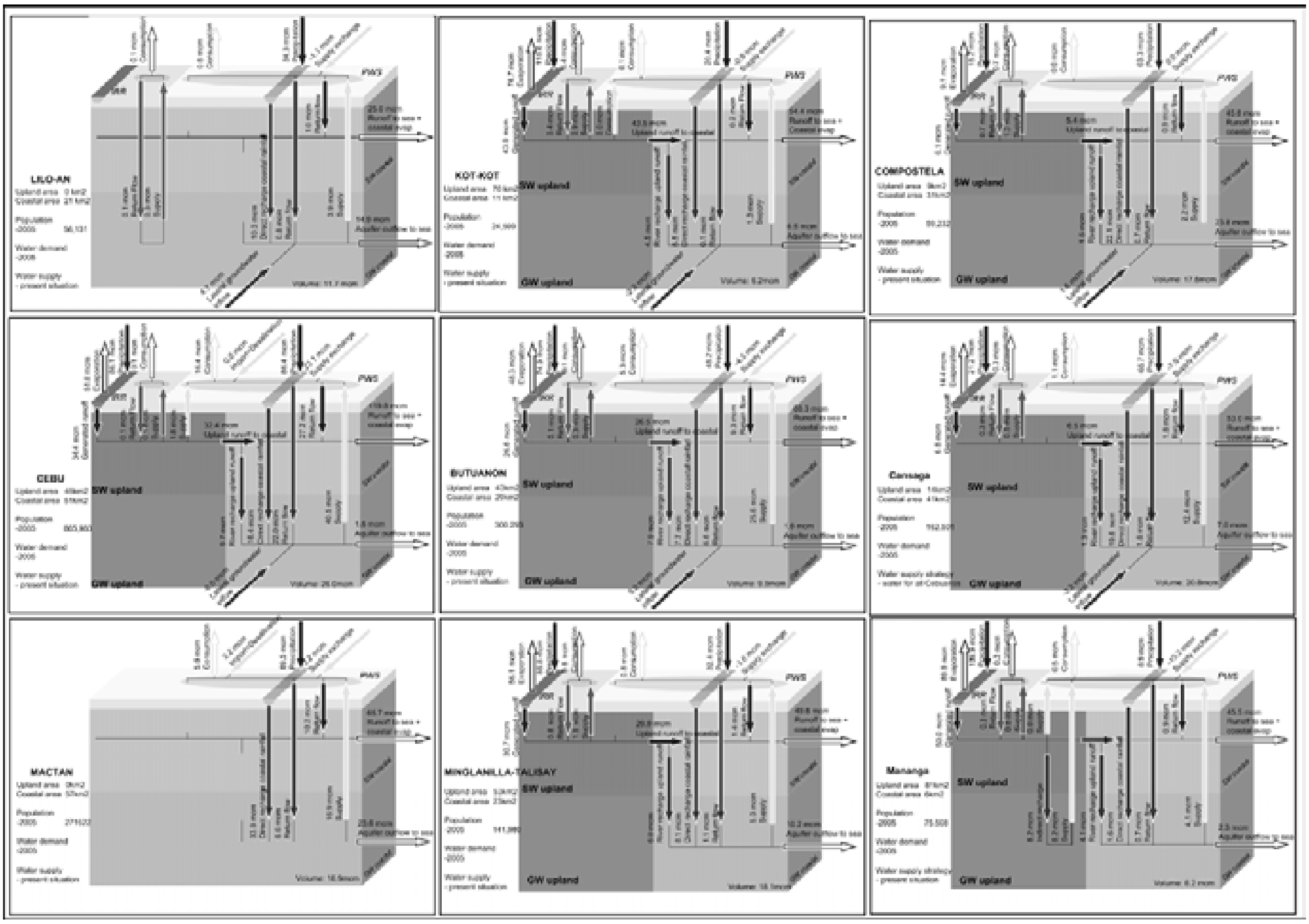


Figure B.II-10 Water Components by WRMUs for the Sub-regional Cebu-GWM-09

II-4 Availability of Data and Information

The Cebu-GWM-09 was built using data and information of following;

- Map Information such as Geology, Topography (including ocean floor), River Networks, etc.
- Water Components obtaining from the Water REMIND Project,
- Abstraction from MCWD and Non-MCWD wells including past modeling reports,
- Well GIS database of LWUA,
- Water right permits database of NWRB,
- Hydrogeological investigations conducted by study scheme, and
- Data, Information, Report collected by the JTFT.

II-4.1 Methodology and Scope of Hydrogeological Investigations

Hydrogeological investigation can be divided into following two portions. Methodology and scope of contract-out were described below.

- (1) Field Survey: surface geology and topography, groundwater quality, etc.
- Contract-out:
  (2) Water Sampling (Dry and Wet Seasons)
  (3) Geo-resistivity Prospecting, Test/ Observation Well Construction, Pumping Test, Interface Depth Sounding
  (4) Infiltration Capacity Test
  (5) Data Compilation for Groundwater Modeling

(1) Field Survey

The JTFT member has surveyed mainly Limestone Formation in Cebu Island. Major points of field survey are:

- Geology: Externals (solidity, weathering, permeability, fissure)
- Topography: Hill (cone karst, inclination), Doline
- Groundwater: Spring Information, Field Examination (EC at Silot Lake)

(2) Water Sampling (Dry and Wet Seasons)

The aims of "Water Sampling (Dry and Wet Seasons)" are:

- To grasp the state of water quality distribution in dry and wet seasons, and
- To grasp the seasonal variation between dry and wet seasons.

In these purposes, water samples were taken in April 2009 (dry season) and July 2009 (wet season) from 50 sites of MCWD production wells (referred to Figure B.II-11). Selection criteria of 50 wells for this contract-out are to cover all MCWD well fields and to choose the range of pumping rate and operation hours, because of following reasons.

- MCWD wells are distributed in the entire study area,
- Most of MCWD wells tapped the Limestone formation,
- Can be compared with past MCWD examination results, and
- Can be taken the raw water samples easily.

Water samples were examined in the field and the laboratory. The aim of field examination was to confirm the groundwater raw water. Following parameters of water samples were examined.

- Field Examination: pH, Temp., TDS/ EC
- Laboratory Examination: Cl, NO_3, Ca, Mn, TH

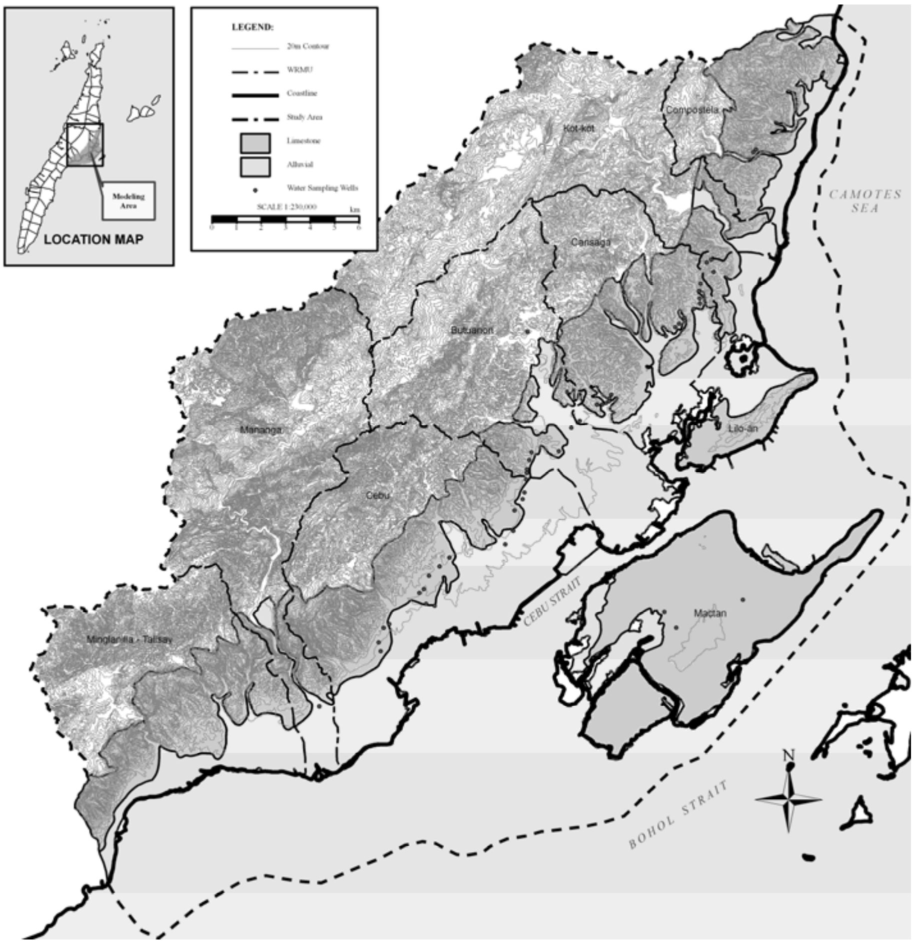


Figure B.II-11 Sampling Location of Water Quality Examination (50 wells)

(3) Geo-resistivity Prospecting, Test/ Observation Well Construction, Pumping Test, Interface Depth Sounding

The aims of this investigation are:

- To confirm the distribution of Alluvial,
- To analyze the aquifer properties in Alluvial Formation,
- To confirm the interface property of saltwater intrusion (Cl) along the coastal area, and
- To construct the observation wells for NO_3 contamination.

Investigation items are shown below and its scope is referred to Table B.II-13 and Figure B.II-12.

- Geo-resistivity: 30 points in Alluvial area
- Well Construction: 5 Test Wells and 5 Observation Wells with Logging
- Pumping Tests: 5 Test Wells
- Interface Sounding: EC profile at 7 wells, water quality examination at 10 wells

Table B.I-13 Scope of Investigations at Test/ Observation Wells

Category	Aquifer	Site	No.	Logging	Pumping	Interface	Quality
Resistivity	Alluvial	Study Area	30	-	-	-	-
Test Well		Cebu Is.	5	Resistivity, Gamma, EC	Aquifer Test	EC, Micro Resistivity	Cl, NO_3, Ca, TH, Mn
Ob. Well	Limestone	Mactan Is.	2		-		
		Cebu Is.	3	Resistivity, Gamma		-	

Note: Specifications of well construction are explained later.

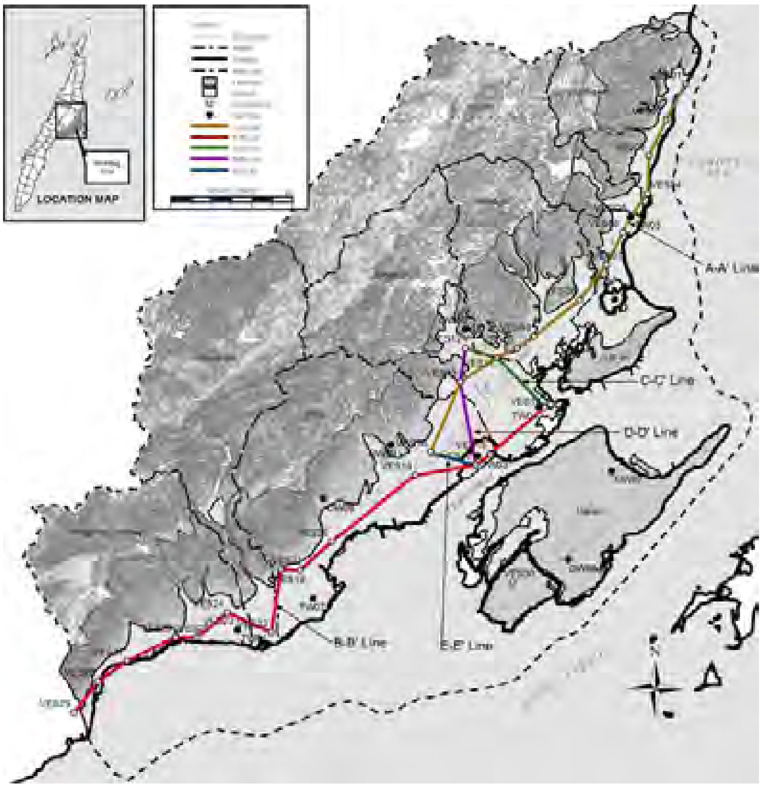


Figure B.II-12 Location Map of Geo-resistivity and Test/ Observation Wells

Specifications of each test are:

< Geo-resistivity Prospecting >

- ✓ Method: Wenner
- ✓ Sounding Depth: 300 m

< Test/ Observation Well Construction: referred to Figure B.II-13>

- ✓ Test (Cebu Is.): 5 wells
- ✓ Observation (Mactan Is): 2 wells
- ✓ Observation (Cebu Is.): 3 wells

< Geo-physical Logging >

- ✓ Electric Conductivity: every 5m from mud water level up to borehole bottom
- ✓ Resistivity: every 1m from mud water level up to borehole bottom
- ✓ Gamma Ray: every 1m from ground surface up to borehole bottom (C/20 sec)

< Pumping Test >

- ✓ Time Drawdown: 96 hours with Constant Pumping Rate
- ✓ Recovery: 12 hours

< Interface Depth Sounding >

- ✓ EC/ micro-R: every 5m from SWL up to the well bottom
- ✓ Water Sampling: 3 samples (SWL, variant depth, stable depth)

< Water Sampling (Dry and Wet Seasons) >

- ✓ Field: pH, EC, converted Salinity
- ✓ Laboratory: Cl, TH, Ca, Mn, NO_3

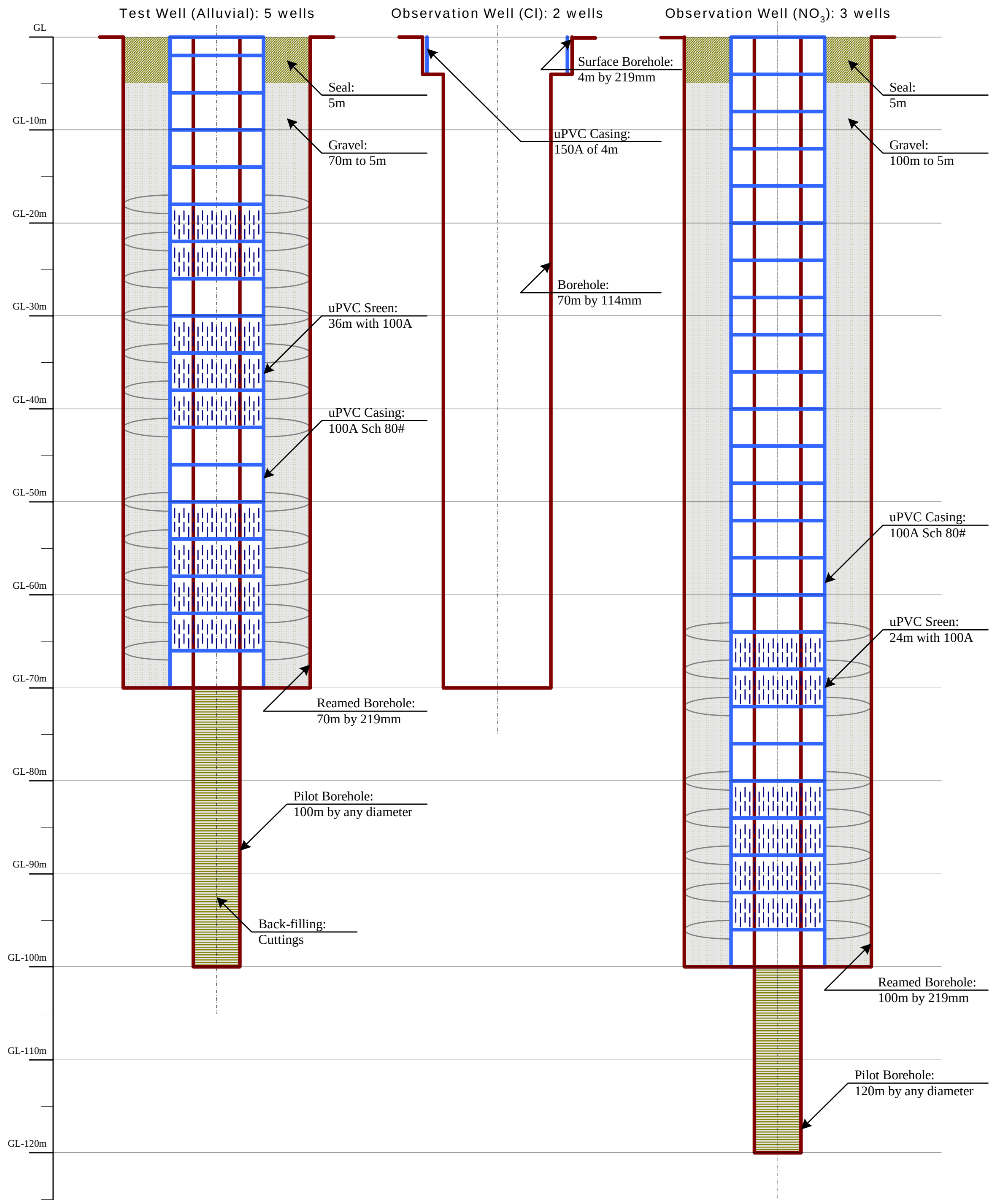


Figure B.II-13 Standard Design of Test/ Observation Well Construction

(4) Infiltration Capacity

The aim of this survey is to grasp the distribution state of alluvial infiltration. Field tests at 300 sites were conducted using injection method. Figure B.II-14 shows location of test sites, while Figure B.II-15 indicates the structure of test equipment.

Value of infiltration capacity was estimated using standard formula with differential method as data analysis. Distribution maps using dot and contour were prepared for visual understanding.

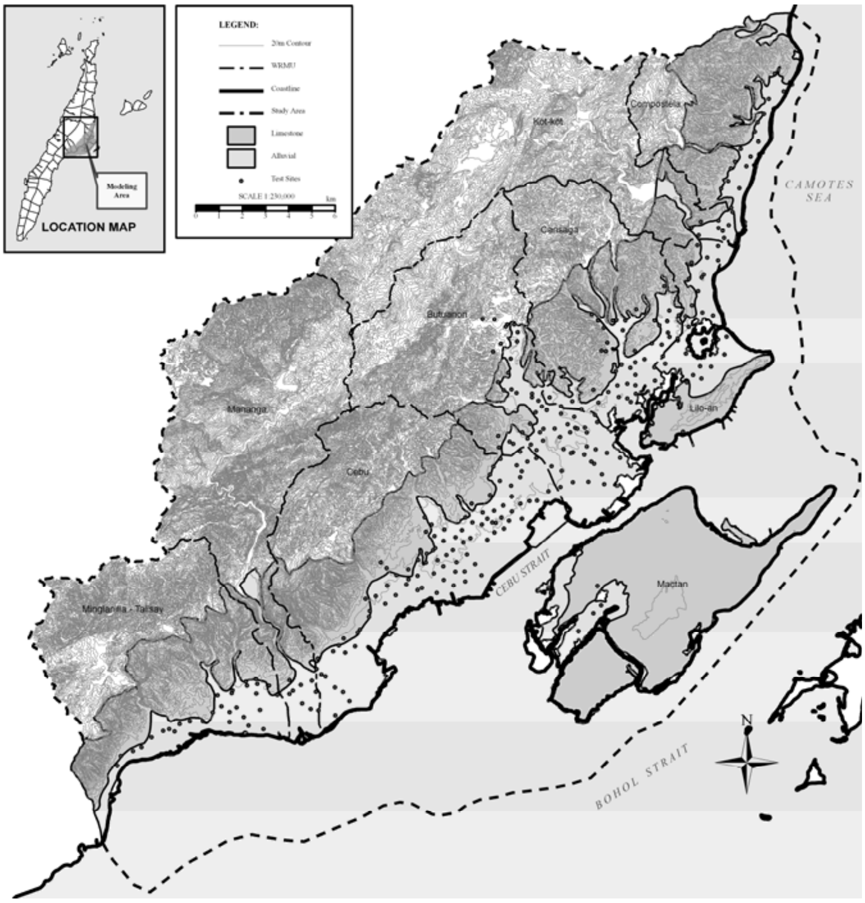


Figure B.II-14 Location Map of Infiltration Test (300 sites)

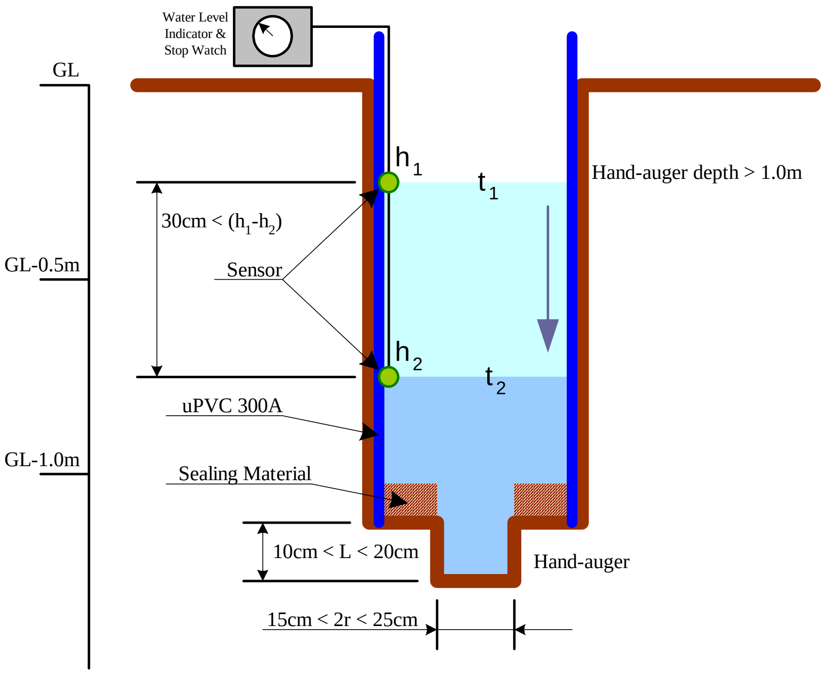


Figure B.II-15 Standard Structures of Infiltration Test Equipment

(5) Data Compilation for Groundwater Modeling

The aims of this works are to compile available data and information mentioned below, and to integrate such materials for groundwater modeling works. Database made of compiled information was applied for model building, while integration materials were used for model calibration.

- ✓ Compilation: Geology, Hydrogeology, Water Components, Groundwater, Topography, Meteorology...
- ✓ Integration: Groundwater Level, Groundwater Quality...

Most of data and information mentioned above were collected from following organization and encoded into the ArcGIS in the EWRKC, MCWD.

- ✓ MCWD: Completion Report, Operation Record, Water Quality Report, Geological Investigation Report...
- ✓ Private Enterprise: Ocean Floor Geology, Sink-hole, Pumping Record...
- ✓ LWUA Databank: Database

Hydrogeological background for groundwater modeling works was examined using existing data and new investigation results. However, following investigations are required to conduct in future for improvement of Cebu-GWM-09 in terms of better calibration and higher sensitivity.

- Geology: (a) Karstic Limestone: Gamma Log at Mactan and Lilo-an Outcrop
- Aquifer Property: (b) Pumping Test: Observation Well and Packer at Limestone/ Alluvial
  (c) Measurement: Coefficient of Diffusion (Karstic Limestone)
- Water Quality: (d) Chloride Intrusion: EC Profile at Well Fields with high Cl
  (e) Specific Gravity: Seawater, Brackish Water, Fresh Water
  (f) Mass-balance of NO_3: Basin, Rainfall, Doline, Concentration
  (g) Chloride Concentration: Karstic Limestone (deeper portion)
- Others (h) Sanitary Statement: Facility, Sludge Treatment at Limestone area
  (i) Water Balance: River Run-off, Rainfall, Water Level, Tidal Level...

II-4.2 Geological Setting

(1) Field Survey

< Findings >

The JTFT conducted the field survey and found following items. Figure B.II-16 (next page) indicates such findings visually.

- ✓ Cebu Is. North: Cone karsts exist in Limestone area. Doline ponds are dotted along the coastal area. Top levels of cone karst, Lilo-an Outcrop and Mactan North Hill can be connected with 2 to 3 % inclination.
- ✓ Cebu Is. Lilo-an: Brackish Lake of Silot and Lilo-an bay seem to be large Doline. Springs are dotted near brackish lake and bay, even on the sea floor.
- ✓ Cebu Is. South: Massive Limestone can be seen at hill side of Limestone area. Slope of Limestone is steeper than that in North side.
- ✓ Mactan Is.: There were many spring along the costal area of Cebu Island side.

According to abstractions of Limestone formation from the field survey and hydrogeological analysis, it can be reached that northern and southern parts have quite different characteristics with boundary of Butuanon River, while it in Mactan Island seems to be the same as Cebu North Limestone. Following assumptions were considered for building of the groundwater model. However, there is no detailed information of volcanic rocks, especially relating to geological setting.

- ✓ Reverse Fault is supposed locating along the Butuanon River,
- ✓ Carcar Limestone is divided into two formations: Karstic and Massive sediments,

- ✓ Bottom face of Karstic Limestone may have inclinations of 3-10% in south and 2-3% in north,
- ✓ Massive Limestone is not outcropped in the Cebu northern area, and
- ✓ Bottom face of Massive Limestone may have inclination of 15% in south, 10% in north merely.

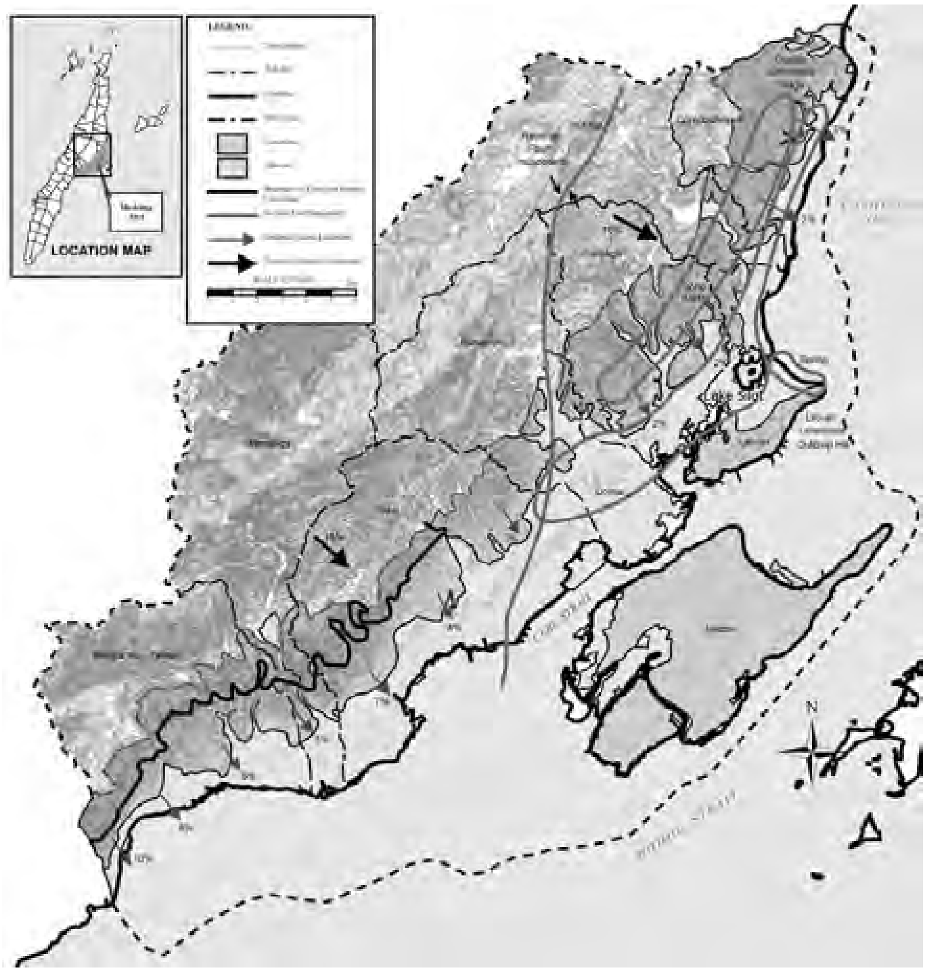


Figure B.II-16 Brief Explanatory Map of Geological Features

< Information Collected >

Following information were collected during the study period.

- ✓ Study Report on Sinkhole: Water Balance and Topographic Map
  "Foundation of Water Resources Center" studied a sinkhole near the University of San Carlos. For identification of sinkhole location, topographic map was prepared with 2 m contour.
- ✓ Ocean Floor Geology: Design Report
  KEI (Katahira Engineers International) was consultants of the Mactan 2nd Bridge. This report contains ocean floor geology.
- ✓ Coastal Geology: Design Drawings of Road Piers
  Geological section along the coastal road in Cebu south was perused at site office of Kajima.

(2) Geo-resistivity Prospecting

Table B.II-14 shows the apparent resistivity vales and geological boundary depths.

Table B.II-14 Boundary Depth and Apparent Resistivity from Geo-resistivity Analysis

VES	Alluvial Formation								Limestone Formation									
	1st Layer		2nd Layer		3rd Layer		4th Layer		1st Layer		2nd Layer		3rd Layer		4th Layer		5th Layer	
	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.	Dep.	Resis.
1	11	240							20	20	28	U	50	5	140	D	200	U
2	9	90							22	38	30	86	80	2	240	<0		
3	8	7	30	20					80	200	150	D						
4	5	200							17	8	40	5	90	2	260	<0		
5	12	5	40	2					90	3	240	1						
6	5	25	10	50					50	20	240	D						
7	8	27							12	13	70	43	120	21	200	D		
8	3	4							16	15	20	7	90	37	130	20	200	5
9	8	45							15	13	100	45	200	D				
10	6	30	14	17	70	60			120	280	240	24						
11	6	5	40	8					100	35	130	130	200	10				
12	4	4	8	8	30	3			50	11	140	U	200	D				
13	8	40							18	12	32	36	70	130	110	15		
14	10	3	16	2	60	3			80	10	90	U						
15	10	1	26	2	52	<0												
16	5	4	16	14					80	30	120	13	170	D				
17	7	1	20	2	34	1			45	5	70	1	90	D				
18	10	10	40	25					70	12	120	1	150	6	180	1		
19	4	12	30	3					96	20	170	4						
20	8	4	40	9					120	19	240	1						
21	5	7	12	1					30	4	70	15	100	126				
22	4	7	12	22					20	10	60	20	150	85	200	2		
23	8	7	30	3					60	6	120	20	220	D				
24	6	5	30	11					150	45	240	10						
25	6	23	16	3	30	8	40	2	80	80	240	<0						
26	6	30	10	11	32	22			80	9	130	24	240	D				
27	6	12	26	52					100	5	260	<0						
28	3	3	20	28					30	12	50	30	100	7	130	D		
29	11	20							30	300	60	8	120	48	260	D		
30	10	200							26	9	76	D						

Note: Symbols of “U” and “D” mean that up and down by the result of sightly analysis.

Geological boundary was analyzed using following distinctive features.

- ✓ Clayey layer can be seen with 10 to 20m in thickness at lower portion of alluvial formation, and
- ✓ Sandy and silty limestone can be seen with 10m in thickness or more at upper portion of karstic limestone.

Figure B.II-20 indicates apparent column section. Locations of section lines are:

- ✓ A-A’ from Danao City until northern Cebu City via Lilo-an
- ✓ B-B’ from Mandaue City until Naga Municipality via coastal Cebu City
- ✓ C-C’ from Butuanon River until Mactan 2nd Bridge
- ✓ D-D’ from Butuanon River until North Declamation site
- ✓ E-E’ from hill area until coastal area in Cebu City

Boundary between alluvial and limestone indicates bold line in Figure B.II-17. Colors in apparent resistivity columns show the groundwater characteristics with following assumption. Deeper formation of limestone (100 mbgs at VES-01) may bear brackish or fresh water below seawater existing. Apparent resistivity at VES-14 below 80 mbgs also indicated fresh water aquifer (same trend of EC profile at TW-04).

- ✓ Blue: Depth of fresh water containing in limestone aquifer
- ✓ Brown: Depth of brackish water containing in limestone aquifer
- ✓ Grey: Depth of seawater containing in limestone aquifer or massive

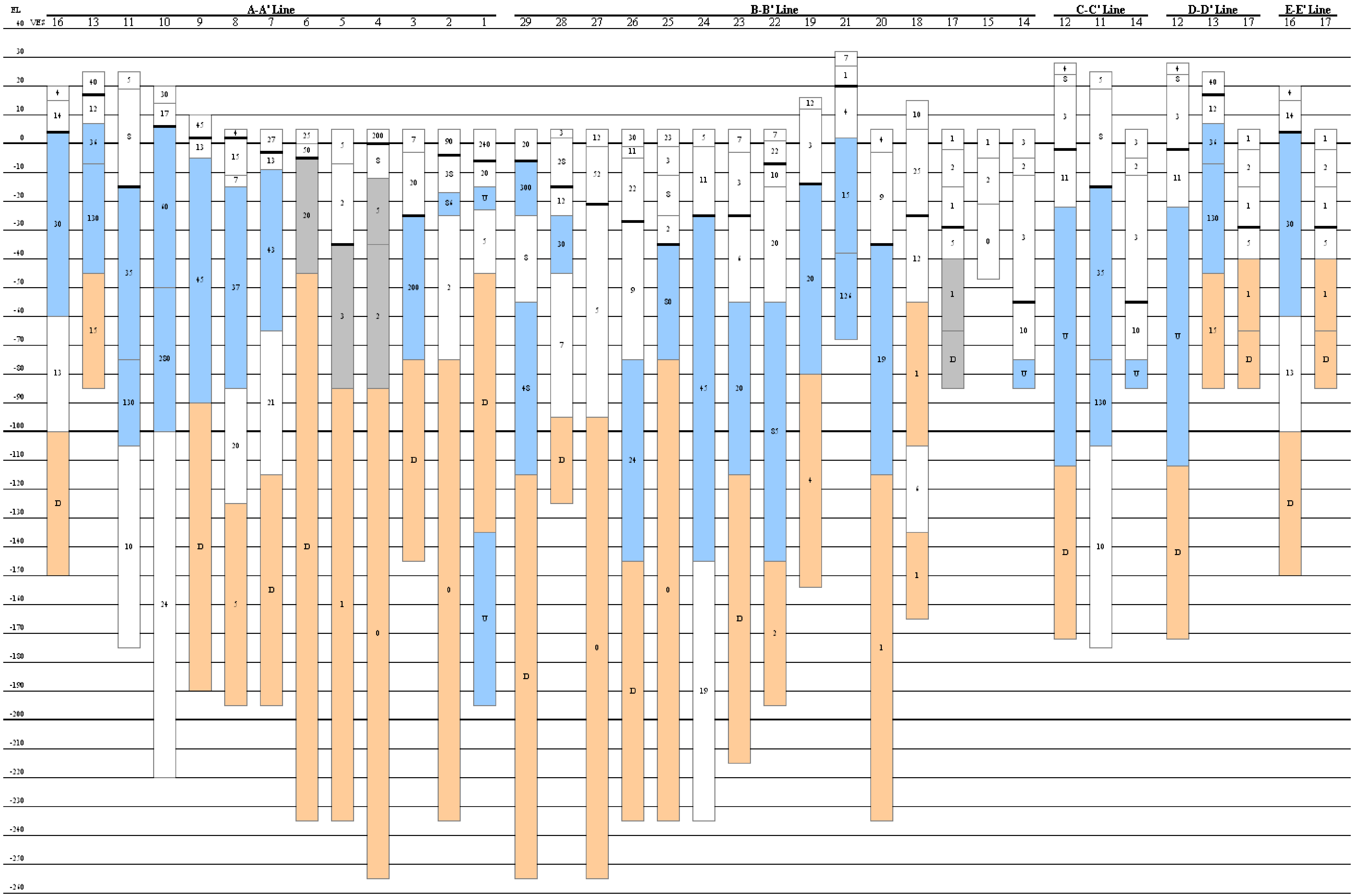


Figure B.II-17 Column Section of Apparent Resistivity

(3) Geo-physical Logging

Geo-physical logging results are shown in following.

< Test Well: TW-01 >

Distribution of alluvial formation is until 72 mbgs. Limestone formation contains sand and silt, and basalt chips (black color) below 80 mbgs. Figure B.II-18 shows logging results at TW-01.

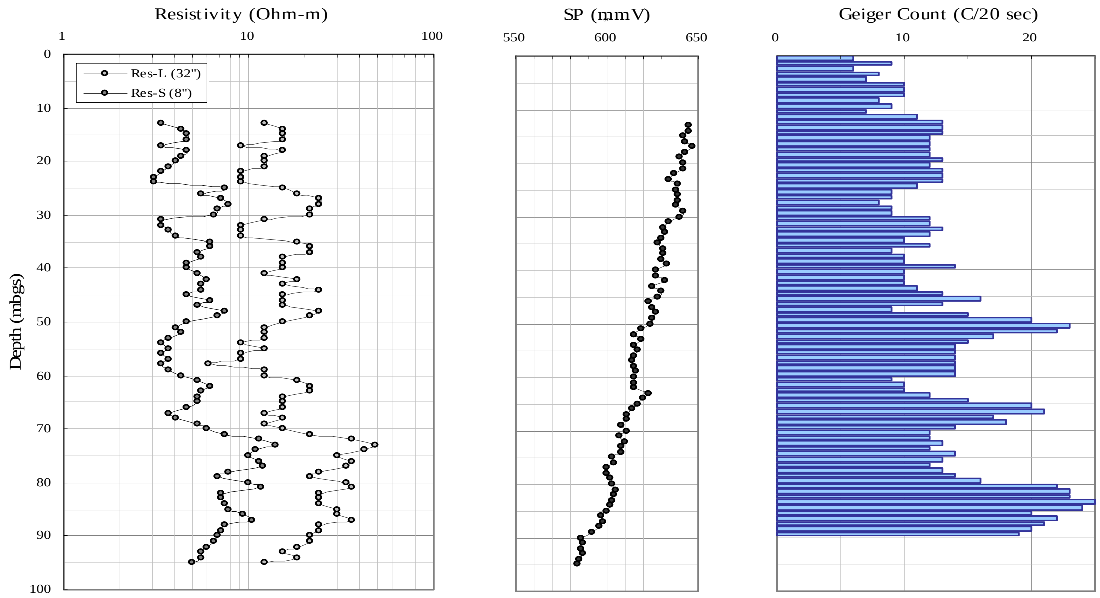


Figure B.II-18 Geo-physical Logging Graph at TW-01

< Test Well: TW-02 >

Distribution of alluvial formation is until 58 mbgs. Because of collapsible formation at upper portion, conductor pipe was installed until 55 mbgs. Limestone can be classified as massive according to penetration rate and gamma log. Figure B.II-19 shows logging results at TW-02.

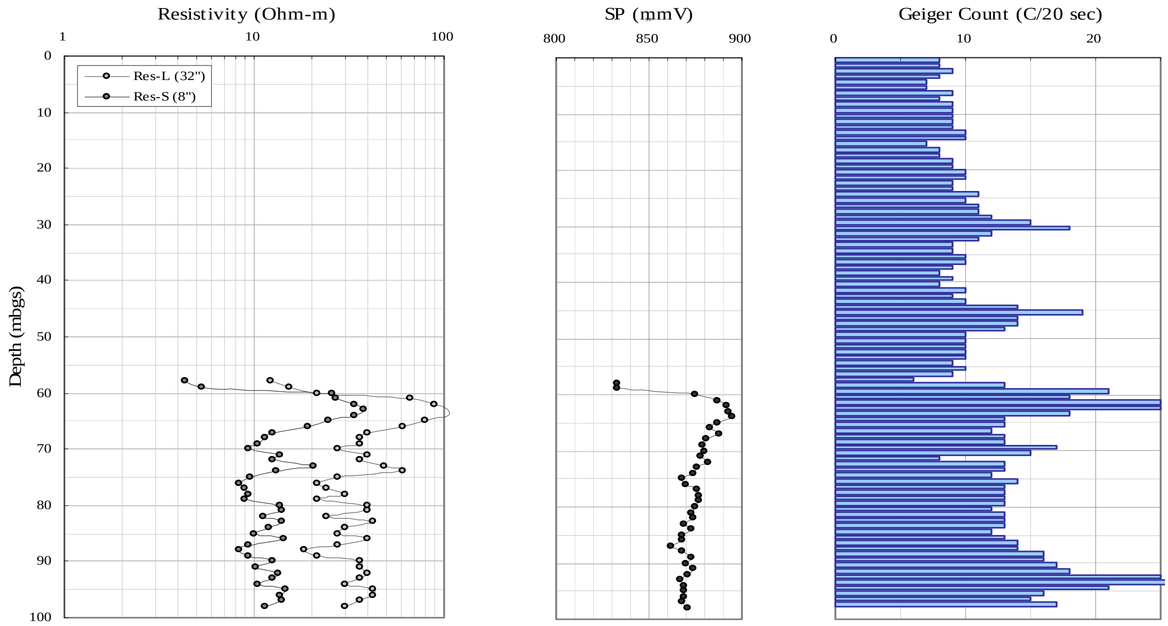


Figure B.II-19 Geo-physical Logging Graph at TW-02

< Test Well: TW-03 >

Distribution of alluvial formation is until 70 mbgs with clayey. Limestone formation is alternation of massive and un-consolidated with sand contents. Figure B.II-20 shows logging results at TW-03.

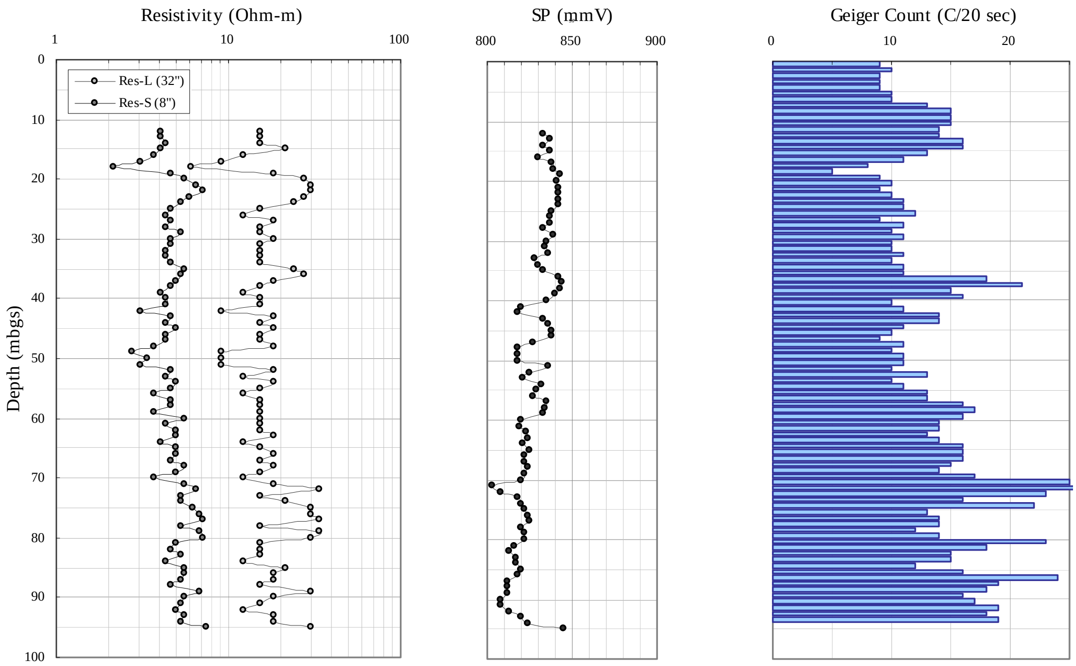


Figure B.II-20 Geo-physical Logging Graph at TW-03

< Test Well: TW-04 >

Logging graph is shown in Figure B.II-21. Thickness of alluvial is 63 mbgs. Limestone is sandy and brackish or fresh water would be anticipated below 85 mbgs.

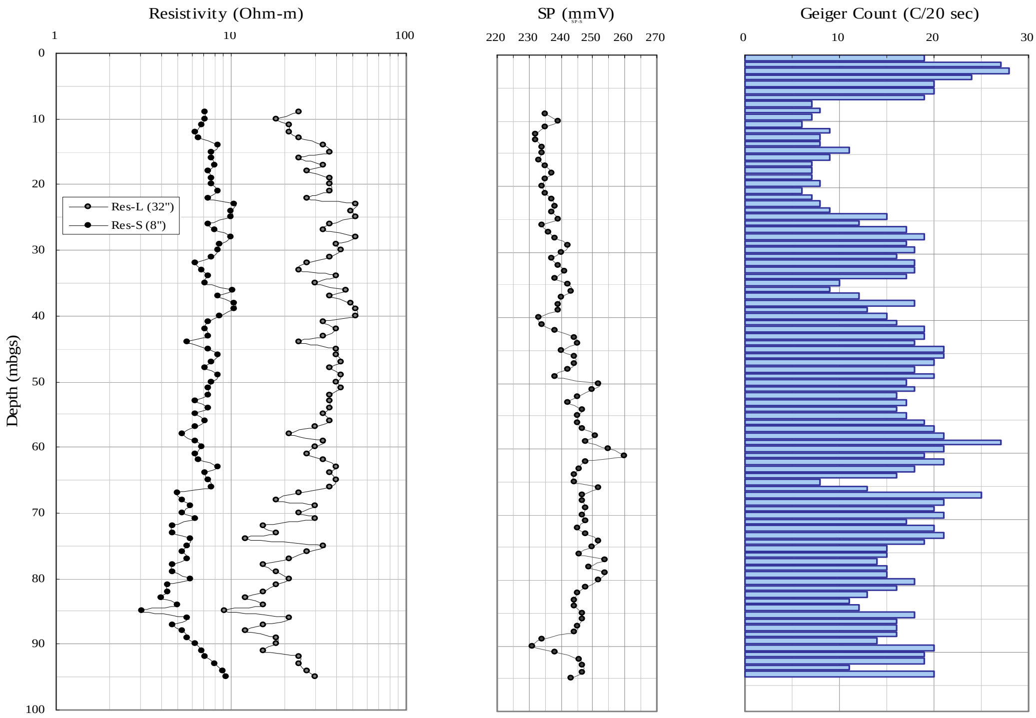


Figure B.II-21 Geo-physical Logging Graph at TW-04

< Test Well: TW-05 >

Logging graph is shown in Figure B.II-22. Conductor pipe was installed up to 30 mbgs. Thickness of alluvial is 77 m. Limestone samples include massive fragments.

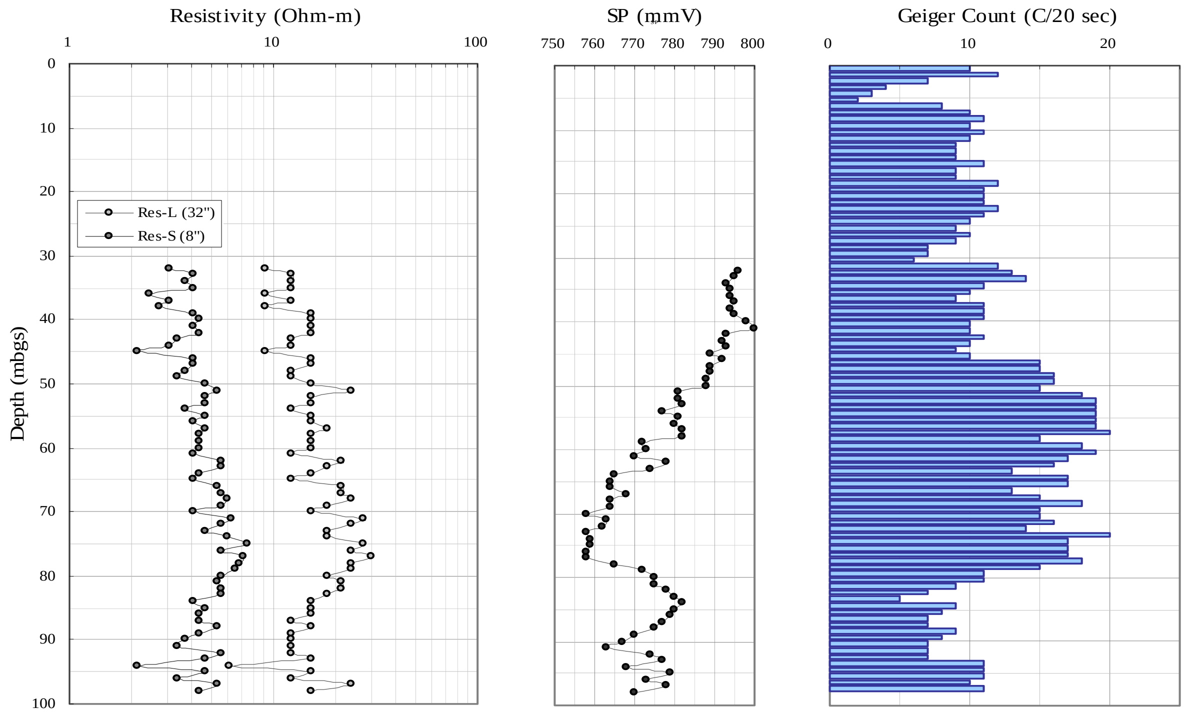


Figure B.II-22 Geo-physical Logging Graph at TW-05

<Observation Well: OW-06>

Logging graph is shown in Figure B.II-23. Porous limestone can be seen until above 15 mbgs and below 25 mbgs without sandy and silty materials.

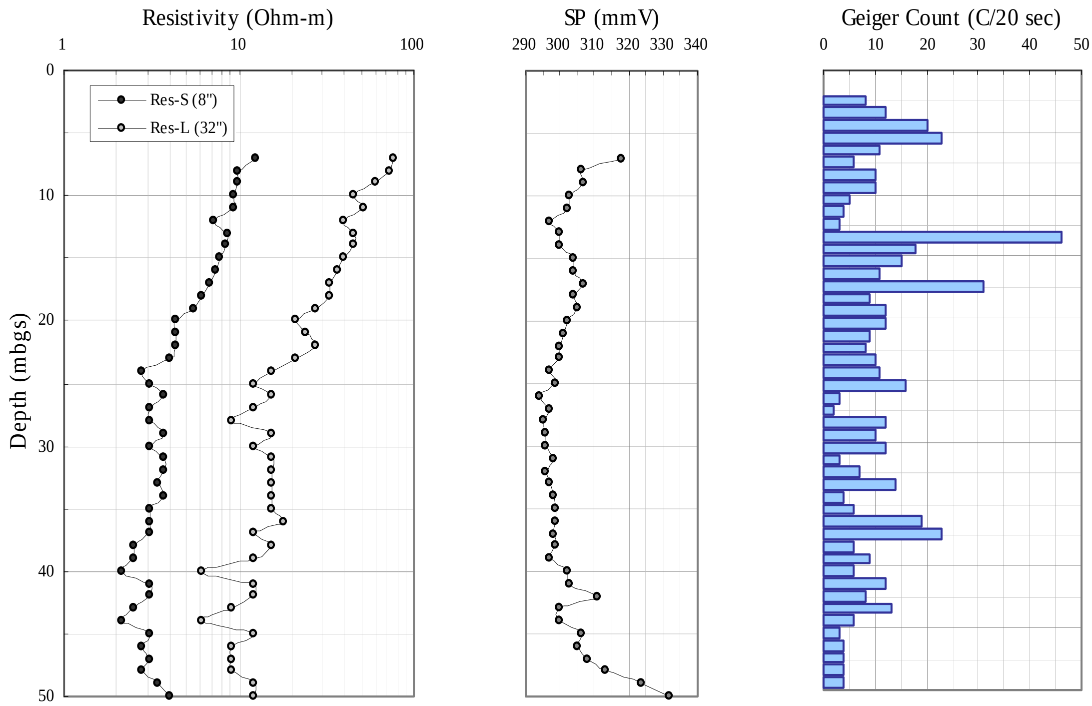


Figure B.II-23 Geo-physical Logging Graph at OW-06

<Observation Well: OW-07>

Logging graph is shown in Figure B.II-24. Very porous limestone can be seen until above 15mbgs and below 30 mbgs without sandy and silty materials.

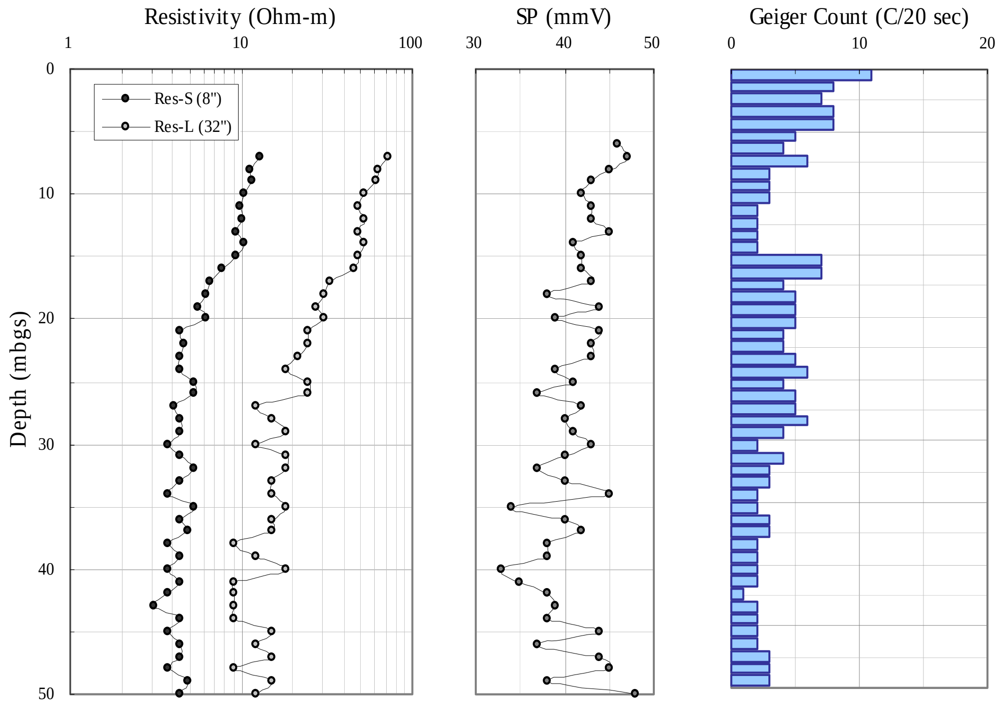


Figure B.II-24 Geo-physical Logging Graph at OW-07

<Observation Well: OW-08>

Logging graph is shown in Figure B.II-25. Groundwater level may be 46 mbgs. Generally, silty limestone is dominance. Porous and soft limestone can be seen below 80 mbgs.

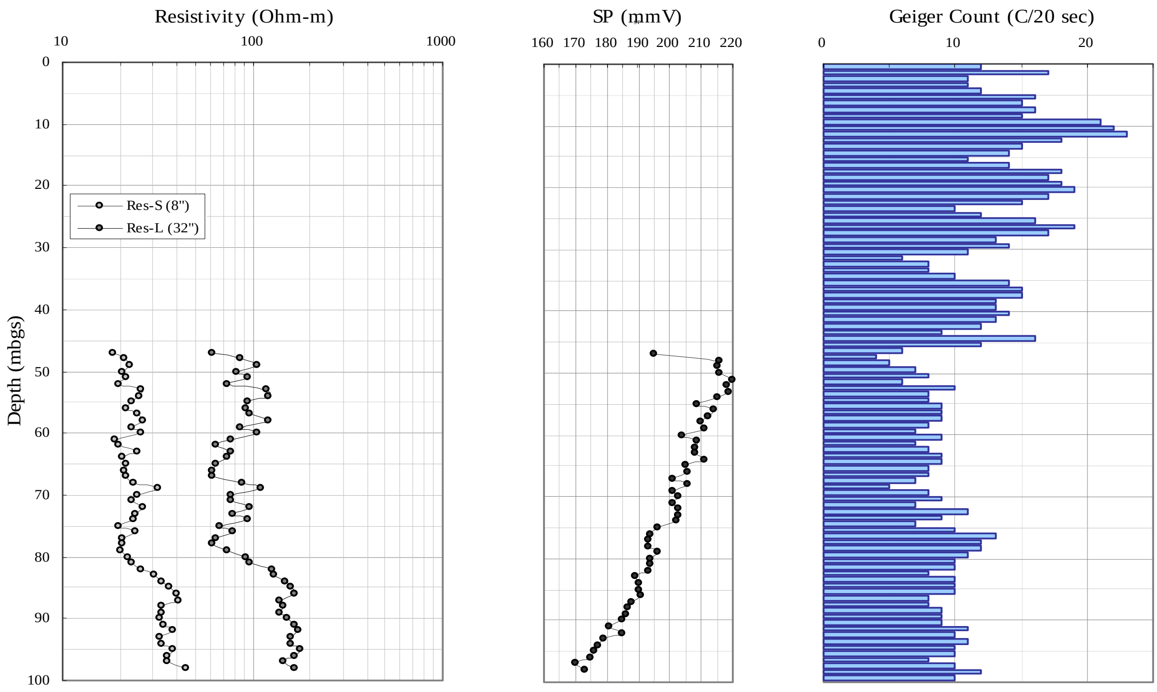


Figure B.II-25 Geo-physical Logging Graph at OW-08

<Observation Well: OW-09>

Logging graph is shown in Figure B.II-26. Groundwater level may be 36 mbgs. Generally, silty limestone is dominance. Porous and soft limestone can be seen below 60 mbgs.

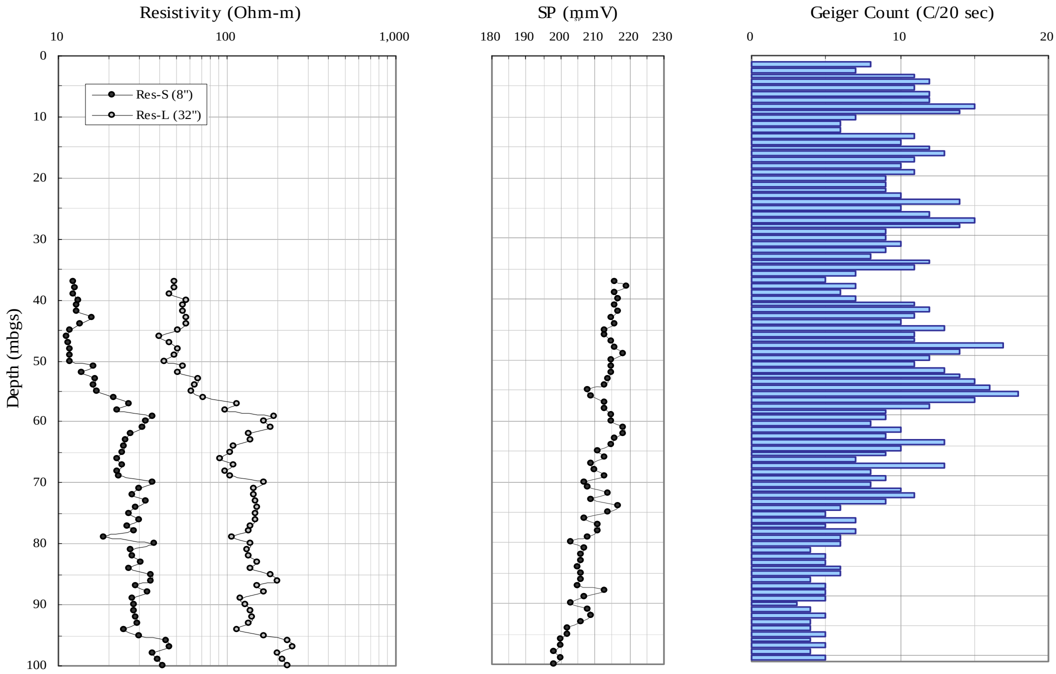


Figure B.II-26 Geo-physical Logging Graph at OW-09

< Observation Well: OW-10 >

This was constructed using percussion method. Water level during drilling was measured at 32 mbgs. Surface limestone formation is massive and un-consolidated limestone with sand contents is followed below 20 mbgs. Figure B.II-27 shows logging results at OW-10.

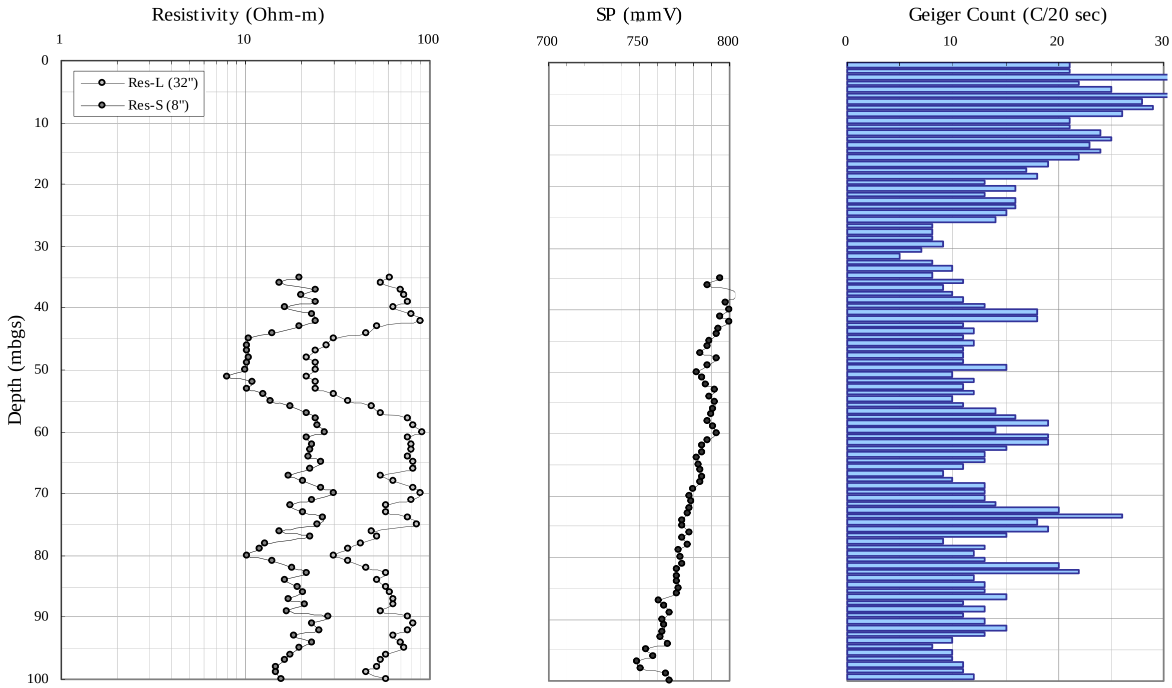


Figure B.II-27 Geo-physical Logging Graph at OW-10

(4) Inferential Setting of Alluvial and Karstic Limestone

< Alluvial Formation >

Distribution of alluvial formation was presumed using following materials.

✓ Maps:	Topography and Geology
✓ Report:	Production Well Construction of MCWD
✓ Well Information:	Private Enterprise
✓ Hydrogeological Investigation:	Soil Sample, Logging, Prospecting

Distribution features of alluvial formation are:

- ✓ Thin alluvial in northern Cebu, comparatively thick in southern Cebu,
- ✓ Narrow alluvial in northern Cebu, comparatively wider in southern Cebu including sea floor,
- ✓ Thin alluvial between hilly limestone and outcrop limestone in Lilo-an,
- ✓ Alluvial in Butuanon river mouth has basin shape with thickness of 60 to 80 m,
- ✓ Alluvial in Butuanon river mouth has different shape from others completely,
- ✓ Thin alluvial can be found in shallow sea at north-east and south-west portion of Mactan Island.

Bottom contour of alluvial formation was prepared using information mentioned above and shown in Figure B.II-28.

Figure B.II-28 Base Contour Map of Alluvial Formation

< Karstic Limestone >

Generally, difference of Karstic Limestone Formation in northern Cebu and southern Cebu is value of inclination. Thickness of limestone was confirmed during the oil exploitation drilling. However, such report can not be seen now. Figure B.II-29 shows bottom contour of Karstic Limestone Formation.

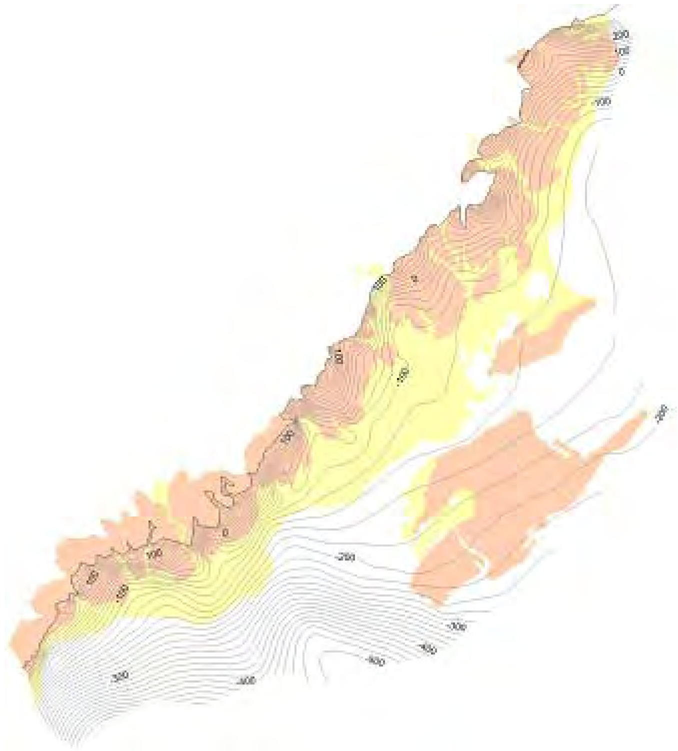


Figure B.II-29 Base Contour Map of Karstic Limestone Formation

II-4.3 Hydrogeological Properties and Infiltration Capacity

Input data of aquifer properties and infiltration capacity are normally classified into in-variables when a model is built, excluding large scale change of groundwater receptacle such as fault movement, volcanic activities, land-slid, etc. These in-variables were analyzed using following data.

- Aquifer Properties analyzed by MCWD Wells
- Pumping Test at Test Well
- Infiltration Capacity Test in Alluvial Area

(1) Aquifer Properties analyzed by MCWD Wells

< History of Groundwater Development by MCWD >

Osmena Waterworks was established in 1908 and started water supply operation at Cebu city central area using newly constructed Buhisan Dam and Tisa Treatment Plant. Since the dam reservoir was dried up due to 3 years draught from 1955, groundwater development was included in 1956 for sustainable water production by different types of water resource utilities. MCWD has constructed totally 198 wells until December 2008. Many of production wells were abandoned due to following reasons. Finally, MCWD has managed 109 wells including 11 observation wells.

✓ Water Quality:	Cl (salt water intrusion),
	NO_3 (drainage contamination)
✓ Water Quantity:	Low Conductivity (aquifer property),
	Well Structures (construction quality: well loss)
✓ Site Change:	Replacement (by road construction),
	Leasehold (change land ownership)

MCWD intakes the raw water of 166,258 m^3/day in the month of December 2008. This amount includes bulk water and surface water. Production ratio of these water sources is:

- ✓ Groundwater (own wells): 87.5 % (109 wells including Jaclupan)
- ✓ Groundwater (bulk): 9.6 % (private enterprise, one of them has de-salination plant)
- ✓ Surface Water (Buhisan): 2.9 % (constructed in 1908)

< Pumping Test in MCWD Wells >

Purposes of pumping test can be classified into two objectives; (a) aquifer test for aquifer properties, (b) well test for intake efficiency. Generally, following tests are conducted depending on the objectives. Aquifer test is usually conducted for well field development. Therefore, this test is applied at well completion period. On the other hand, well test is planned and conducted periodically for evaluation of well efficiency.

- ✓ Aquifer Test: Time Drawdown Test, Recovery Test
- ✓ Well Test: Step Drawdown Test, Sand Pumping Test

Necessary data groundwater modeling is aquifer properties in formations of Alluvial and Karstic Limestone. Some of MCWD developed both aquifers without packer test (isolated tests). Analyzed hydraulic properties are shown below.

- ✓ Hydraulic Conductivity: Permeability of Fluid Flow (cm/sec)
- ✓ Storativity: Production Rate by unit Drawdown (none)
- ✓ Specific Yield: Production Rate in unit Thickness by unit Drawdown (m/day)

Some of MCWD wells do not have pumping test record. Some of other wells have pumping test record but aquifer properties can not be analyzed because of no observation well near-by its production well. Therefore, applied properties were adopted depending on parameters of hydraulic properties. For compilation of these data, WRMUs (water resources management units) were adopted for statistical analysis as shown below.

- ✓ Northern District: 4-WRMUs: Compostela, Kot-kot, Lilo-an, Cansaga
- ✓ Central District: 2-WRMUs: Butuanon, Cebu
- ✓ Southern District: 2-WRMUs Mananga, Minglanilla-Talisay
- ✓ Mactan District: 1-WRMU Mactan

Tables B.II-15, B.II-16 and B.II-17 show summary of aquifer properties using MCWD wells with WRMUs categories.

Table B.II-15 Hydraulic Conductivity of MCWD Wells by WRMUs (cm/sec)

Basin (WRMU)		Northern				Central		Southern		Mactan	Entire
		Com	Kot	Lil	Can	But	Ceb	Man	Min	Mac	
Alluvial	Min	1.9E-03	2.7E-02	-	-	2.6E-02	9.7E-03	1.1E-02	-	-	1.9E-03
	Max	1.9E-03	5.0E-01	-	-	2.6E-02	1.5E-02	1.5E+00	-	-	1.5E+00
	Mid	1.9E-03	2.6E-01	-	-	2.6E-02	1.2E-02	7.4E-01	-	-	7.3E-01
	Arith-mean	1.9E-03	1.4E-01	-	-	2.6E-02	1.2E-02	5.3E-01	-	-	3.4E-01
	Geo-mean	1.9E-03	8.0E-02	-	-	2.6E-02	1.2E-02	2.5E-01	-	-	1.0E-01
	data No.	1	5	0	0	1	2	12	0	0	21
Limestone	Min	3.4E-03	2.2E-02	8.4E-02	5.3E-03	1.5E-03	2.2E-05	1.8E-03	5.1E-03	5.6E-01	2.2E-05
	Max	1.4E+01	2.1E-01	1.6E-01	1.7E+00	2.6E-01	1.2E+00	3.0E-01	5.1E-03	4.7E+00	1.4E+01
	Mid	7.1E+00	1.2E-01	1.2E-01	8.3E-01	1.3E-01	5.9E-01	1.5E-01	5.1E-03	2.6E+00	7.1E+00
	Arith-mean	2.4E+00	7.9E-02	1.3E-01	1.9E-01	9.1E-02	1.0E-01	1.1E-01	5.1E-03	2.5E+00	4.8E-01
	Geo-mean	2.8E-01	5.2E-02	1.3E-01	6.1E-02	3.5E-02	1.8E-02	1.8E-02	5.1E-03	1.8E+00	5.3E-02
	data No.	8	4	3	23	12	27	3	1	5	86

Note: The first 3-letters indicate name in WRMUs.

Table B.II-16 Storativity of MCWD Wells by WRMUs (none)

Basin (WRMU)		Northern				Central		Southern		Mactan	Entire
		Com	Kot	Lil	Can	But	Ceb	Man	Min	Mac	
Qal	data No.	0	0	0	0	0	0	0	0	0	0
Limestone	Min	-	-	-	1.6E-02	6.7E-02	-	-	-	1.1E-02	1.1E-02
	Max	-	-	-	2.0E-01	3.8E-01	-	-	-	1.1E-02	3.8E-01
	Mid	-	-	-	1.1E-01	2.3E-01	-	-	-	1.1E-02	2.0E-01
	Arith-mean	-	-	-	7.2E-02	2.4E-01	-	-	-	1.1E-02	1.2E-01
	Geo-mean	-	-	-	5.4E-02	2.0E-01	-	-	-	1.1E-02	7.3E-02
	data No.	0	0	0	7	4	0	0	0	1	12

Note: The first 3-letters indicate name in WRMUs.

Table B.II-17 Specific Yield of MCWD Wells (m^3/day/m/m: m/day)

Basin (WRMU)		Northern				Central		Southern		Mactan	Entire
		Com	Kot	Lil	Can	But	Ceb	Man	Min	Mac	
Qal	data No.	0	0	0	0	0	0	0	0	0	0
Limestone	Min	-	-	-	6.9E-04	1.2E-03	-	-	-	1.5E-03	6.9E-04
	Max	-	-	-	3.0E-03	1.7E-02	-	-	-	1.5E-03	1.7E-02
	Mid	-	-	-	1.9E-03	9.2E-03	-	-	-	1.5E-03	9.0E-03
	Arith-mean	-	-	-	1.5E-03	9.3E-03	-	-	-	1.5E-03	4.1E-03
	Geo-mean	-	-	-	1.3E-03	5.2E-03	-	-	-	1.5E-03	2.1E-03
	data No.	0	0	0	7	4	0	0	0	1	12

Note: The first 3-letters indicate name in WRMUs.

Figure B.II-30 shows the range of hydraulic conductivity values in Karstic Limestone by MCWD wells.

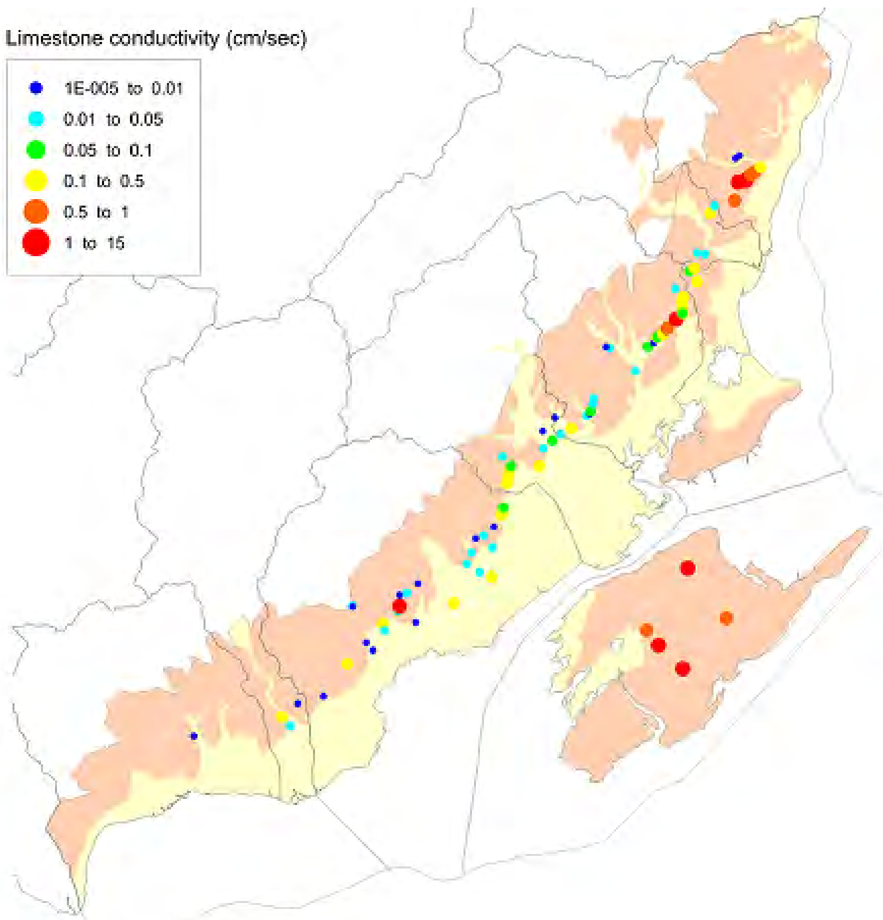


Figure B.II-30 Dot Map of Hydraulic Conductivity at Karstic Limestone (MCWD Well)

Most important parameter of aquifer properties is hydraulic conductivity, which affects flow direction and velocity of groundwater and salt water intrusion. Values of hydraulic conductivity were examined using positioning information. The joint task force team presumed reverse fault along the river of Butuanon. Following are major reasons of such supposition. Districts with high values can be seen along the supposed fault line and Cebu north District including Mactan Island.

✓ Values of Hydraulic Conductivity in Cebu North and Cebu South
✓ Topographic Features: inclination of ground surface, encroachment, Doline ponds
✓ Spring Fields

(2) Pumping Test at Test Well

< Contents of Test >

The test contains time drawdown (92 hours) and recovery (12 hours). Pumping rate was studied according to preliminary step drawdown test results. Most of time drawdown test were applied maximum pumping rate. Storativity, one of aquifer properties, can be analyzed at existing observation well near the test well within 200 m. Only test well TW-04 can produce the storativity.

< Analysis Results >

Test/ observation well designs and pumping test curves including existing observation well are referred to the Data Report. TableB.II-18 shows parameters of aquifer properties (k: hydraulic conductivity, T: transmissivity, S: storativity) using Theis Formula.

Table B.II-18 Analysis Results of Pumping Tests

Properties	TW-01		TW-02		TW-03		TW-04		TW-05	
	TDD	TR	TDD	TR	TDD	TR	TDD	TR	TDD	TR
k: cm/sec	5.6E-4	4.0E-4	1.2E-3	9.0E-4	1.4E-2	1.2E-2	8.9E-3	1.1E-2	2.9E-3	2.7E-3
T: m^3/day/m	12	8	24	19	286	258	190	230	59	57
S: none	-	-	-	-	-	-	-	2.0E-4	-	-

Note: TDD means "Time Drawdown", while TR is "Time Recovery", respectively.

Test well are distributed the entire modeling area along the coast. Features of test results are:

- Conductivity within Butuanon (TW-03 and TW-04) seems to be higher than others,
- Conductivity at Talisay (TW-01 and 02) was slightly smaller than Compostela (TW-05), and
- Storativity at TW-04 was only available because of limited existing observation well at site.

TW-03 and 04 are located within Butuanon basin. There is only one MCWD well which develops alluvial formation, while there is no well in Cansaga basin and 2 wells in Cebu basin. Hydraulic conductivity values of these wells including TW-03 and TW-04 seem to be same range.

Wells — Values of Hydraulic Conductivity (cm/sec)

- TW-03 and 04: $8.9\times10^{-3} \sim 1.4\times10^{-2}$ (Butuanon Basin)
- MCWD 3 Wells: $9.7\times10^{-3} \sim 2.6\times10^{-2}$ (Butuanon and Cebu basins)

There was no observation well beside of MCWD wells at construction period. Therefore, storativity can not be compared. According to test curves, well interference and tide variation can be seen. Accumulation of test results in MCWD and privately owned wells is required.

(3) Infiltration Capacity Test in Alluvial Area

< Dot Distribution >

Field tests were conducted in May and June 2009 (beginning of wet season). Dot distribution map is shown in Figure B.II-31.

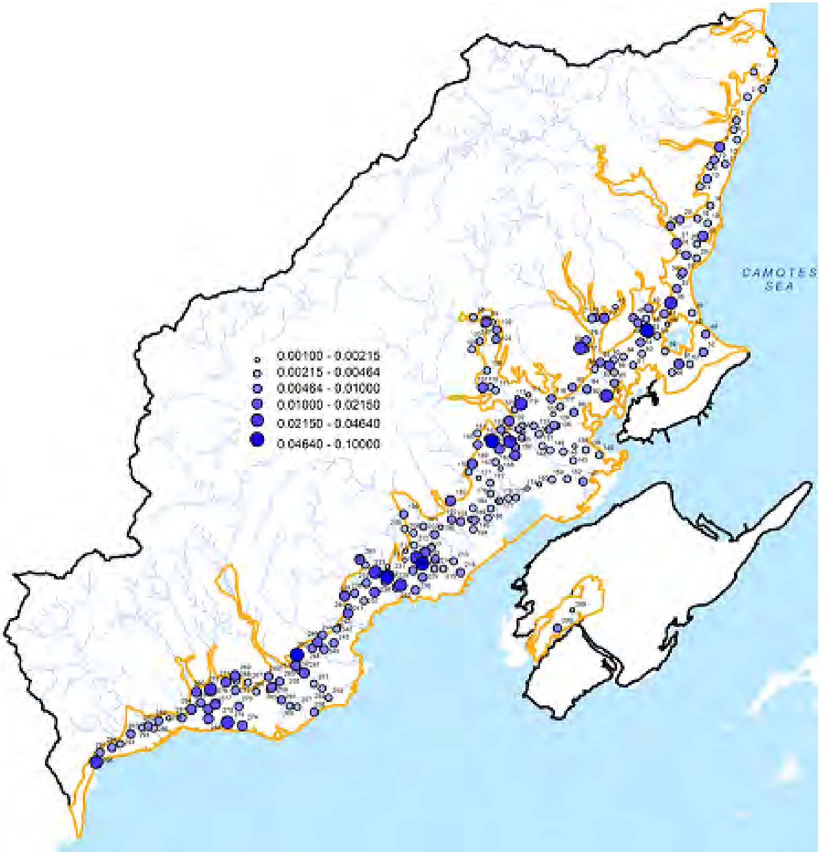


Figure B.II-31 Distribution Map of Infiltration Capacity (cm/sec)

< Consideration >

Following tendencies can be seen.

✓ Scattered aquicludes exist (72/ 300 sites: 24%) due to land improvement and development,
✓ Low infiltration capacity due to high groundwater level along the coastal area,
✓ High infiltration capacity along the river course,
✓ General Trend: Southern area (Mandaue to Naga) > Northern area (Lilo-an to Danao)

Zoning area for recharge input shall be prepared for groundwater modeling. Infiltration capacity test would be one of information to be reflected to such zoning works. However, most of alluvial districts in the study area were classified into the build-up area excluding both ends of Cebu Island and central part of Mactan Island. Therefore, undulation of recharge areas was considered with both infiltration capacity test and land-use information.

II-4.4 Groundwater Quality

Groundwater quality was examined using following data and information.

- Interface between Fresh Water and Seawater
  ✓ Assumed Seawater Intrusion by Geo-resistivity Prospecting
  ✓ Interface Depth Sounding at Test/ Observation Wells with Water Quality Examination

- Characteristics of Raw Groundwater
  - ✓ Seasonal Variation on Concentration of Cl and NO_3 at 50 MCWD wells
  - ✓ Range of Groundwater Quality by MCWD Laboratory Report about 60 MCWD wells for Cl and 90 MCWD wells for NO_3

(1) Interface between Fresh Water and Seawater

< Assumed Seawater Intrusion by Geo-resistivity Prospecting >

Table B.II-19 shows expected statement of seawater intrusion based on the geo-resistivity results.

Table B.II-19 Assumed Seawater Intrusion

Location: Color of Resistivity Curve	Feature of Groundwater Quality
Northern End District Danao City to Compostela Red Lines	Saltwater may be intruded from shallower depth of alluvial. Limestone layer along the coast contains almost seawater. There may be brackish and or fresh groundwater in limestone layer below 150m depth in Danao City (VES-01).
Northern Outcrop District Lilo-an (limestone outcrop hill) to Butuanon Flat Land Green Lines	Limestone layer in this area has high permeability or conduitable fissures but groundwater containing saltwater.
Central District Butuanon to Cebu Central Blue Lines	Saltwater intrusion can be seen along coastal alluvial. Inland limestone layer has still fresh groundwater.
Southern District Talisay City to Naga Black Lines	Alluvial layer is narrow and very thin. Fluvial deposits are only potential aquifer in this area as alluvial development. Limestone layer has fresh groundwater.
Mactan Island Lapu-lapu and Cordova Purple Lines	Fresh or brackish groundwater stays at only surface portion (shallower than 15mbgs). Lower portion was confirmed saltwater containing.

Sounding points of geo-resistivity were located along the coastal line. Even the points in hilly area, distance from the coast is only 4km. Alluvial formation overlay limestone layer. Thickness of alluvial is approximately 60m in Butuanon basin or thinner in other flat area. Figure B.II-32 shows the resistivity curves of 30 points. In the depth where apparent resistivity downs abruptly, it may have saltwater intrusion. On the other hand, where resistivity curve springs up in depth of 70 to 80 mbgs, it is anticipated to contain brackish or fresh groundwater in limestone layer.

< Interface Depth Sounding at Test/ Observation Wells with Water Quality Profile >

Following field measurement including laboratory examination was adopted for analysis of interface depth sounding. Mud water EC profile was measured by the MCWD instrument; however it is now malfunctioned due to electronic leakage. In this regard, mud water was sampled and measured by EC meter.

✓ Borehole: drilling mud water at each 5 m in depths (together with geo-physical logging)

After well development, groundwater quality in the well were sampled and examined for its profiling. Five parameters of Cl, NO_3, Ca, TH and Mn were examined at MCWD Laboratory.

✓ Well: groundwater at depths of below SWL, brackish zone and seawater zone

Following Table B.II-20 shows integrated observations of interface depth sounding. EC profiles are referred to the Data Report.

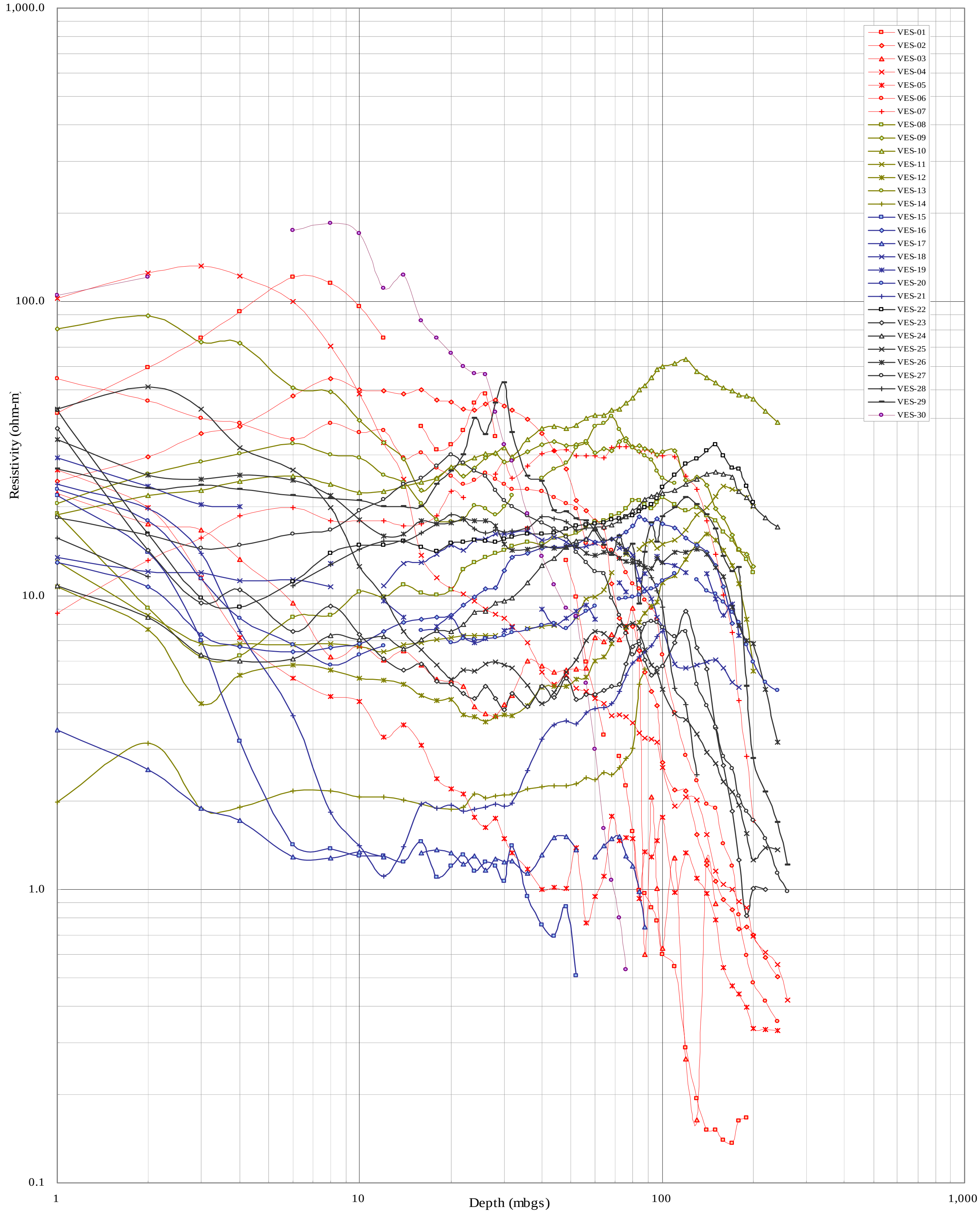


Figure B.II-32 Local Features of Depth-Resistivity Curves