Table B.II-20 Interface between Fresh and Saltwater

Well No.	Test Fluid	Observations
TW-01 Talisay	Mud water (Borehole)	Distribution of alluvial was assumed at 72 mbgs according to the physical logging. EC values (2,500 μS/cm) increase from 30 mbgs and are stable (3,000 μS/cm) below 60 mbgs.
	Groundwater (Well)	Lowest well screen is 44 mbgs and well depth is 50 m. Brackish water can be recognized and EC values (2,500 μS/cm) are stable below SWL.
TW-02 Talisay	Mud water (Borehole)	Distribution depth of alluvial is judged at 58 mbgs. EC values (900 μS/cm) are stable.
	Groundwater (Well)	Well screen was installed up to 44 mbgs, while well depth is 50 m. EC values (2,300 μS/cm) are stable. Groundwater in alluvial formation is affected by saltwater intrusion.
TW-03 Mandaue	Mud water (Borehole)	Mud sampler could not be lowered due to collapsible formation.
	Groundwater (Well)	Alluvial formation is distributed up to 70 mbgs. EC values (14,000 μS/cm) are stable. Saltwater intrusion is aggravated.
TW-04 Mandaue	Mud water (Borehole)	Alluvial boundary depth was judged at 63 mbgs. EC values (4,000 μS/cm) increased from the depth of 40 mbgs may be saltwater intrusion (up to 21,000 μS/cm). Groundwater bearing of brackish and/ or fresh may be anticipated at limestone aquifer below 80 mbgs (down to 3,000 μS/cm).
	Groundwater (Well)	Groundwater EC was measured on 2-weeks after the pumping test. Groundwater EC (2,000 μS/cm) increased from 40 mbgs (4,000 μS/cm). Groundwater EC during pumping test was measures at 2,090 to 2,200 μS/cm. In this regard, following statement can be assumed. • Transmissibility in upper alluvial may larger than lower portion or • Groundwater level in upper alluvial may higher than lower portion.
TW-05 Lilo-an	Mud water (Borehole)	Mud sampler could not be lowered due to collapsible formation.
	Groundwater (Well)	Alluvial formation is distributed up to 77 mbgs, and well screen was installed up to 60 mbgs. Brackish water (2,800 μS/cm) is intruded.
OW-06 Lapu-lapu	Groundwater (Borehole)	Karstic limestone layer above 15 mbgs may have thin brackish or fresh groundwater. EC values at 35 to 45 mbgs were measured at approximately 20,000 μS/cm. Chloride concentration may be estimated at 8,000 mg/L.
OW-07 Lapu-lapu	Groundwater (Borehole)	Karstic limestone layer above 15 mbgs may have thin brackish or fresh groundwater. It is the same trend of OW-06 above.

Tables B.II-21 and B.II-22 show the observations by each parameter and its examination results of groundwater quality.

Table B.II-21 Groundwater Quality Observations at Test/ Observation Wells

Para.	TW-01 Pooc	TW-02 San Roque	TW-03 Subangdaku	TW-04 Pakna-an	TW-05 Kot-kot	OW-06 Marigondon	OW-07 Buaya
Cl	Medium	Low	High	Low-Medium	Medium	Low-High	
TH	High		Very High	High			
Ca	Higher than PNSDW						
Mn	Low Concentration						
NO_3	None			High-shallow	None	High-shallow	

Table B.II-22 Results of Groundwater Quality Examination at Test/ Observation Wells

Well No. and	Sampling Depth	Water Quality: mg/L, μS/cm (PNSDW-93: applied by MCWD)					
		Cl (250)	TH (300)	Ca (100)	Mn (0.5)	NO_3 (50)	EC (none)
TW-01	2 mbgs	449	743	180	<0.010	<0.89	2,434
Pooc,	30 mbgs	396	743	182	<0.010	<0.89	2,216
Talisay	50 mbgs	392	743	180	<0.010	<0.89	2,223
TW-02	2 mbgs	129	550	115	<0.010	<0.89	1,597
San Roque,	30 mbgs	140	535	115	<0.010	<0.89	1,678
Talisay	46 mbgs	136	565	107	<0.010	<0.89	1,669
TW-03	4 mbgs	5,247	2,200	369	<0.010	<0.89	16,550
Subangdaku,	40 mbgs	5,125	2,125	361	<0.010	<0.89	16,150
Mandaue	70 mbgs	5,080	2,121	363	<0.010	<0.89	15,970
TW-04	8 mbgs	194	506	179	<0.010	59	1,615
Pakna-an,	40 mbgs	433	191	51	<0.010	8	2,489
Mandaue	60 mbgs	571	231	65	<0.010	6	2,994
TW-05	2 mbgs	272	753	218	<0.010	<0.89	2,486
Kot-kot,	40 mbgs	284	743	214	<0.010	<0.89	2,503
Lilo-an	60 mbgs	294	753	214	<0.010	<0.89	2,554
OW-06	7 mbgs	278	411	144	<0.010	45.8	1,459
Marigondon,	10 mbgs	345	413	140	<0.010	43.1	1,663
Lapu-lapu	20 mbgs	1,241	734	156	<0.010	40.3	4,320
OW-07	6 mbgs	169	353	109	<0.010	38.7	1,081
Buaya,	10 mbgs	222	366	86	<0.010	35.2	1,254
Lapu-lapu	20 mbgs	1,667	804	157	<0.010	25.5	5,550

(2) Characteristics of Raw Groundwater

Examination of groundwater quality was studied based on the water sampling in dry and wet seasons, and the annual report from MCWD Laboratory. Major parameters of groundwater examination are chloride and nitrate with due consideration of natural conditions and social activities in Metropolitan Cebu.

< Seasonal Variation on Concentration of Cl and NO_3 >

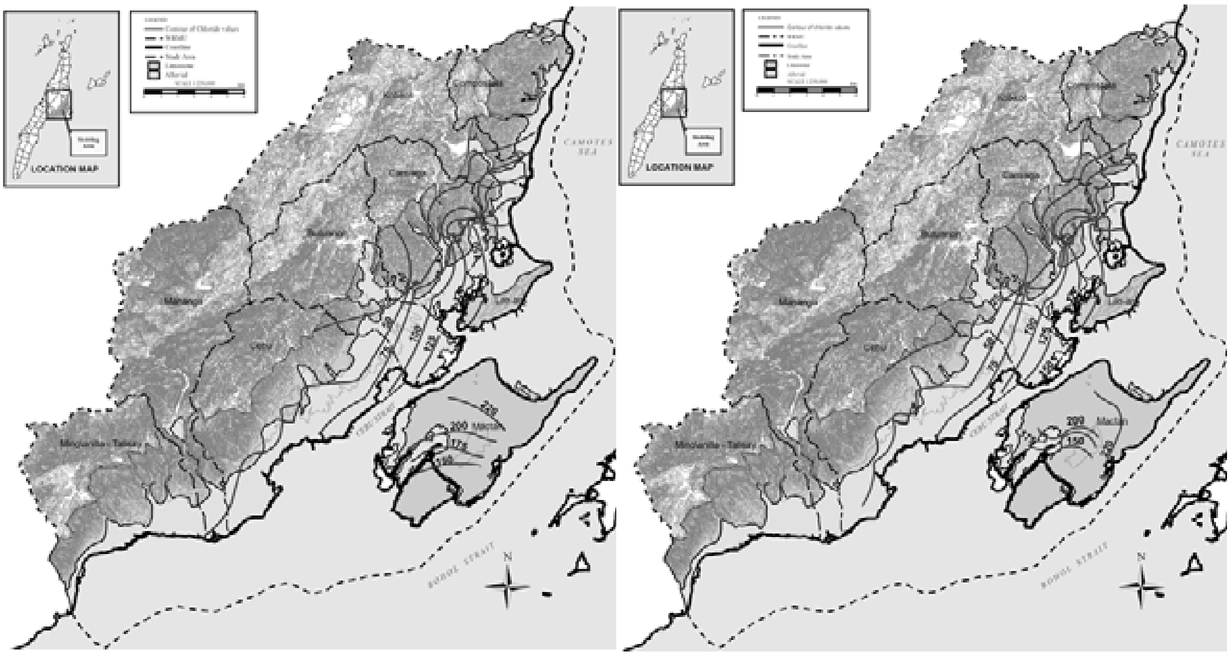
Groundwater from 50 MCWD wells were taken and examined during April and July 2009 for comparing of seasonal variations.

a. Chloride Concentration

Groundwater salinity in the equilibrium statement depends on; (1) specific gravity of fresh water and seawater, (2) distance from shore line, (3) water head from sea level and (4) pitot elevation where sample taken. Therefore, plane contour map of groundwater salinity using various well structures is not real intention scientifically. Figure B.II-33 shows plane contour map of Cl (mg/L) in dry and wet seasons merely under condition indicated above. Among the MCWD well fields, San Vicente with maximum 242 mg/L in Lilo-an and Mactan with maximum 221 mg/L have higher chloride concentration.

The concentration gap in dry and wet seasons is shown in Figure B.II-34. Colored dot means following and dot size indicates the quantity of gap.

- ✓ Blue: Wells with Cl concentration in Dry > Wet
- ✓ Red: Wells with Cl concentration in Dry < Wet



April 2009 (dry season) July 2009 (dry season)

Figure B.II-33 Plane Contour Map of Cl at 50 MCWD Wells

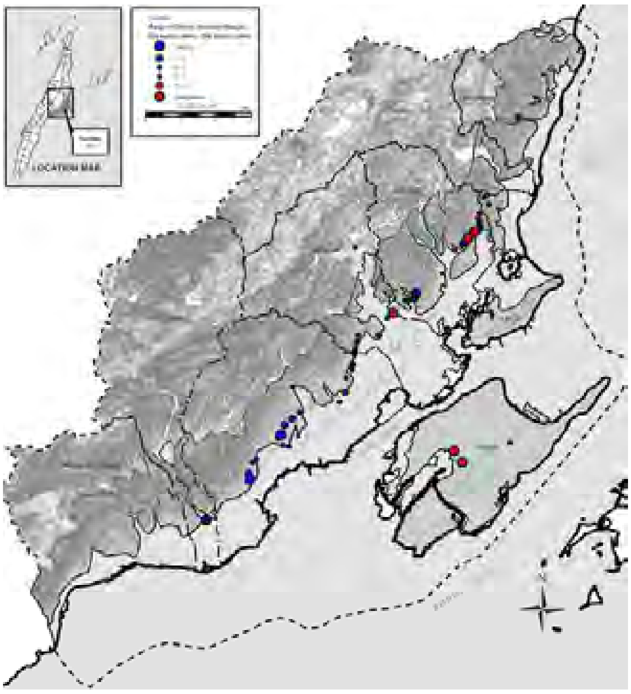


Figure B.II-34 Seasonal Variation of Cl (as Gap between Dry: April and Wet: July)

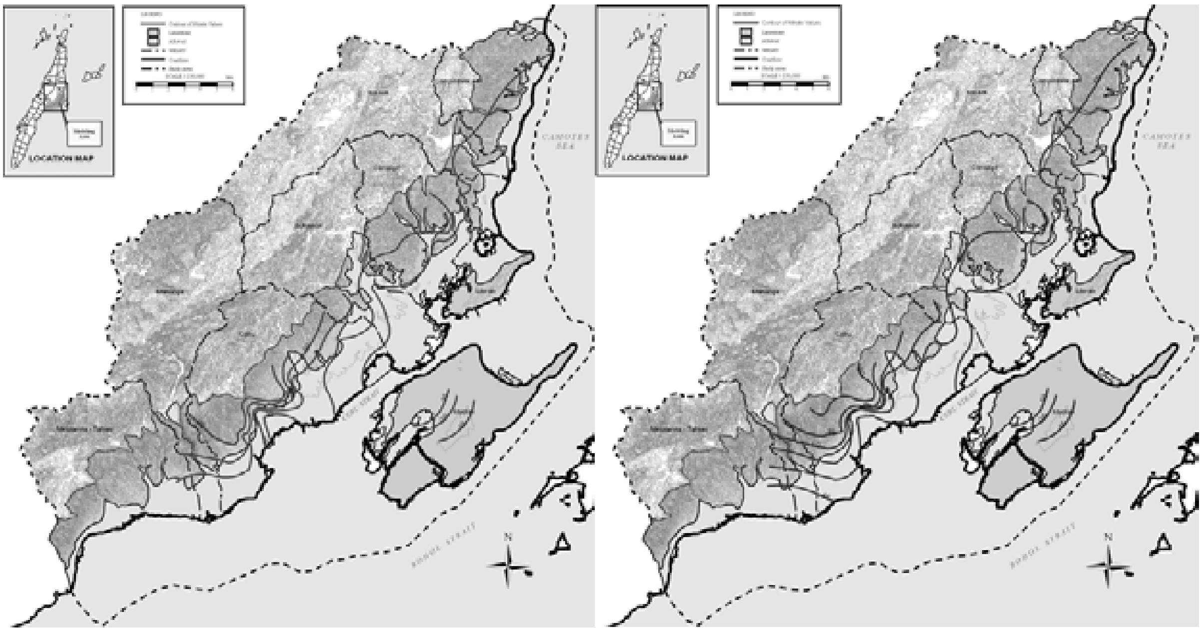
Pumping rate from MCWD wells have been managed according to following criteria.

- ✓ Intake amount is increased in dry season because of less surface water potential, and
- ✓ Pumping rate and operation hour of well with high Cl is controlled to avoid aggravation.

Generally, Cl concentration in dry season is higher than that in wet season. However some wells in well fields at San Vicente and Mactan have higher Cl concentration in wet season, because production wells in such well fields are controlled by mainly local demand.

b. Nitrate Concentration

Origin of Nitrogenous compound is mainly from human waste. Nitrate in raw groundwater is judged as maximum 50 mg/L by MCWD. In this regard, groundwater in shallower portion may have high concentration of Nitrate if contaminants infiltrate from ground surface. Figure B.II-35 shows plane contour map of NO_3 (mg/L) in dry and wet seasons merely under condition indicated above. Among the MCWD well fields, hilly area of Cebu City has maximum Nitrate concentration of 112 mg/L.



April 2009 (dry season) July 2009 (dry season)

Figure B.II-35 Plane Contour Map of NO_3 at 50 MCWD Wells

Trend of NO_3 seasonal variation can be seen that the concentration in dry season is higher than that in wet season as shown in Figure B.II-36. Colored dot means following and dot size indicates the quantity of gap.

- ✓ Blue: Wells with NO_3 concentration in Dry < Wet
- ✓ Red: Wells with NO_3 concentration in Dry > Wet

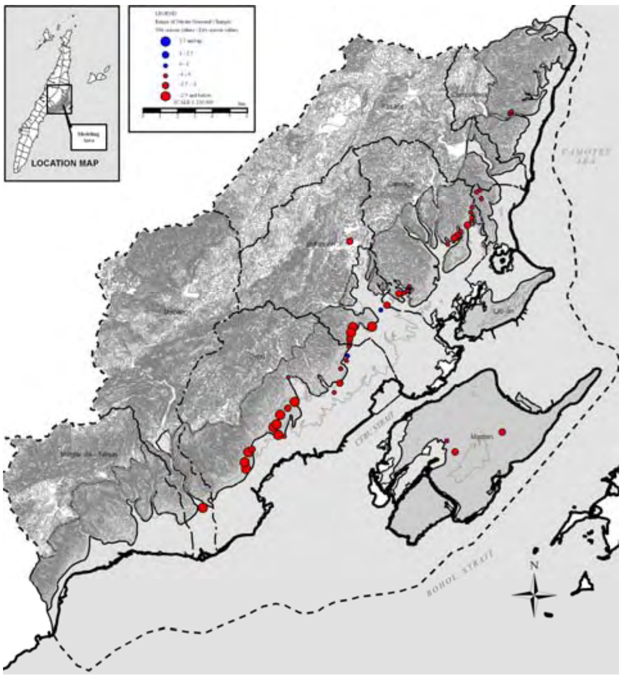
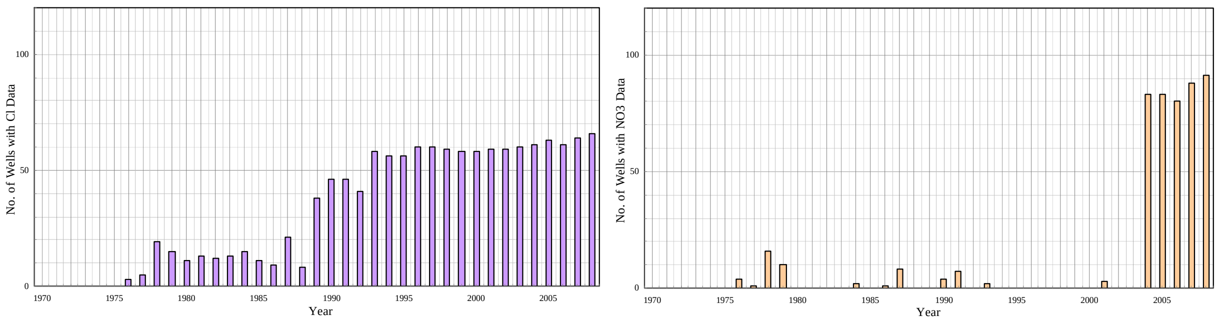


Figure B.II-36 Seasonal Variation of NO_3 (as Gap between Dry: April and Wet: July)

There is no seasonal variation of waste outlet, therefore NO_3 concentration may be depending on rainfall amount and groundwater storage time in the ground. Contamination system of NO_3 shall be studied with due consideration of sinkhole location, mass balance of rainfall and NO_3, and its basin.

< Range of Groundwater Quality by MCWD Laboratory Report >

Currently, groundwater from MCWD wells has been examined periodically. Examination of chloride was started from 1974. MCWD targets sampling wells excluding Jaclupan well field where fluvial deposits were developed in inland area from 1993. On the other hand, NO_3 examination of groundwater started from 2004. Most of wells are nominated for groundwater sampling. Figure B.II-37 shows historical graph of well number which monthly Cl and NO_3 examination has been done annually.



Cl: as annual No. of MCWD Wells　　　　NO_3: as annual No. of MCWD Wells

Figure B.II-37　Historical Graph of Water Examination

a. Annual and Seasonal Variation in Cl

Chloride concentration in groundwater of MCWD wells has been examined monthly from January 1989. Average monthly Cl concentration in each well field is shown in Figure B.II-38. Among MCWD well fields, San Vicente and Mactan has an increasing trend of Cl concentration.

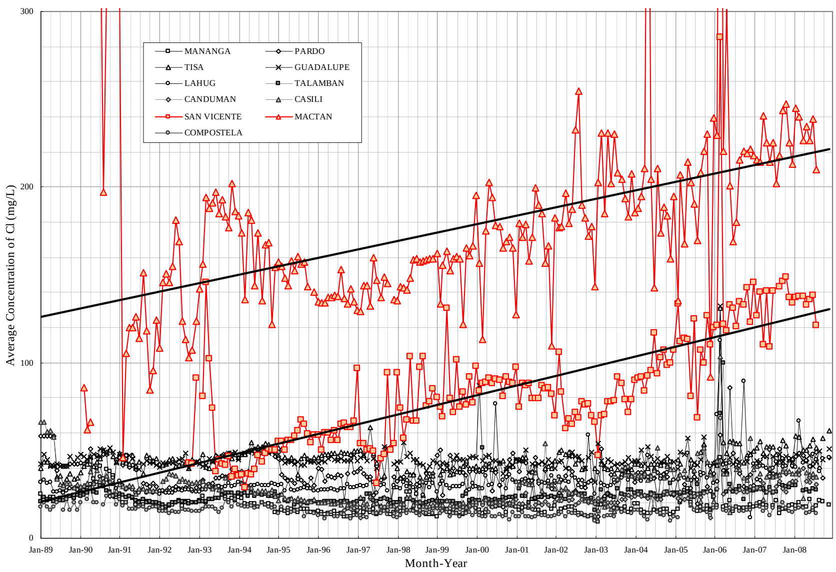


Figure B.II-38　Monthly Cl by MCWD Well Fields (Jan-1989 to Dec-2008)

Figure B.II-39 indicates monthly Cl concentration at each well in the well fields of San Vicente and Mactan. According to this Figure B.II-39, different features of increasing trend can be seen as listed below. Reason of this features may depend on the media type whether porous or conduit fissure.

- ✓ San Vicente (Blue): Some identified wells have higher Cl concentration
- ✓ Mactan (Orange): All wells have higher Cl concentration

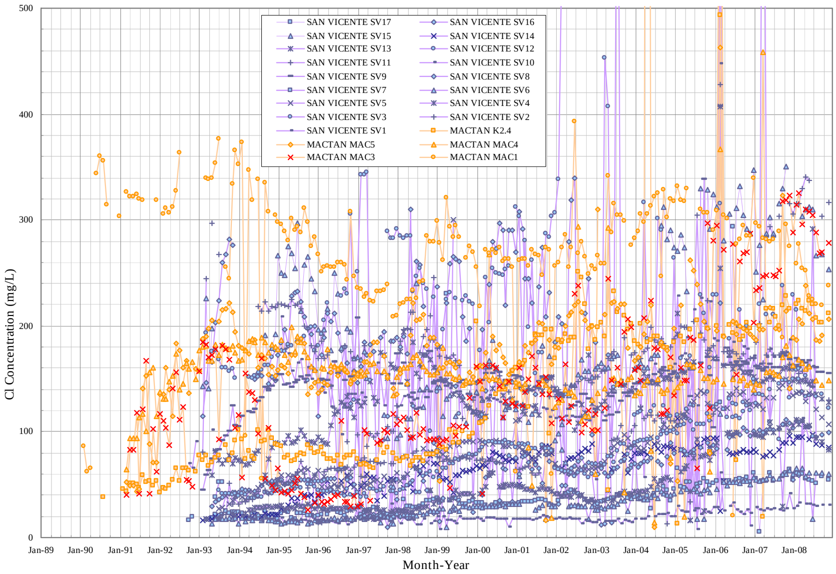
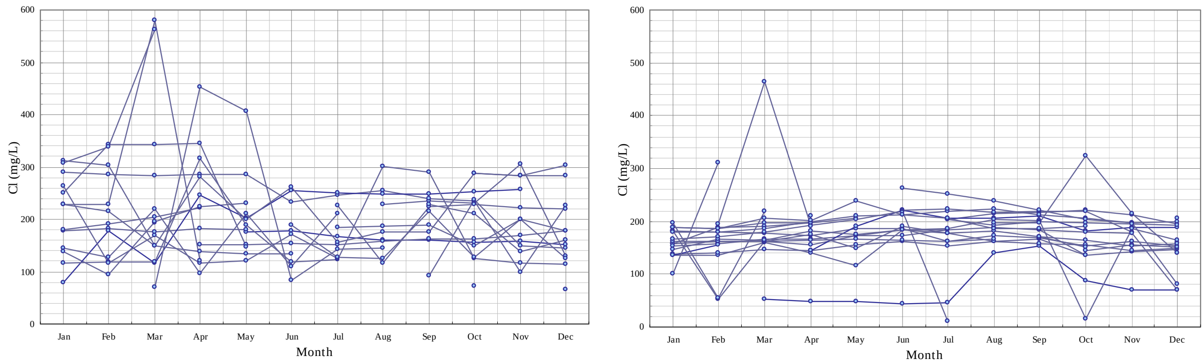


Figure B.II-39 Monthly Cl of Wells in MCWD 2 Well Fields (Jan-1989 to Dec-2008)

Figure B.II-40 indicates the monthly Cl concentration at SV-12 and MAC-5, wells of which are located in San Vicente and Mactan well fields with highest Cl concentration.

For SV-12 well, trend of higher Cl in dry season can be seen but it is not conspicuously. Because of increasing on Cl concentration annually, range of seasonal Cl variation can be seen dispersively. On the other hand, seasonal variation at MAC-5 can not be seen, it was well controlled pumping rate and operation hour. Fresh groundwater exists on shallow and thin limestone aquifer in Mactan well field. In this regard, Cl concentration shall be controlled well and must be decreased for residential use.

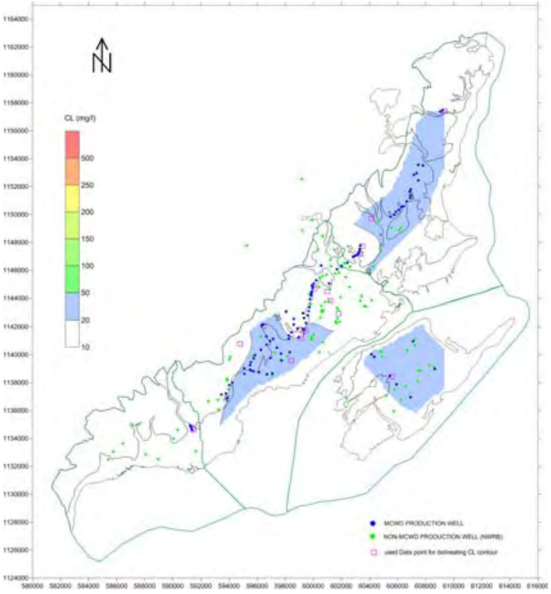


SV-12 Well (Mar-1993 to Dec-2008) MAC-5 Well (Mar-1991 to Dec-2008)

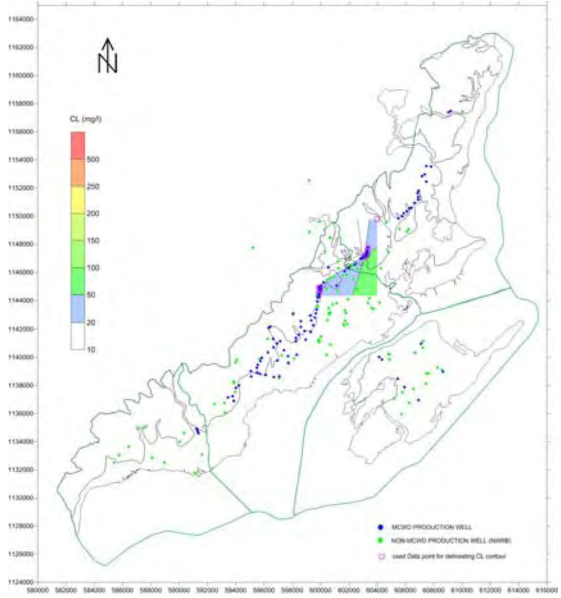
Figure B.II-40 Seasonal Variation of Cl

Using examination records of Cl at MCWD wells, Figure B.II-41 shows Cl contour maps with assumptions below.

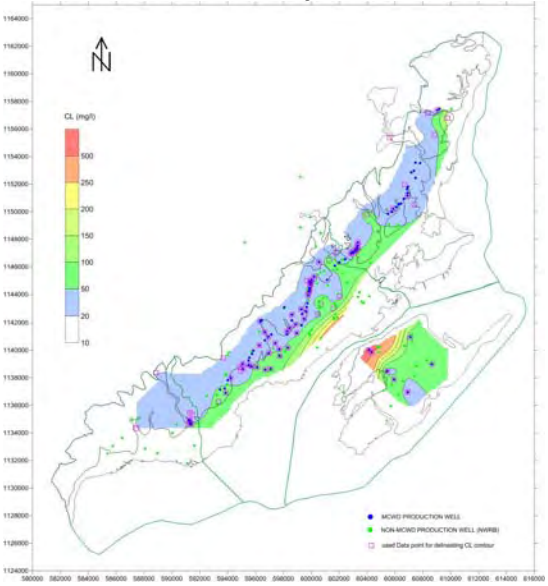
- ✓ Pitot point in well is located at the middle of well screen top and bottom.
- ✓ Cl concentration exists at pitot depth of intake well.



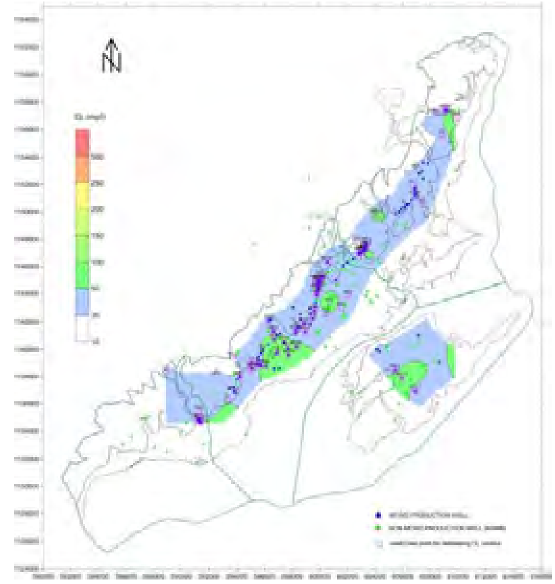
Annual Average 1978



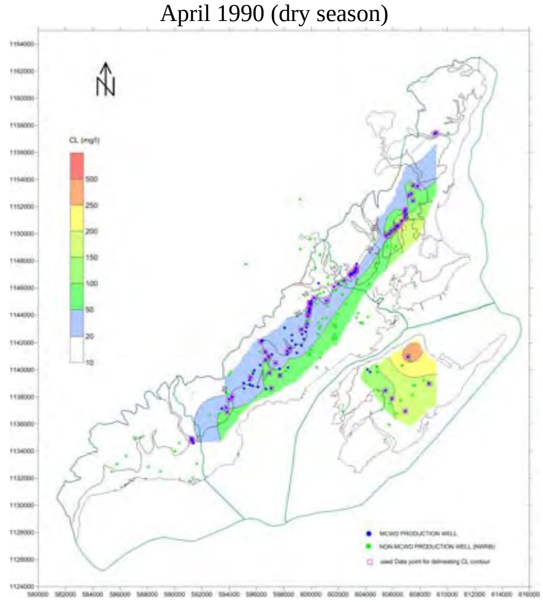
Annual Average 1980



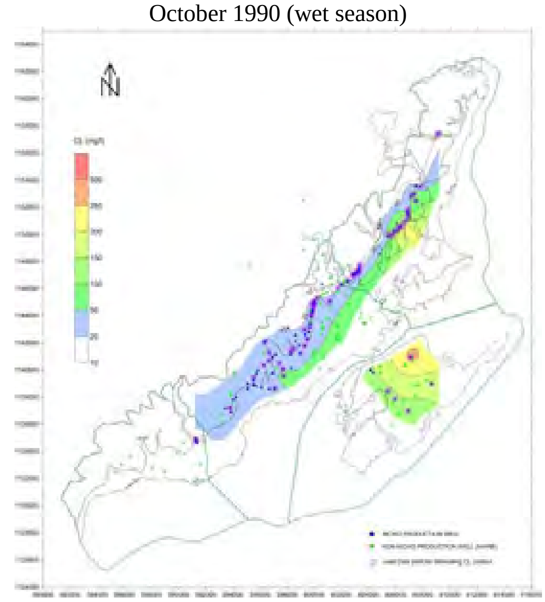
April 1990 (dry season)



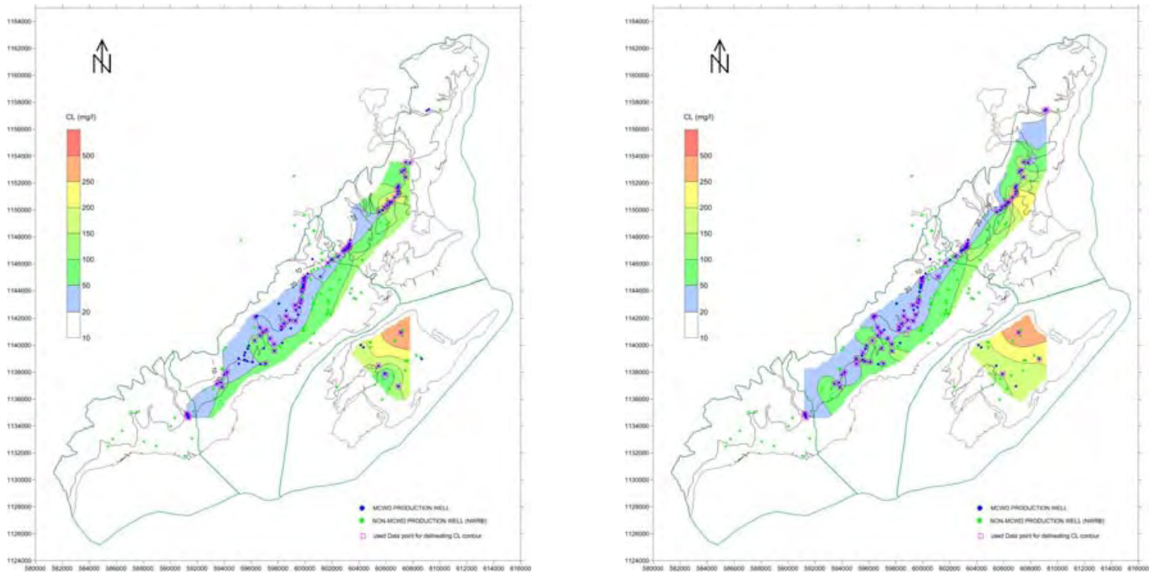
October 1990 (wet season)



April 2000 (dry season)



October 2000 (wet season)



April 2005 (dry season) October 2005 (wet season)

Figure B.II-41 Cl Contour Maps (Left side: dry season and Right side: Wet season)

a. Annual and Seasonal Variation in NO_3

As shown in Figure B.II-42, all of well fields have an increasing trend of NO_3 concentration. Especially, well fields of Pardo, Tisa and Guadalupe (reddish lines) have high rate of increase. These well fields coincide with areas being developed as residential houses.

Figure B.II-43 indicates monthly NO_3 concentration at each well in the 3 well fields of Pardo, Tisa and Guadalupe. According to this Figure B.II-43, all of wells have an increasing trend of NO_3. Figure B.II-44 indicates the monthly NO_3 concentration at following well, which is located in the said 3 well fields with highest NO_3 concentration.

- ✓ Pardo: MC-02
- ✓ Tisa: MC-06
- ✓ Guadalupe: G-03

Conspicuous trend of NO_3 increasing can not be seen. However, relationship between rainfall and NO_3 concentration shall be studied with due consideration of its catchment area.

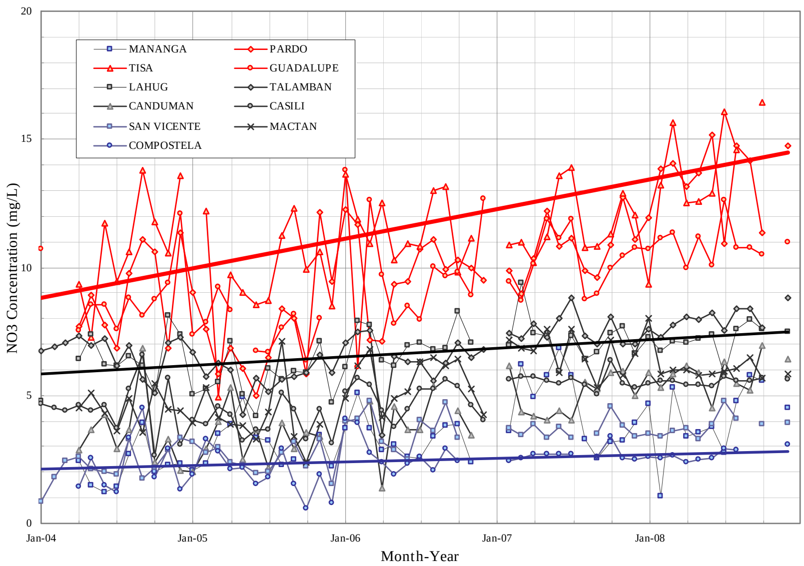


Figure B.II-42 Monthly NO_3 by MCWD Well Fields (Jan-2004 to Dec-2008)

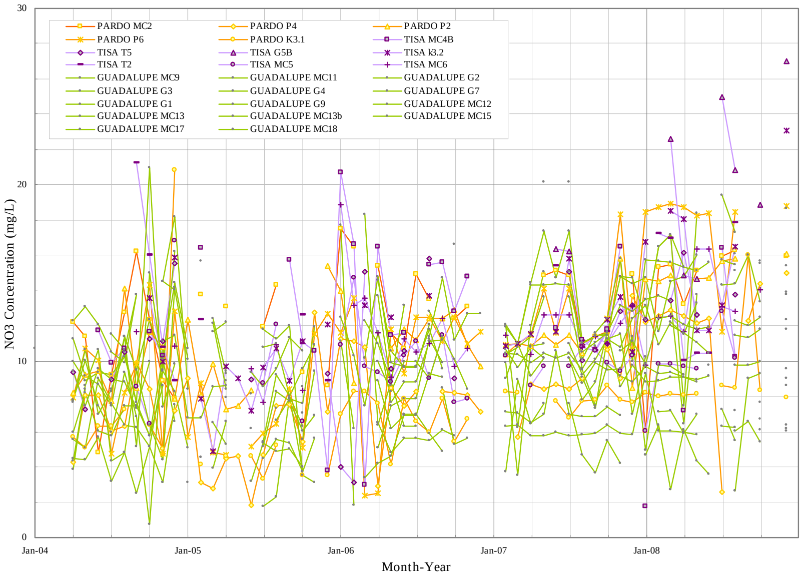
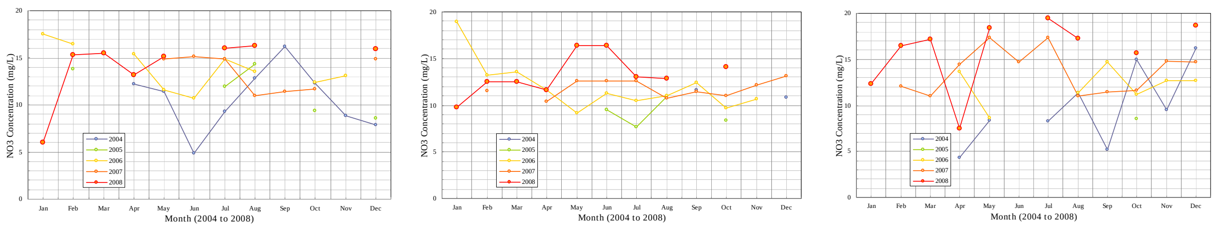


Figure B.II-43 Monthly NO_3 of Wells in MCWD 3 Well Fields (Jan-2004 to Dec-2008)

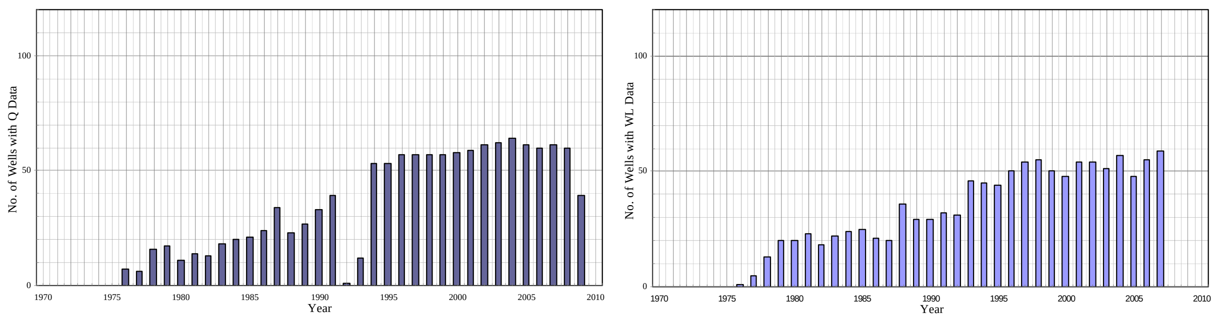


MC-02 (Jan-2004 to Dec-2008) MC-06 (Jan-2004 to Dec-2008) G-03 (Jan-2004 to Dec-2008)

Figure B.II-44 Seasonal Variation of NO_3

II-4.5 Groundwater Abstraction and Water Level

MCWD abstraction record is available, while non-MCWD abstraction has been not researched. Historical graphs of pumping rate and water level are shown in Figure B.II-45.



Intake Record (lost during February-1992 and April-1993) Water Level Record (no classification of SWL and PWL)

Figure B.II-45 Historical Graph of MCWD Wells

(1) Intake Record

MCWD wells with intake record can be classified into following groups.

• Surface Water:	(a) Tisa WTP	Buhisan Dam	
		River-bed Water (Jaclupan)	15 wells
• Groundwater:	(b) Own Wells	Confined Groundwater (10 well fields)	97 wells
		Un-confined Groundwater (Mananga)	4 wells
	(c) Bulk Water	Confined Groundwater:	Cebu Island
		De-salination Plant:	Mactan Island

Among these water sources, monthly average intake amount (indicated as daily intake amount) of MCWD wells excluding Jaclupan well field is shown in Figure B.II-46. Presently, MCWD has promoted to construct wells instead of old wells (aggravated quality and/ or small yield). Intake amount in well field is subjected to well number and yield capacity. However, first priority of well site selection has been given to low pressure zones for supplemental water supply.

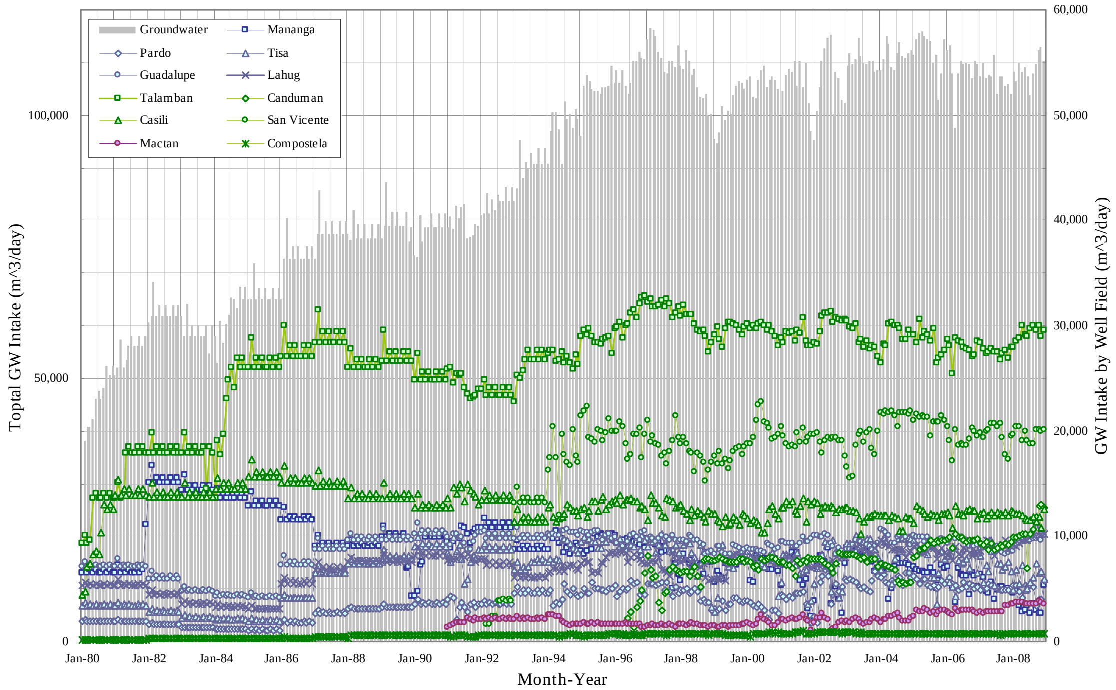
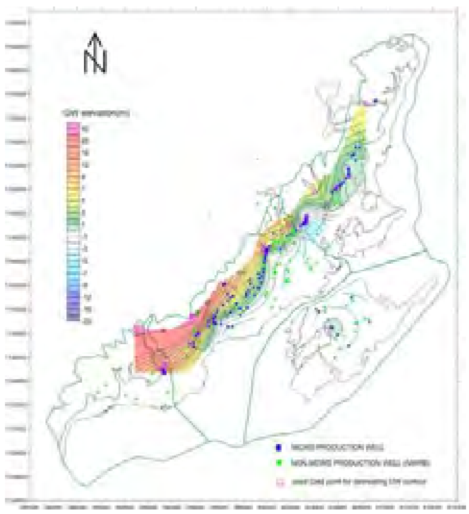


Figure B.II-46 Transitional Graph of Intake Amount at Well Field (Jan-1980 to Dec-2008)

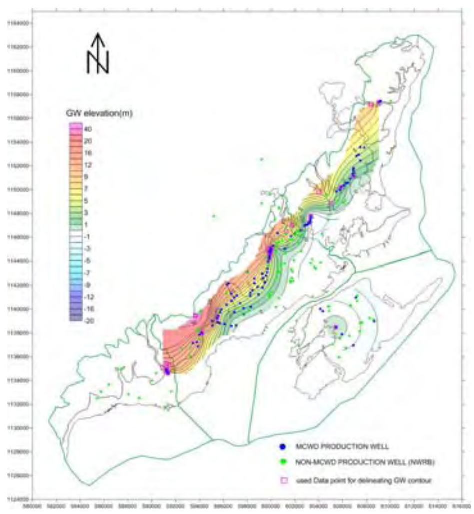
(2) Groundwater Level

Using sounding records of water level in MCWD wells, Figure B.II-47 shows groundwater level contour maps with assumptions below.

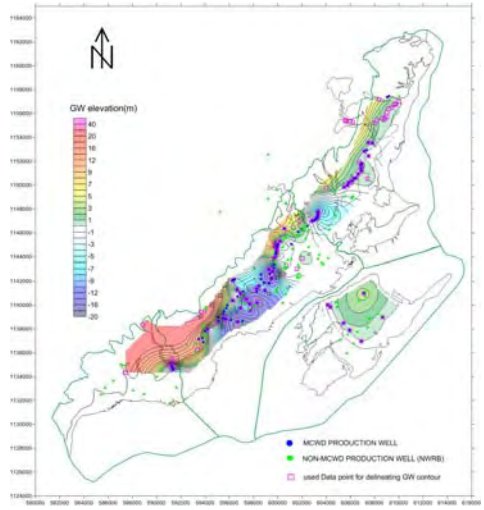
- Pitot point in well is located at the middle of well screen top and bottom.
- Water head exists at pitot depth of intake well.



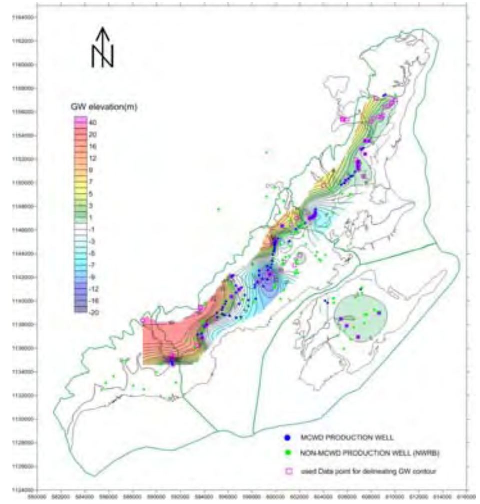
April 1980 (dry season)



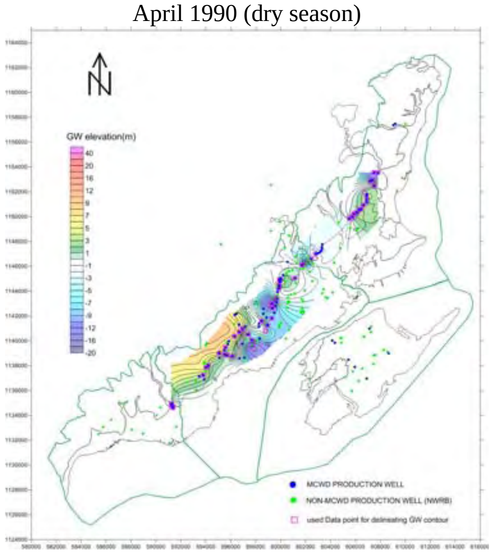
October 1980 (wet season)



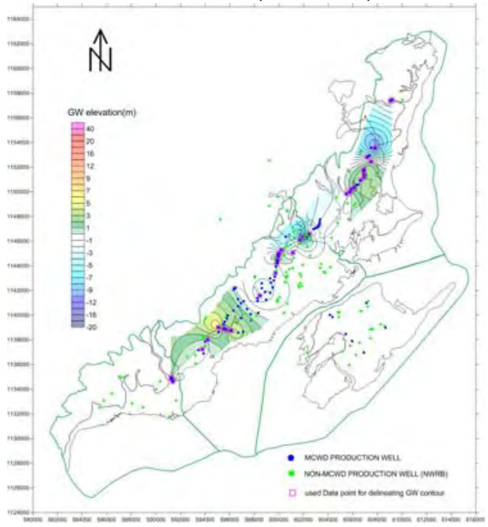
April 1990 (dry season)



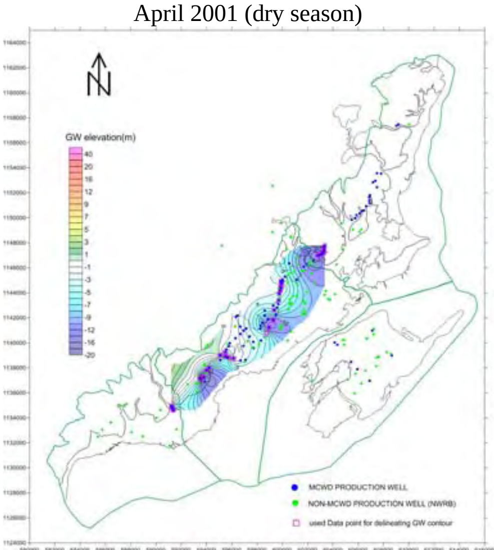
October 1990 (wet season)



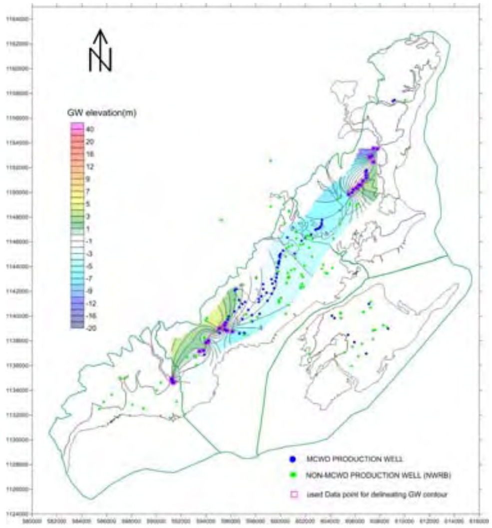
April 2001 (dry season)



October 2000 (wet season)



April 2005 (dry season)



November 2005 (wet season)

Figure B.II-47 Groundwater Level Contour Maps (Left side: dry season and Right side: Wet season)

II-4.6 Other Information

Following data and information were referred for building of the Cebu-GWM-09.

- Water Permits: NWRB (water rights database)
- Groundwater Regulation: NWRB (water policy)
- Built-up Area: Study Team (satellite image)
- Pipeline Area: MCWD (pipeline network)
- Administrative Population: NSO (population census)

(1) Water Permits

Registration system of water permit has been operated by NWRB. Water source potential was evaluated by following criteria without potential study.

- Domestic: 0.0029 lps; planned population served (capita)
- Commercial: based on the clearance for processing water permit to be issued by the WD
- Industrial: based on the clearance for processing water permit to be issued by the DENR
- Irrigation: 1.5 lps; planned rice field area (ha.), other crops/plants have different projections
- Livestock: 0.00024 lps; planned animal head of cattle and swine
- Recreation: 0.6 lps; planned area (ha); golf course
- Fisheries: 0.9259 lps; planned pond area (ha) of other than prawns, 3.15 and 6.30 lps per ha. for prawns in freshwater and brackish water
- Power: based on the clearance for processing water permit to be issued by the NPC

(2) Groundwater Regulation

On the 15th day November 2006, NWRB together with DENR/ NEDA/ DOF/ DOJ/ DOH/ NHRC-UP had issued the regulation of groundwater development in the critical areas namely: Consolacion, Lilo-an, Mactan, Cebu and Mandaue. This regulation was made according the study results of "Water Resources Assessment for Prioritized Critical Areas (NWRB Groundwater Modeling)" and "Water Resources Integrated Developments (Water REMIND)". In this regulation, criteria in following Table B.II-23 were adopted.

Table B.II-23 Water Policy in Metropolitan Cebu

<table>
<tr><td rowspan="4">Critical Area (5 LGUs)</td><td rowspan="2">With Existing Permits</td><td>Adequate Water Supply Service</td><td>Users shall reduce the extraction volume to keep Cl concentration below 210 mg/L.</td></tr>
<tr><td>In-adequate Water Supply Service</td><td>Well shall be closed and plugged when Cl concentration exceeds 250 mg/L.</td></tr>
<tr><td rowspan="2">New/ Pending Permit</td><td>Adequate Water Supply Service</td><td>Only back-up users of Hospital can be processed.</td></tr>
<tr><td>In-adequate Water Supply Service</td><td>Applications may be processed until commercial connection becomes available.</td></tr>
<tr><td rowspan="4">None Critical Area (2 LGUs)</td><td rowspan="2">With Existing Permits</td><td>Adequate Water Supply Service</td><td>Existing permit shall be revoked when trend of Cl concentration indicates increasing.</td></tr>
<tr><td>In-adequate Water Supply Service</td><td>Applications may be processed but permit shall be revoked when Cl exceeds 250 mg/L.</td></tr>
<tr><td rowspan="2">New/ Pending Permit</td><td>Adequate Water Supply Service</td><td>Only back-up users of Hospital can be processed.</td></tr>
<tr><td>In-adequate Water Supply Service</td><td>Applications may be processed until commercial connection becomes available.</td></tr>
</table>

Note: Cordova is not included in the regulatory operation area.

Additionally, following conditions are included into the regulatory operation.

- De-salination of brackish water and sea water for domestic use may be processed.
- Water re-use and re-cycle shall be promoted as a groundwater conservation measure.

NWRB has examined the said reports and monitoring results of groundwater in Metropolitan Cebu uninterruptedly. Guideline for groundwater regulation (No.004-0507) was established and added to the resolution No.002-1106 on the 16th day of May 2007. Features of this guideline are summarized below.

- Critical area was restricted by topographical conditions (below 70 masl).
- Applicants of water permit shall report the groundwater quality with parameters of Cl and NO_3.
- Reduction rate of groundwater abstraction was mentioned clearly according to the said report.
- MCWD shall inform NWRB his service area using map for correspondence to new applicants.

(3) Built-up Area

LGUs in the groundwater study area have land-use and vegetation maps. However, these maps have following in-accuracies.

- No survey and no scale
- No map date
- No indication of base sources

Following satellite images were used to estimate undulation values relating on water balancing items for building of groundwater model. E-files of satellite images were installed in the semi-workstation computer.

- AVNIR-2: 31-March-2007
- SPOT-2: 12-March-1992

Based on these satellite images, built-up districts were classified. Table B.II-24 indicates area information of built-up districts. Features of built-up area growth rate are;

- Limestone area has high growth rate more than 20% between 1992 and 2007
- Cebu and Mananga Limestone area indicates its growth rates of 163% and 60%, respectively.
- Alluvial area was saturated with built-up in 1992 excluding Mactan Island.

Table B.II-24 Built-up Area Analysis using Satellite Image

Domain	WRMUs	Area		Image in 1992				Image in 2007			
				Limestone		Alluvial		Limestone		Alluvial	
		L	Qal	area	coverage	area	coverage	area	coverage	area	coverage
North	Compostela	23.1	7.8	3.1	13	6.7	86	3.8	16	6.8	87
	Kot-kot	4.9	3.6	1.6	33	3.2	89	2.1	42	3.3	90
	Lilo-an	9.8	11.5	8.4	86	10.3	90	9.0	91	10.9	95
	Cansaga	24.4	12.3	5.9	24	10.2	83	7.5	31	10.9	89
	Sub-total	62.2	35.3	19.0	31	30.4	86	22.3	36	31.9	91
Central	Butuanon	6.3	20.6	3.5	56	18.4	89	5.0	79	20.4	99
	Cebu	31.2	37.3	12.1	39	37.3	100	19.3	62	37.3	100
	Sub-total	37.5	57.9	15.6	42	55.7	96	24.3	65	57.7	100
South	Mananga	6.2	5.5	0.8	14	3.8	69	2.1	34	4.4	79
	M-Talisay	27.4	13.1	9.5	35	12.4	94	11.4	42	12.7	97
	Sub-total	33.5	18.7	10.4	31	16.2	87	13.5	40	17.1	92
Mactan	Mactan	50.3	6.7	41.8	83	3.7	55	45.3	90	3.7	55
	Sub-total	50.3	6.7	41.8	83	3.7	55	45.3	90	3.7	55
Entire Domain		183.6	118.5	86.8	47	105.9	89	105.4	57	110.4	93

Note: Area unit is km^2, coverage is %.

(4) Pipeline Area

Return flow (waste water drainage and leakage from pipeline) is large factor of water balance. Drainage amount from domestic use will be subjected depending on service ability and household economy. Generally, this drainage recharge of return flow will be in proportion to population.

Leakage amount from water supply pipeline has been studied by MCWD using MDA (Metered District Area) data. MCWD water supply area is shown in Figure B.II-48.

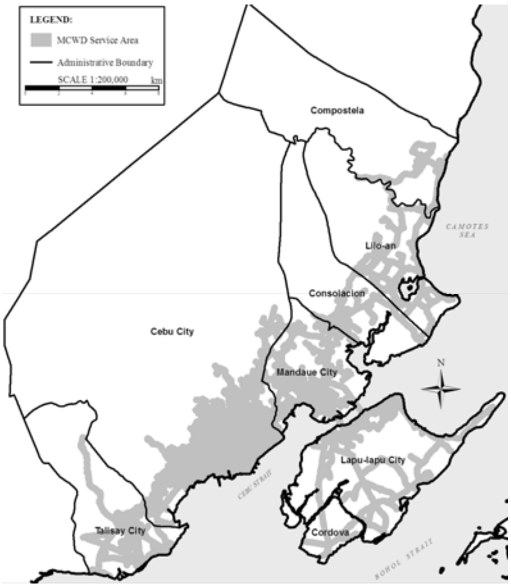


Figure B.II-48 MCWD Water Supply Service Area (Dec-2008)

There are many water supply providers in the Metropolitan Cebu, other than MCWD. Stake-holders of WATSAN sector shall prepare the monitoring system of following PIs (performance indicators) for maintaining of public service level and sector monitoring as basic information of planning.

- Service: No. of HHs, Population, Area
- Supply: Intake Amount (location, well structures, pumping rate), NRW, Supply Amount

(5) Administrative Population

Table B.II-25 shows the population transition of Metro Cebu in the past 12 years based on the NSO census data. The population of Metro Cebu has increased from 1.30 million in 1995 to 1.85 million in 2007, which gives an average annual growth rate of 3.0%.

Table B.II-25 Population and Its Growth Rate in Past 12 Years

LGUs	Census Record			Average Annual Growth Rate (%)		
	1-Sep-95	1-May-00	1-Aug-07	1995-2000	2000-2007	1995-2007
Cebu City	662,299	718,821	798,809	1.77	1.46	1.58
Lapu-lapu City	173,744	217,019	292,530	4.88	4.20	4.47
Mandaue City	194,745	259,728	318,575	6.36	2.86	4.22
Compostela	26,499	31,446	39,167	3.73	3.07	3.33
Consolacion	49,205	62,298	87,544	5.18	4.80	4.95
Cordova	26,613	34,032	45,066	5.41	3.95	4.52
Lilo-an	50,973	64,970	92,181	5.33	4.94	5.10
Talisay City	120,292	148,110	179,359	4.56	2.67	3.41
Total	1,304,370	1,536,424	1,853,231	3.57	2.62	2.99

Source: NSO census

However, the annual growth rate from 2000 to 2007 has decreased compared to that from 1995 to 2000 in all cities and municipalities. This implies that the population growth has certain saturation due to the limited habitable space.

The Water Remind Project assumes the population growth rate during 2005-2030 to be 1.6-3.2% depending on the cities and municipalities considering that the growth in the dense areas will decline (saturated growth), while in the less dense areas the growth rates will be fairly constant.

Regarding Cebu City and Talisay City, however, the assumed growth rates are considered as overestimated because these rates exceed the actual growth rates during 2000-2007.

Therefore, the actual growth rate during 200-2007 is adopted in the population projection for Cebu City and Talisay City, while assumptions in the Water Remind Project have been employed for other cities and municipalities. Thus, the future population is projected as presented in Table B.II-26.

Table B.I-26 Population Projection

LGUs		2007	2010	2015	2020	2025	2030	Assumed Growth Rate
Cebu City		798,809	834,300	897,000	964,400	1,036,900	1,114,900	1.46%
Lapu-lapu City		292,530	321,100	375,200	438,300	512,100	598,300	3.16%
Mandaue City		318,600	344,300	391,800	445,900	507,400	577,500	2.62%
Compostela		39,167	42,500	48,700	55,900	64,000	73,400	2.77%
Consolacion		87,544	91,800	99,500	107,700	116,700	126,400	1.61%
Cordova		45,066	47,600	52,000	56,900	62,200	68,100	1.81%
Lilo-an		92,200	98,900	111,100	124,800	140,300	157,600	2.36%
Talisay City		179,359	194,100	221,400	252,600	288,200	328,800	2.67%
Total	JICA	1,853,231	1,974,600	2,196,800	2,446,700	2,728,000	3,045,000	2.19%
	Water Remind	-	2,039,693	2,341,679	2,645,917	2,928.839	3,201,665	2.28%

The population in Metro Cebu will increase from 1.8 million in 2007 to 2.2 million in 2015, and to 3.0 million in 2030. Cebu City will be the most populated area, followed by the cities of Lapu-lapu and Mandaue.

Figure B.II-49 shows population growth of the study area in past and projection visually including the said projection result of the Water Remind Project.

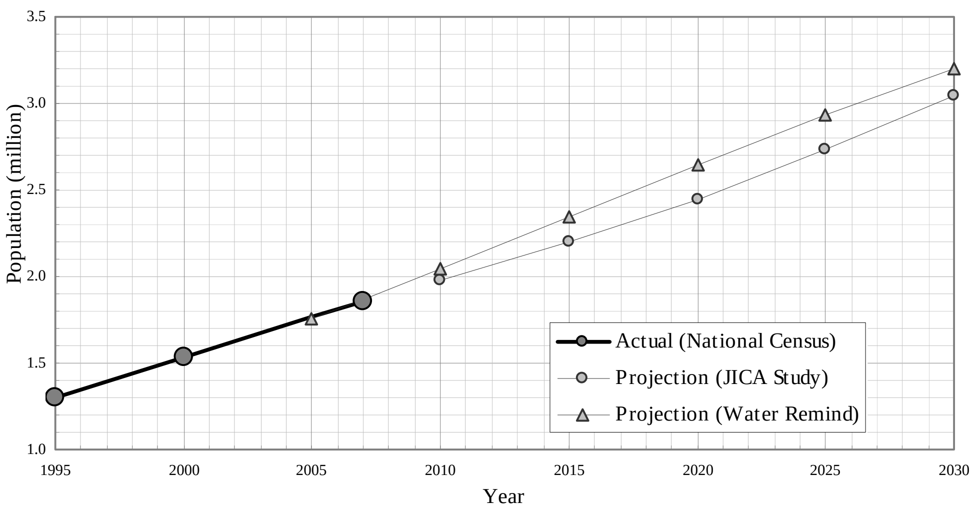


Figure B.II-49 Population Projection

II-5 Modeling Works

The Cebu-GWM-09 was built according to following order.

II-5.1 Simulation Code

SEAWAT version 4 (USGS, 2008) was used for simulation of calibration and prediction in this study. This code is modified version of the original SEAWAT code to simulate groundwater flow and saltwater intrusion in saturated aquifer based on FDM.

II-5.2 Temporal Discretization

Following temporal discretization was adopted (see Figure B.II-50). Periods on terms of model calibration and prediction were given almost the same time scale of 25 years and 26 years.

- Initialization Term: Jan-980 to Dec-1979 (1,000 years) with constant stress, to represent a state of dynamic equilibrium and to obtain initial groundwater conditions in terms of hydraulic head and chloride concentration for calibration term
- Calibration Term: Jan-1980 to Dec-2004 (25 years) with transient stress, to calibrate model with calculated data being approximation to observed data
- Prediction Term: Jan-2005 to Dec-2030 (26 years) with transient stress, to estimate groundwater potential for the plans of development and conservation

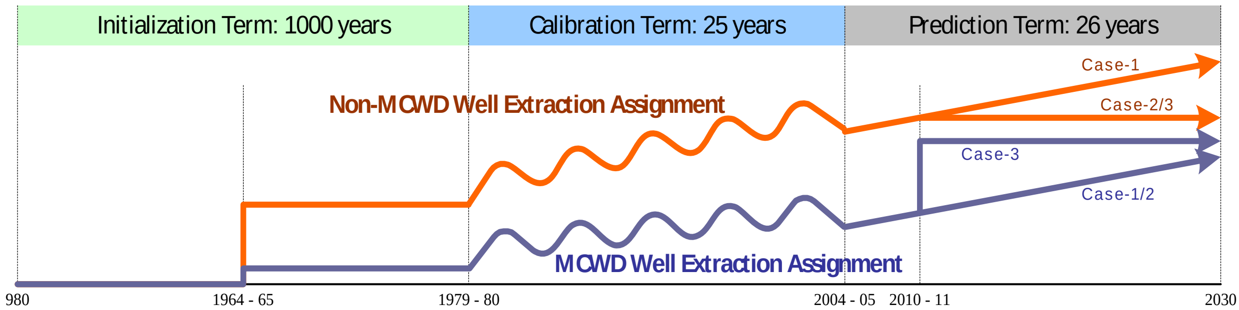


Figure B.II-50 Temporal Discretization adopted for Modeling Work

II-5.3 Boundary Conditions

Boundary conditions as shown in Table B.II-27, and Figures B.II-51 and B.II-52 were adopted to build Cebu-GWM-09, which were designed in terms of chloride concentration and groundwater head. Tidal condition was not applied for modeling works because target aquifer is Limestone formation. Features of boundary condition in sub-regional models are;

- Flank sides at 3-districts in Cebu Island and Cebu Island side at Mactan District are set up as “Wall-off” condition, and
- Mactan side at Central District is set up as “General Head” condition with due consideration of representation of seawater intrusion from Cebu Strait.

Most careful study item for boundary setting was located between the districts of Central and Mactan along the Cebu Strait. In the regional model, groundwater flow direction below the Cebu Strait was simulated as bumping each other from both sides of Cebu and Mactan Islands, and flowing out on the ocean floor (spring).

In the Mactan district, seawater inflow from the Cebu Strait was estimated at very minimal and most of seawater inflow was intruded from other sides. On the other hand, saltwater intrusion can not be simulated when wall-off was supposed to put below the Cebu Strait within the Central district.

Table B.II-27 Boundary Conditions for Cebu-GWM-09

District with Contact Face			Boundary Conditions: Cl Concentration	Boundary Conditions: Flow (Head)
Northern	inland side	face to volcanic rocks	20 mg/L	wall-off (equilibrium)
	top side	ground surface		transient stress
	flank side	face to adjoin WRMUs	Not Applicable	wall-off
	bottom side	200 mbsl		
	ocean floor	face to ocean under the sea level	19,000 mg/L	Constant: h=0 m
	coastal side	face to other WRMUs under the sea level		
Central	inland side	face to volcanic rocks	20 mg/L	wall-off (equilibrium)
	top side	ground surface		transient stress
	flank side	face to adjoin WRMUs	Not Applicable	wall-off
	bottom side	200 mbsl		
	Mactan side	along the Cebu Strait under the sea level	19,000 mg/L	General: h=0 m
	ocean floor	face to ocean under the sea level		Constant: h=0 m
	coastal side	face to other WRMUs under the sea level		
Southern	inland side	face to volcanic rocks	20 mg/L	wall-off (equilibrium)
	top side	ground surface		transient stress
	flank side	face to adjoin WRMUs	Not Applicable	wall-off
	bottom side	200 mbsl		
	ocean floor	face to ocean under the sea level	19,000 mg/L	Constant: h=0 m
	coastal side	face to other WRMUs under the sea level		
Mactan	Cebu Island side	along the Cebu Strait under the sea level	Not Applicable	wall-off
	flank side	face to adjoin WRMUs		
	bottom side	200 mbsl		
	top side	ground surface	20 mg/L	transient stress
	ocean floor	face to ocean under the sea level	19,000 mg/L	Constant: h=0 m
	coastal side	face to other WRMUs under the sea level		

Note: "Inflow and Outflow" was applied by Water REMIND Project and MCWD record including dummy abstraction.

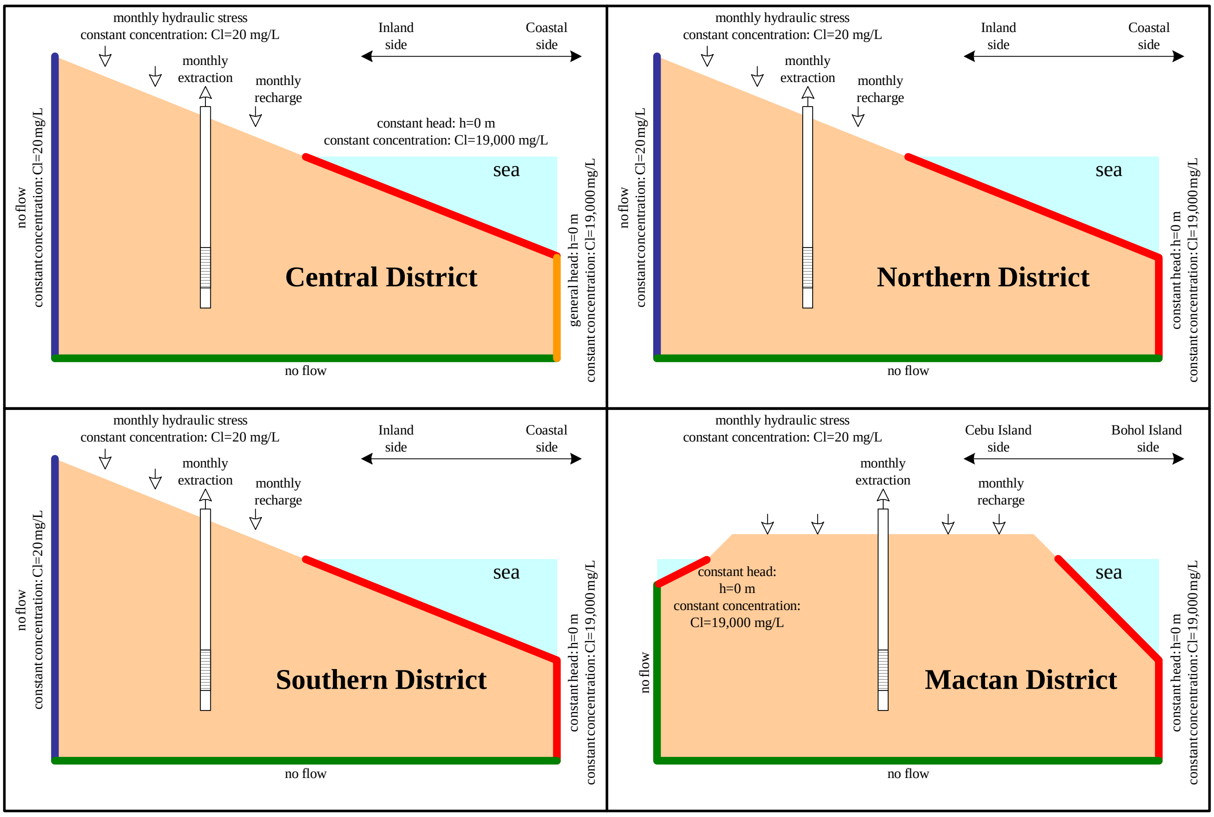


Figure B.II-51 Cross Section Map of Boundary Conditions

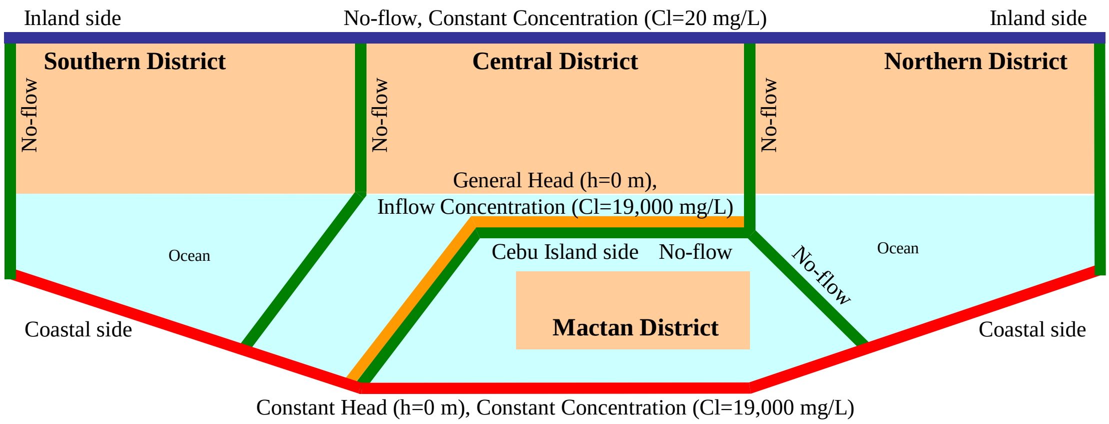


Figure B.II-52 Plane Section Map of Boundary Conditions

II-5.4 Input Assigned Parameters

Following are process to assume assigned parameters and its values for Cebu-GWM-09.

(1) Fluid Densities

Groundwater receives fresh water recharge from precipitation, return flow, lateral flow, aquifer leakage (through well screens), etc. and salinity water intrusion from seawater, brackish lakes/ sinkholes, etc. Fresh water has high TDS (total dissolved solid) values due to rich limestone aquifer. On the other hand, salinity water fluctuates according to diluted solutions and evaporation. Variable fluid densities exist in the natural environments. However, there is no investigation report to date. Assignments with fluid densities were adopted for modeling works showing below.

- Seawater: Cl concentration of 19,000 mg/L (density of 1.025 g/cm^3 by seawater)
- Freshwater: Cl concentration of 20 mg/L (density of 1.000 g/cm^3 by wind transfer salt)

(2) Aquifer Properties

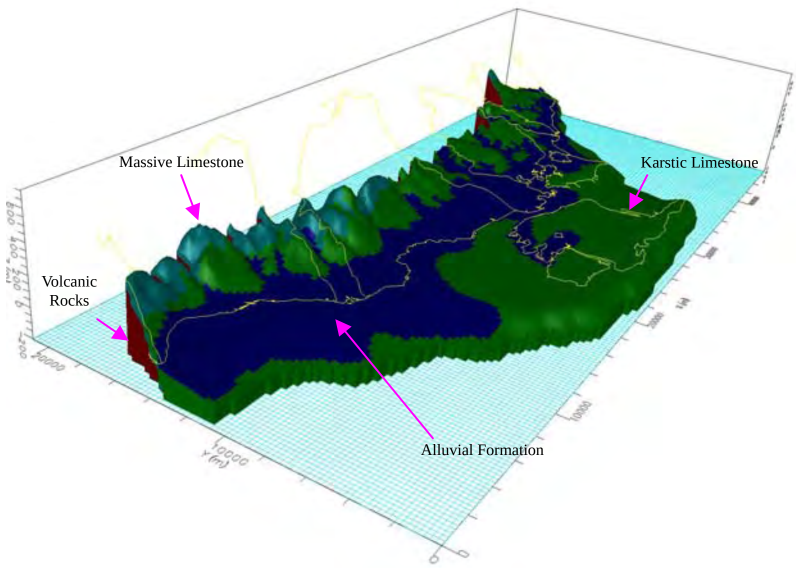
Zonings of Cebu-GWM-09 with assigned properties are referred to Figure B.II-53 and Table B.II-29 using hydrogeological investigation results, field survey results, pumping test results and model calibration results in terms of analyzed chloride concentration and hydraulic head.

As the results of this study for zoning properties in Cebu-GWM-09, following features are itemized. There might be other considerations to the zoning works. However, the JTFT adopted only significant items which could be justified as hydrogeological background.

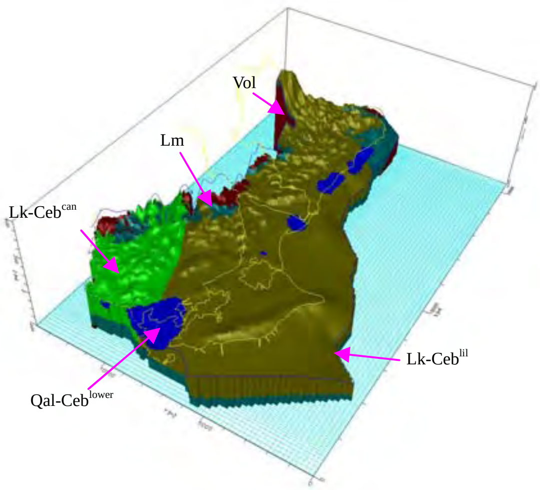
- Karstic Limestone (incl. massive): (1) Fault lines located along the west side of Butuanon and Mactan WRMUs were assumed to assign values.
  (2) Seven portions of karstic limestone and solo massive limestone were assigned according to the calibration.
- Alluvial (incl. Fluvial): (3) Seven portions of alluvial and solo fluvial were assigned as infiltrating and/ or confining layers.

Other parameters of aquifer property are assumed by following manners. Extent of saltwater intrusion was not influenced significantly by dispersivity values. In this regard, it was merely assumed at the middle-index value. However, value and distribution of dispersivity coefficient in Cebu-GWM-09 shall be examined when NO_3 contamination study is required.

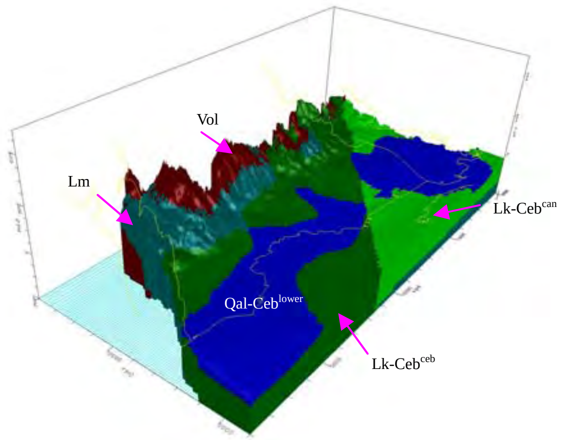
- Effective Porosity: It was assumed at the same values of 0.05 to 0.3 with S_Y in Table B.II-28
- Dispersivity: $\alpha_L = 10$m, $\alpha_T/\alpha_L = 0.1$, $\alpha_V/\alpha_L = 0.01$



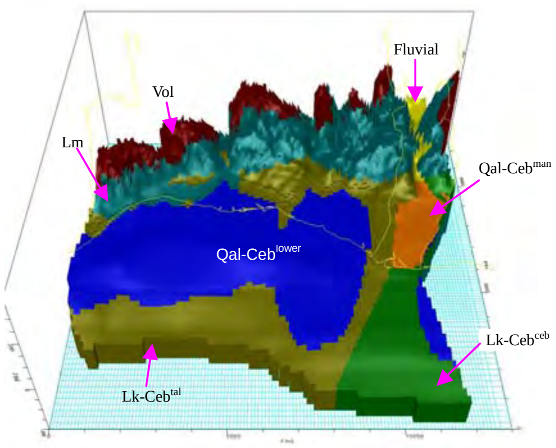
Regional Model
9-WRMUs



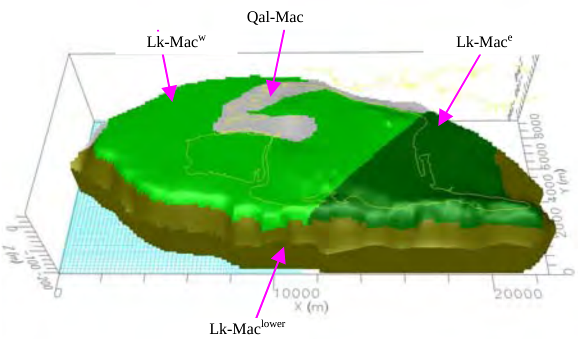
Sub-regional Model: Northern District
WRMUs: Compostela/ Kot-kot/ Lilo-an/ Cansaga



Sub-regional Model: Central District
WRMUs: Butuanon/ Cebu



Sub-regional Model: Southern District
WRMUs: Mananga/ Minglanilla-Talisay



Sub-regional Model: Mactan District
WRMUs: Mactan

Figure B.II-53 Zoning Map of Aquifer Properties

Table B.II-28 Assigned Aquifer Properties

Zoning Units				Aquifer Properties			
Hydrogeology		Code and Location		k_H (cm/sec)	S_S (m^{-1})	S_Y (-)	Remarks
Alluvial Formation		Fluvial	Southern: Mananga upstream	1 E 0	1 E-3	2 E-1	• Initial estimate value of k_H was applied at 1E-1 cm/sec based on aquifer test data. • Storage test data not available. • Ratio k_V/k_H was assumed at 0.1 excluding isometric Qal-Ceb ^{lower} and Qal-Mac.
		Qal-Ceb ^{kot}	Northern: Kot-kot	1 E-1			
		Qal-Ceb ^{com}	Northern: w/o Kot-kot	1 E-3			
		Qal-Ceb ^{ceb}	Central:	1 E-1			
		Qal-Ceb ^{man}	Southern: Mananga downstream	5 E-1			
		Qal-Ceb ^{tal}	Southern: Minglanilla-Talisay	1 E-3			
		Qal-Ceb ^{lower}	Cebu 3-districts: below 20 mbsl	1 E-4	1 E-4	1 E-1	
		Qal-Mac	Mactan:				
Limestone Formation	Karstic	Lk-Ceb ^{lil}	Northern: w/o West-Cansaga	1 E-1	4 E-3	5 E-2	• Initial estimate values of k_H, S_S, S_Y were used based on aquifer test data. • Ratio k_V/k_H was assumed at 0.1.
		Lk-Ceb ^{can}	Central: East-Cansaga	5 E-2		1 E-1	
		Lk-Ceb ^{ceb}	Central: West-Mananga	2 E-2			
		Lk-Ceb ^{tal}	Southern: Minglanilla-Talisay	5 E-3			
		Lk-Mac ^{e}	Mactan: East	2 E-1		3 E-1	
		Lk-Mac ^{w}	Mactan: West	1 E 0			
		Lk-Mac ^{lower}	Mactan: below 30 mbsl	5 E-3		2 E-1	
	Massive	Lm	Overall	1 E-3		1 E-1	• No test data available. • Ratio k_V/k_H was assumed at 0.1.
Volcanic and Others		Vol	Bedrock	5 E-5	1 E-3		• No test data available. • Ratio k_V/k_H was assumed at 1.

Note: S_Y was used only in Mactan District because of no-conversion of storage coefficient between confined and unconfined to avoid numerical instability and to save simulation time. S_S was always used for storage coefficient within entire simulation of 3-districts in Cebu Island.

II-5.5 Input Hydrologic Stress

Monthly hydrologic stresses were studied by Water REMIND Project in 2006. The gross stresses obtaining from the said project was applied and given to Cebu-GWM-09 transiently. Following examination works were done before the model calibration.

- Allocation method to distribute the gross hydrologic stresses of Water REMIND Project into Cebu-GWM-09, and
- Appling method to undulate the gross hydrologic stresses within Cebu-GWM-09 domains.

(1) Input Parameters

Different points of model domain between Water REMIND Project and JICA study are shown in Table B.II-29.

Table B.II-29 Comparison of Model Domains in Water REMIND Project and JICA Study

Model	Area		Domain	
	Boundary	No.	Boundary	No.
Tank Model	WRMUs*	21	Altitude: Coastal (below 100 masl), Upland	2
Numerical Model		9	Geology: Alluvial, Limestone (Volcanic*)	2

Note: WRMUs means that “Water Resources Management Units”. Volcanic is recognized as passing zone.

In the Water REMIND Project, following parameters of water balance were studied with period from Jan-1980 until Dec-2004 (25 years: 300 months) as shown in Figure B.II-54.

- Direct Recharge: (A) infiltration recharge from the ground surface by mainly precipitation
- Indirect Recharge: (B) groundwater recharge from up-stream within WRMUs etc.
- Lateral Flow: (C) groundwater inflow from or (C’) outflow to adjoin WRMUs,
- Abstraction: (D) transport flow gap from and to groundwater (spring=0)
- Return Flow: (E) return flow to groundwater such as waste water, pipeline leakage, etc.

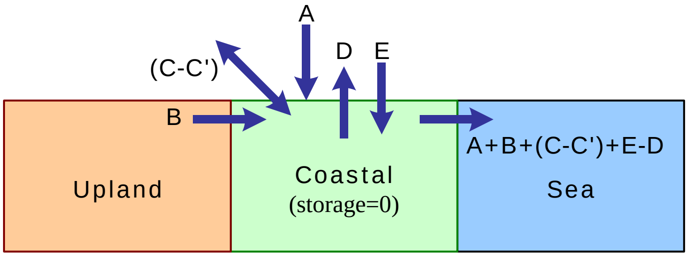


Figure B.II-54 Parameters of Water Balance with Input Allocation in Water REMIND

(2) Allocation of Hydrologic Stress

Figure B.II-55 shows model domain in JICA study.

Figure B.I-55 Model Domain in JICA Study

The gross hydrologic stresses shall be maintained and allocated with following concepts.

- Direct Recharge: (A) is allocated to Limestone (β) and Alluvial (γ) by area ratio,
- Indirect Recharge: (B) is given to Limestone (β),
- Lateral Flow: (C-C') is given to Limestone (β) as additional recharge,
- Abstraction: (D) - MCWD is given to Alluvial (γ), MCWD is actual record, and
- Return Flow: (E) is given to areas with built-up and water supply service.

Accordingly, the gross hydrologic stresses were allocated using following conversion formulas as shown in Table B.II-30.

Table B.II-30 Allocation Formulas of the Gross Hydrologic Stress

Sub-regional Domains		Recharge	Lateral Flow	Abstraction	Return Flow
Northern, Central and Southern	Limestone	(A+B)×(α+β)/ Σ*	C-C'	MCWD	-
	Alluvial	(A+B)×γ/ Σ*	-	D-MCWD	E
Mactan	Limestone	A+B	0*	D	E
	Alluvial	-	-	-	-
Gross Hydraulic Stresses within Regional Domain		A+B	C-C'	D	E

Note: Σ*＝α＋β＋γ (no α: volcanic area in Mactan District). Lateral flow in Mactan District was assumed at 0.

(3) Undulation of Hydrologic Stress

Hydraulic stresses were considered to be undulated according to following four conditions.

- Natural Recharge: (A+B)
- Lateral Flow: (C-C')
- Abstraction: (D)
- Return Flow: (E)

< Natural Recharge: (A+B) >

Natural recharge depends on following major factors.

✓ Meteorology: Precipitation, Evaporation = f(x); humidity/ wind velocity/ temperature
✓ Ground Surface: Vegetation, Infiltration, Paving, Rainwater Drainage System, etc.

Land use in the model domain is occupied mainly business and residential buildings. Therefore, undulation of natural recharge is not reflected by vegetation information. In this study, infiltration capacity test was conducted in alluvial area. Following features were observed but the test results of infiltration capacity were not considered significantly as the undulation factor.

✓ Non-infiltration points because such land was improved by land development,
✓ Depreciation of infiltration capacity depending on water level in coastal area, and
✓ Higher infiltration capacity along the river bed deposits.

Most of roads down to Barangay control in the study area are paved either by non-filterable concrete or asphalt. On the other hand, drainage system of rainwater is quite limited in its coverage area. In this regard, following undulation of natural recharge was considered within the same gross stresses in WRMUs.

✓ Undulation Rate: Built-up Area: Non Built-up Area = 9:10
✓ Cebu Island: Limestone Area: Uniformity, Alluvial Area: Undulation
✓ Mactan Island: Limestone Area: Undulation, Alluvial Area: Uniformity

As shown in Table B.II-31, alluvial area in Cebu Island is almost saturated by the built-up classification (91% in 1992 and 95% in 2007), while limestone hilly area is under development of residential housing for mid-high income stratums according to visual analysis of the satellite images in the study area. Limestone flat area in Mactan Island has the same trend of built-up classification with alluvial area in Cebu Island.

Table B.II-31 Built-up Area Information Analyzed by the Satellite Images

Cebu-GWM-09		Area		Satellite Image in 1992				Satellite Image in 2007			
District	WRMUs	Limestone	Alluvial	Limestone		Alluvial		Limestone		Alluvial	
				Area	%	Area	%	Area	%	Area	%
Northern	Compostela	23.1	7.8	3.1	13	6.7	86	3.8	16	6.8	87
	Kot-kot	4.9	3.6	1.6	33	3.2	89	2.1	42	3.3	90
	Lilo-an	9.8	11.5	8.4	86	10.3	90	9.0	91	10.9	95
	Cansaga	24.4	12.3	5.9	24	10.2	83	7.5	31	10.9	89
	Sub-total	62.2	35.3	19.0	31	30.4	86	22.3	36	31.9	91
Central	Butuanon	6.3	20.6	3.5	56	18.4	89	5.0	79	20.4	99
	Cebu	31.2	37.3	12.1	39	37.3	100	19.3	62	37.3	100
	Sub-total	37.5	57.9	15.6	42	55.7	96	24.3	65	57.7	100
Southern	Mananga	6.2	5.5	0.8	14	3.8	69	2.1	34	4.4	79
	M-Talisay	27.4	13.1	9.5	35	12.4	94	11.4	42	12.7	97
	Sub-total	33.5	18.7	10.4	31	16.2	87	13.5	40	17.1	92
Cebu Island		133.2	111.9	45.0	34	102.3	91	60.1	45	106.7	95
Mactan	Mactan	50.3	6.7	41.8	83	3.7	55	45.3	90	3.7	55
	Sub-total	50.3	6.7	41.8	83	3.7	55	45.3	90	3.7	55
Regional Domain		183.6	118.5	86.8	47	105.9	89	105.4	57	110.4	93

Note: Data source is prepared by JICA study team. Unit of area is km^2, while % means its occupation rate.

In this situation of built-up area classification, the constant rate of built-up area in 1992 was applied to model during entire calibration term of 25 years (Jan-1980 until Dec-2004: 300 months).

Appling the occupation rates with yellow cells in Table B.II-31, the natural recharge rates in built-up and non-built-up areas are indicated in Table B.II-32 with due consideration of undulation rate 90%.

Table B.II-32 Rate of Natural Recharge assumed by Satellite Image in 1992

Model District	WRMUs	Rate in Built-up Area		Rate in Non-built-up Area	
		Area A	Natural Recharge X	Area B	Natural Recharge Y
Northern	Compostela	86%	98.4%	14%	109.4%
	Kot-kot	89%	98.8%	11%	109.7%
	Lilo-an	90%	98.9%	10%	109.8%
	Cansaga	83%	98.1%	17%	109.0%
Central	Butuanon	89%	98.8%	11%	109.8%
	Cebu	100%	100.0%	0%	111.1%
Southern	Mananga	69%	96.7%	31%	107.4%
	M-Talisay	94%	99.4%	6%	110.4%
Mactan	Mactan	83%	98.2%	17%	109.1%

Note: Estimation criteria are X/Y=90% and AX+BY=100%.

In-direct recharge rate to the fluvial deposits from up-stream volcanic rocks via surface water run-off was applied as the same situation of limestone area at following sites.

- ✓ Northern District: Compostela River, Kot-kot River and Cansaga River
- ✓ Central District: Butuanon River
- ✓ Southern District: Mananga River

In-direct recharge rate to the limestone area from up-stream volcanic rocks via surface water run-off was applied as following assumptions.

- ✓ Limestone Outcrops: In-direct recharge was not considered in Lilo-an WRMU because it is independence from any other WRMUs.
- ✓ Massive Limestone: In-direct recharge was converted to Karstic from Massive in Southern district.

< Lateral Flow: (C-C') >

Lateral flows are related to 8-WRMUs being located in Cebu Island, while 1-WRMU in Mactan Island is independent. Volume of lateral flow from the central district to the northern district was estimated at 0.030 m^3/sec within three modeling districts in Cebu Island composing of such 8-WRMUs. Water balance between the model districts and the WRMUs in the Water Remind study (25 years from January 1980 until December 2004) was shown in Table B.II-33.

Table B.II-33 Water Balance in the Water Remind Study (1980 - 2004)

Model Districts and WRMUs		Lateral Flow in WRMUs	Lateral Flow in Districts
Northern District	Compostela	+0.046	+0.030
	Kot-kot	-0.065	
	Lilo-an	+0.149	
	Cansaga	-0.100	
Central District	Butuanon	+0.160	-0.030
	Cebu	-0.190	
Southern District	Mananga	0.000	0.000
	M-Talisay	0.000	
Mactan District	Mactan	0.000	0.000
Model Domain		0.000	0.000

Note: Unit of lateral flow is m^3/sec.

Among the water balance in WRMUs, lateral flows (unit: m^3/sec) in the northern district and the central district are indicated below.

Central District		Northern District			
Cebu	Butuanon	Cansaga	Lilo-an	Kot-kot	Compostela
0.000→-0.190	+0.190→-0.030	+0.030→-0.130	+0.130→←+0.019	-0.019←→-0.046	+0.046→
-0.190	+0.160	-0.100	+0.149	-0.065	+0.046
-0.030		+0.030			

In this relationship of lateral flow, following water balance was adopted in the modeling.

- ✓ Cebu: deduct 0.190 m^3/sec from direct recharge in Limestone and Alluvial
- ✓ Butuanon: add 0.160 m^3/sec to direct recharge in Limestone
- ✓ Cansaga: deduct 0.100 m^3/sec from direct recharge in Limestone and Alluvial
- ✓ Lilo-an: add 0.149 m^3/sec to direct recharge in Northern Limestone
- ✓ Kot-kot: deduct 0.065 m^3/sec from direct recharge in Limestone
- ✓ Compostela: add 0.046 m^3/sec to direct recharge in Southern Limestone

< Abstraction: (D) >

Monthly average abstraction was adapted as hydraulic stress to the model. Wells for abstraction stresses were classified into MCWD and Non-MCWD. Following are assumption criteria to be applied to the stresses of MCWD and Non-MCWD.

✓ MCWD Abstraction Stresses

- Monthly average abstraction from MCWD wells was estimated by the MCWD operation record.
- Stresses from MCWD wells abstraction were pointed within cell in the model using the exact location.
- Even though this study applied the gross water balance obtaining from the Water Remind Project, the application priority was given to MCWD abstraction record when it exceeded gross water balance in some portions.

✓ Non-MCWD Abstraction Stresses

- The difference between MCWD abstraction and the gross water balance was fallen on Non-MCWD stresses.
- Location of Non-MCWD abstraction was allocated to the alluvial area where population is concentrated in Cebu Island, while it was distributed to the limestone area in Mactan Island, respectively.
- There are huge numbers of un-licensed wells, which extract groundwater as preferential rights in the study area. Dummy abstraction stresses were added to the model depending on the calibration result.

< Return Flow: (E) >

This stress was estimated by Water Remind Project as total value in the WRMU composing of human waste water and leakage water from the water supply pipeline. For the model building work, zoning areas were considered to allocate the stresses. Places of high density population and water supply pipeline network are mainly located in the alluvial area of Cebu Island and the limestone area of Mactan Island. In this regard, the return flow was given to such areas basically.

Return flows from the human waste water were estimated by population density and water consumption in each WRMU using Census data of year 2000. Then the differential stresses between return flow from human waste water and the gross water balance were fallen on leakage water from the pipeline network. Table B.II-34 shows the ratios of return flows, which were applied to the model.

Table B.II-34 Ratios of Return Flows from Human Waste and Pipeline Leakage

Model Domain District	WRMU	Pop2000	Return Flow MCM/Y	Consumption Lpcd	Waste MCM/Y	Leakage MCM/Y	Ratio Waste and Leakage
Northern	Compostela	107,325	0.7	15	0.59	0.11	85:15
	Kot-kot	9,641	0.1		0.05	0.05	55:45
	Lilo-an	58,473	0.8		0.32	0.48	40:60
	Cansaga	62,298	1.6		0.34	1.26	20:80
Central	Butuanon	181,809	6.8	70	4.65	2.15	70:30
	Cebu	841,172	22.9		21.49	1.41	95:05
Southern	Mananga	74,055	0.7	15	0.41	0.29	60:40
	M-Talisay	151,023	1.1		0.83	0.27	75:25
Mactan	Mactan	224,261	6.6	35	2.86	3.74	45:55
Total		1,710,057	41.30	-	31.54	9.76	75:25

Note: Population in WRMUs was assumed from LGU population. Unit of MCM/Y means million m^3/year.

In 36 years operation period of MCWD since 1974, there were limited areas of water supply services expansion excluding Cordova municipality in 2003. Therefore, uniform water supply areas in 2008 were applied to the model for giving return flow stresses. Table B.II-35 indicates MCWD water supply areas in 2008.

Table B.II-35 Area Information of MCWD Water Supply in 2008

District with WRMUs		A	L	WRMU	WS	Remarks of WS
Northern	Compostela	7.8	23.1	31.0	5.1	Up to the right bank of Compostela River
	Kot-kot	3.6	4.9	8.5	3.6	Entire Alluvial area
	Lilo-an	11.5	9.8	21.3	11.5	
	Cansaga	12.3	24.4	36.7	12.3	
	Sub-total	35.3	62.2	94.5	32.5	92.3% of Alluvial area
Central	Butuanon	20.6	6.3	26.9	18.7	Exclusive upstream area of Butuanon River
	Cebu	37.3	31.2	68.5	37.3	Whole Alluvial area
	Sub-total	57.9	37.5	95.4	56.1	96.8% of Alluvial area
Southern	Mananga	5.5	6.2	11.7	4.7	Exclusive upstream area of Mananga River
	M-Talisay	13.1	27.4	40.5	1.4	Only Talisay City
	Sub-total	16.7	33.5	52.2	6.1	32.4% of Alluvial area
Mactan	Mactan	6.7	50.3	57.0	20.4	Surrounding of lap-road
	Sub-total	6.7	50.3	57.0	20.4	40.5% of Limestone area
Entire Model Domain		118.5	183.6	302.0	115.0	

Note: "A" means alluvial area, "L" is limestone area and "WS" is water supply service area. Unit of values is km^2.

(4) Design Values of Transient Stresses

Appling the gross water balance from Water Remind with examination results of this study above, monthly transient stresses were designed for the model building. Table B.II-36 shows the basic area information which was applied to the model zoning for applying of hydraulic transient stresses.

Table B.II-36 Area Information relating to the Model Zoning

District	WRMUs	Basic Area: WRMUs (A)	Basic Area: Volcanic (B)	Basic Area: Model Domain (A-B=C+D)	Limestone Area: Non-built-up No water supply (C_1)	Limestone Area: Built-up No water supply (C_2)	Limestone Area: Built-up Water supply (C_3)	Limestone Area: Sub-total ($C=C_1+C_2+C_3$)	Alluvial Area: Non-built-up No water supply (D_1)	Alluvial Area: Built-up No water supply (D_2)	Alluvial Area: Built-up Water supply (D_3)	Alluvial Area: Sub-total ($D=D_1+D_2+D_3$)
Northern	Compostela	39.69	8.73	30.96	23.14	0.00	0.00	23.14	0.00	5.09	2.73	7.82
	Kot-kot	80.53	72.02	8.51	4.87	0.00	0.00	4.87	0.00	0.00	3.64	3.64
	Lilo-an	21.31	0.00	21.31	9.80	0.00	0.00	9.80	0.00	0.62	10.89	11.51
	Cansaga	54.90	18.21	36.69	24.40	0.00	0.00	24.40	0.00	2.21	10.08	12.29
	Sub-total	196.43	98.96	97.47	62.21	0.00	0.00	62.21	0.00	7.92	27.34	35.26
Central	Butuanon	72.50	45.61	26.89	6.31	0.00	0.00	6.31	1.84	0.00	18.74	20.58
	Cebu	98.31	29.77	68.54	31.23	0.00	0.00	31.23	0.00	0.00	37.31	37.31
	Sub-total	170.81	75.38	95.43	37.54	0.00	0.00	37.54	1.84	0.00	56.05	57.89
Southern	Mananga	87.13	75.45	11.68	6.15	0.00	0.00	6.15	0.83	0.00	4.70	5.53
	M-Talisay	76.13	35.63	40.50	27.38	0.00	0.00	27.38	0.41	11.36	1.35	13.12
	Sub-total	163.26	111.08	52.18	33.53	0.00	0.00	33.53	1.24	11.36	6.05	18.65
Mactan	Mactan	56.96	0.00	56.96	8.48	21.46	20.36	50.30	6.66	0.00	0.00	6.66
	Sub-total	56.96	0.00	56.96	8.48	21.46	20.36	50.30	6.66	0.00	0.00	6.66
Total		587.46	285.42	302.04	141.76	21.46	20.36	183.58	9.74	19.28	89.44	118.46

Note: Unit of area is km^2. Area does not include ocean face.

Table B.II-37 indicates allocation rate of input values with undulation, definitions of Table B.II-37 are described below.

- Natural Recharge: (A+B) Direct and In-direct Recharges
- Lateral Flow: (C) Balance of Groundwater in WRMUs
- Abstraction: (D) MCWD (D1) and Non-MCWD (D2)
- Return Flow: (E) Ratio of Human Waste Water and Leakage Water

Table B.II-37 Examination Results on Allocation Rate of Input Values with Undulation

District	WRMU	Limestone Area: A+B	C	D1	D2	E	Alluvial Area: A+B	C	D1	D2	E
Northern	Compostela	78.9%	100.0%	point	0%	-	21.1%	0.0%	point	100%	85:15
	Kot-kot	95.5%	93.5%	point	0%	-	4.5%	6.5%	point	100%	55:45
	Lilo-an	77.0%	79.3%	point	0%	-	23.0%	20.7%	point	100%	40:60
	Cansaga	77.6%	66.5%	point	0%	-	22.4%	33.5%	point	100%	20:80
Central	Butuanon	57.4%	77.0%	point	0%	-	42.6%	23.0%	point	100%	70:30
	Cebu	62.0%	100.0%	point	0%	-	38.0%	0.0%	point	100%	95:05
Southern	Mananga	83.4%	100.0%	point	0%	-	16.6%	0.0%	point	100%	60:40
	M-Talisay	82.8%	100.0%	point	0%	-	17.2%	0.0%	point	100%	75:25
Mactan	Mactan	100.0%	0.0%	point	100%	45:55	0.0%	100.0%	point	0%	-

Note: Mactan District is independent from other model districts.

As examination result on allocation methodology of transient hydraulic stresses, model domain was classified into 31 zones according to the geo-graphical zoning criteria composing of geology, population density (relating to built-up area) and water supply service area as shown in Table B.II-38. Furthermore, MCWD abstraction namely D1 is not included into Table B.II-38, because that is not surface stress.

Table B.II-38 Zoning Information of Cebu-GWM-09

Model District with WRMUs		Geo-graphical Zoning Criteria				Numerical Information (average of monthly stresses in m^3/sec)				
		Geology	Pop Density	Water Supply	ID	Area km^2	A+B	C	D2	E
Northern	Compostela	Northern L	Non Built-up	Non Service	(01)	18.22	0.459	0.000	0.000	0.000
		Southern L			(02)	4.92	0.330	0.935	0.000	0.000
		Fluvial	Built-up		(03)	0.34	0.023	0.065	0.043	0.043
		Coastal A			(04)	4.75	0.120	0.000	0.607	0.607
				Service Area	(05)	2.73	0.069	0.000	0.349	0.349
	Kot-kot	Limestone	Non Built-up	Non Service	(06)	4.87	0.770	0.793	0.000	0.000
		Fluvial	Built-up	Service Area	(07)	1.27	0.201	0.207	0.349	0.349
		Coastal A			(08)	2.37	0.029	0.000	0.651	0.651
	Lilo-an	Northern L	Non Built-up	Non Service	(09)	3.08	0.145	1.000	0.000	0.000
		Southern L			(10)	6.72	0.315	0.000	0.369	0.369
		Alluvial	Built-up		(11)	0.62	0.029	0.000	0.034	0.034
				Service Area	(12)	10.89	0.511	0.000	0.597	0.597
	Cansaga	Limestone	Non Built-up	Non Service	(13)	24.40	0.776	0.665	0.000	0.000
		Alluvial	Built-up		(14)	2.21	0.040	0.060	0.180	0.036
				Service Area	(15)	10.08	0.184	0.275	0.820	0.964
Central	Butuanon	Limestone	Non Built-up	Non Service	(16)	6.31	0.452	0.580	0.000	0.000
		Alluvial			(17)	4.56	0.327	0.420	0.222	0.156
			Built-up	Service Area	(18)	16.02	0.221	0.000	0.778	0.844
	Cebu	Limestone	Non Built-up	Non Service	(19)	31.23	0.620	0.456	0.000	0.100
		Alluvial	Built-up	Service Area	(20)	37.31	0.380	0.544	1.000	0.900
Southern	Mananga	Limestone	Non Built-up	Non Service	(21)	6.15	0.417	1.000	0.000	0.000
		Fluvial			(22)	0.83	0.529	0.000	0.150	0.090
		Alluvial	Built-up	Service Area	(23)	4.70	0.054	0.000	0.850	0.910
	M-Talisay	Limestone	Non Built-up	Non Service	(24)	27.38	0.828	1.000	0.000	0.000
		Alluvial			(25)	0.41	0.005	0.000	0.031	0.023
			Built-up		(26)	11.36	0.149	0.000	0.866	0.649
				Service Area	(27)	1.35	0.018	0.000	0.103	0.327
Mactan	Mactan	Limestone	Non Built-up	Non Service	(28)	8.48	0.169	0.000	0.169	0.076
			Built-up		(29)	21.46	0.427	0.000	0.427	0.192
				Service Area	(30)	20.36	0.405	0.000	0.405	0.732
		Alluvial	Non Built-up	Non Service	(31)	6.66	0.000	0.000	0.000	0.000

Note: “L” means Limestone area, while “A” is alluvial area.

Figure B.II-56 indicates 31 zones with surface input stresses which were summed up using natural recharges, lateral flow balance, Non-MCWD abstraction and return flows. Values of surface input stresses were estimated as average of monthly (Jan-1980 until Dec-2004: 300 months).

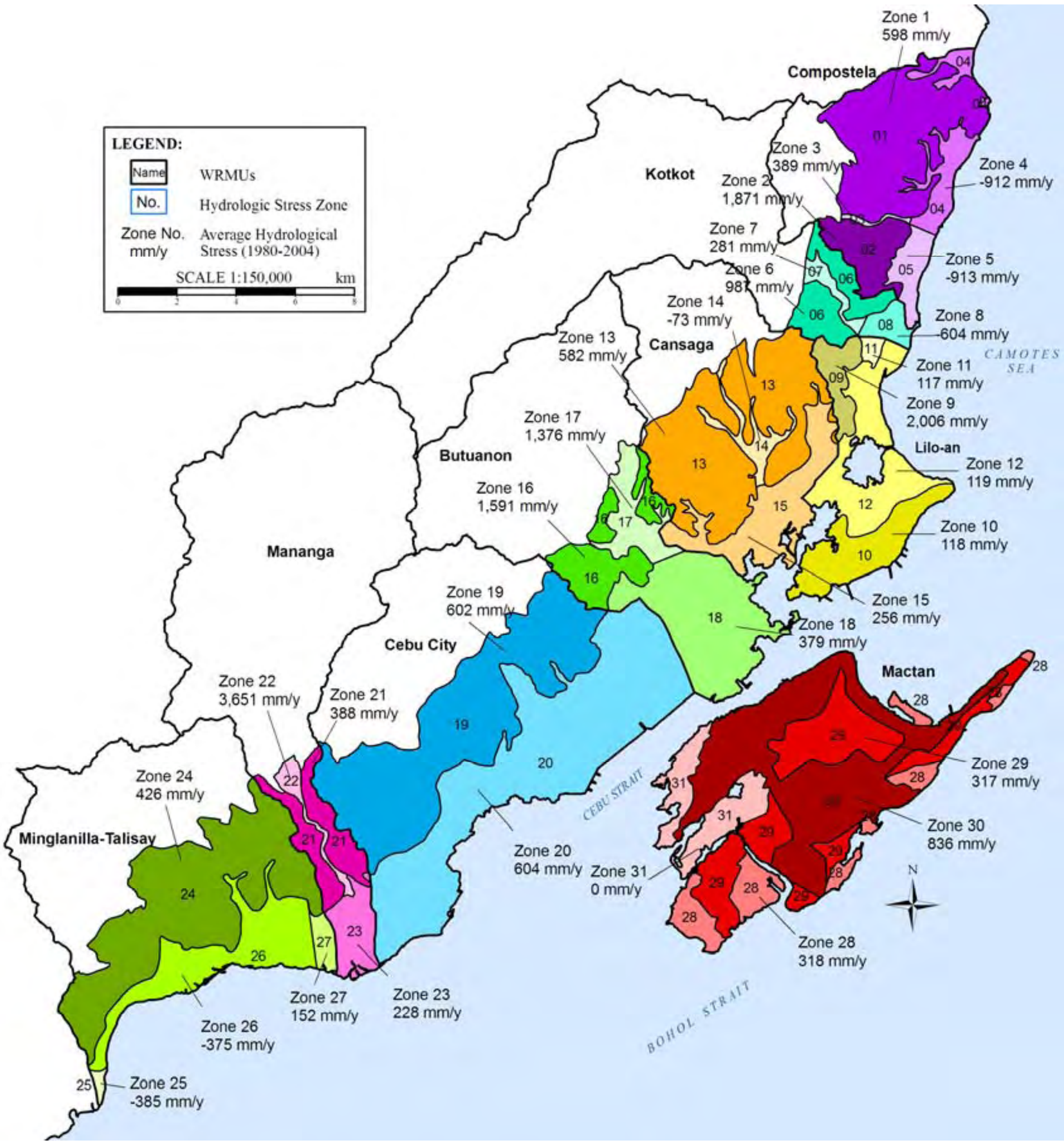


Figure B.II-56 Zoning Map of Transient Stresses (excluding MCWD Abstraction)

II-5.6 Model Calibration

Calibrated model was finalized through the initial term from Jan-980 until Dec-1979 (1,000 years) and the calibrated term from Jan-1980 until Dec-2004 (25 years), respectively. The initial term of 1,000 years was divided into two periods namely non-abstraction sub-term (985 years) and constant abstraction sub-term (15 years) to represent initial groundwater situation for the calibrated term.

Following Table B.II-39 presents the relationships of these terms.

Table B.II-39 Relationships of Initial Term and Calibrated Term

Temporal Discretization				Hydrologic Stress		Judgment Criteria
Term	Sub-term	Period	Years	Inflow and Outflow	Abstraction	
Initial	Non Abstraction	Jan- 980 to Dec-1964	985	Constant (average 1980-2004): Recharge and Lateral-flow	Assumed as None (ignore)	Equilibrium: by Mass-balance
	Constant Abstraction	Jan-1965 to Dec-1979	15	Constant (at Jan-1980): Recharge, Return and Lateral flows	Constant (at Jan-1980)	Cl Concentration Hydraulic Head for Calibration
Calibrated		Jan-1980 to Dec-2004	25	Monthly Transient (Jan-1980 to Dec-2004): Recharge, Return-flow, Lateral-flow and Abstraction		

Note: The same values have been given to assigned parameters (fluid density and aquifer properties).

Calibration concepts were examined with due consideration of groundwater crisis situation in Metropolitan Cebu and data availability. Aquifer properties of the 3D zoning were examined at the first to imitate the situations of Cl and water level in the calibration works. Then, dummy abstraction on the 2D zoning was given for preparing the forms of Cl and water level. In this study, recharge allocation into the 2D zoning was not adjusted because the Cebu-GWM-09 seemed to be acceptable level in terms of saltwater intrusion.

- Method: Calculated values were compared with observation values by trial-and-error.
- Items: (1) Parameters: Chloride Concentration and Hydraulic Head.
  (2) Observations: Seasonal Variation of Parameters in Individual Wells and Contour Map of Parameters.
- Priority: (1) Parameters: Quality (Cl) > Quantity (WL)
  (2) Observations: Seasonal Variation > Contour Map
- Reflection: Aquifer Property (3D) > Abstraction (2D) > Recharge Allocation (2D)

(1) Assigned Aquifer Properties

Trial-and-error processes were omitted but the range of aquifer property was calibrated within tested values. Final values of assigned aquifer property were indicated in Table B.II-29.

(2) Dummy Abstraction

Un-licensed wells have been constructed and operated since long year back. Privately owned wells in Mactan area and some districts in Cebu City were researched by the San Carlos University and MCWD in late 1990's. Most of concerned parties understand that the un-known pumping discharge in Metropolitan Cebu has been critical issue to induce the difficulty of groundwater regulation. However, well registration including annual monitoring has never been carried over a long periods by the stakeholders.

As a result of the model calibration, dummy abstraction in Table B.II-40 was assumed.

Table B.II-40 Abstraction given to the Calibrated Model

Model Domain		Abstraction		
District	WRMU	MCWD	Non-MCWD	Dummy Wells (addition to Non-MCWD)
Northern	Compostela	Monthly Records of MCWD were applied.	= PWS*- MCWD	None
	Kot-kot			MCWD value was distributed.
	Lilo-an			
	Cansaga			
Central	Butuanon			NWRB granted value (1980-2004) was added.
	Cebu			None
Southern	Mananga			3-times of MCWD value were allocated.
	M-Talisay			None
Mactan	Mactan			None

Note: The value of "Public Water System (PWS*)" was derived from Water Remind Project.

(3) Calibration Result

Figure B.II-57 shows the location map of observation data available in the GIS of MCWD, while Figure B.II-58 indicates the detective map and post evaluation map of the calibrated model in chloride parameter.

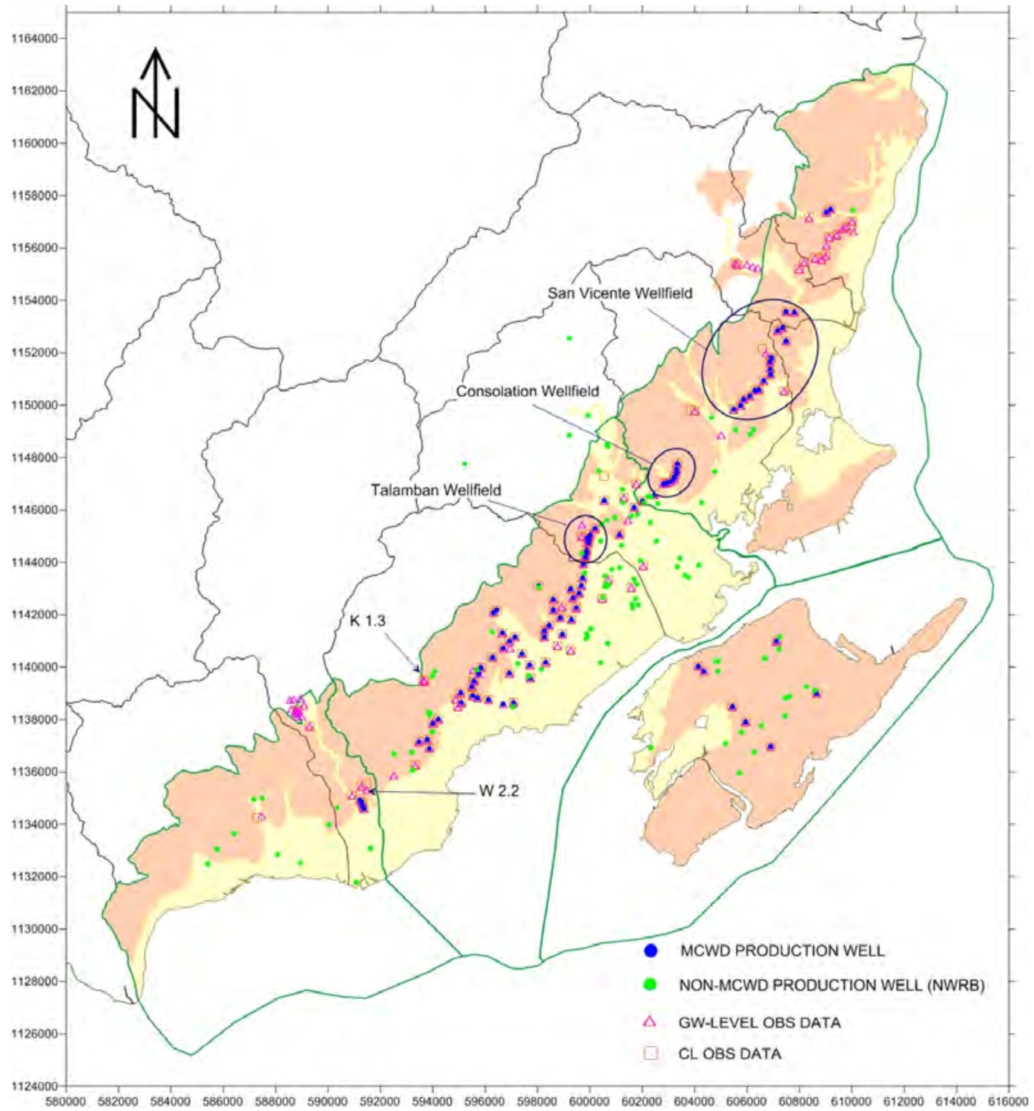


Figure B.II-57 Location Map of Observation Wells for Calibration Work

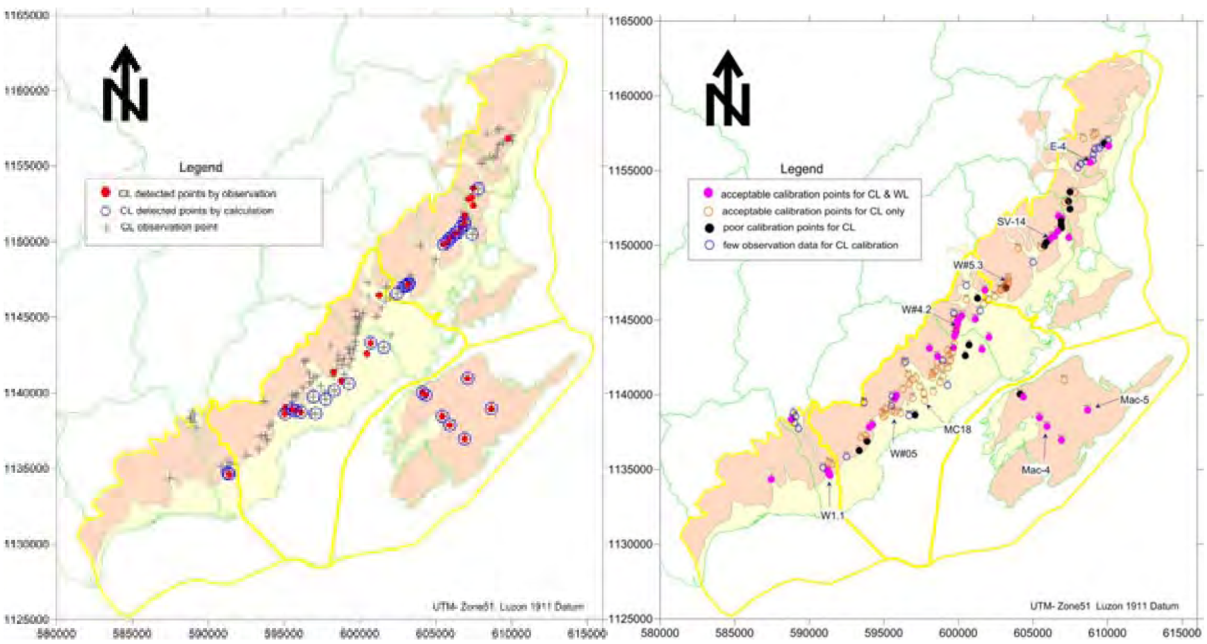


Figure B.II-58 Detective Map and Post Evaluation Map of Calibrated Model in Cl Parameter

< Chloride Calibration >

In the left side of Figure B.II-58, following chloride calibration was analyzed by the two dimensional distribution. Figure B.II-59 shows the overall rate of Cl observation.

✓ Chloride observation points:	119 wells
✓ Cl observed > 20 mg/L:	40 wells
✓ Cl calculated > 20 mg/L:	36 wells
✓ Cl both observed and calculated > 20 mg/L:	27 wells

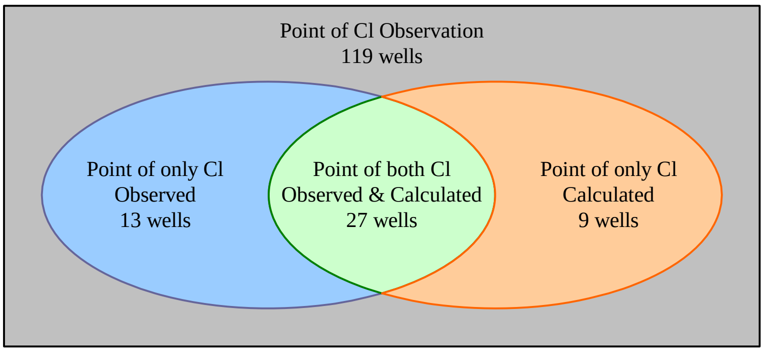


Figure B.II-59 Chloride Calibration in the Model

There are 13 Cl-observation points having non Cl-calculation, most of which are located along the karstic limestone area. On the other hand, there are 9 Cl-calculated points having non Cl-observation, locations of which are concentrated in the central alluvial plain of Cebu city. It means that 68% of Cl observed points were recognized as Cl calculated points, while 75% of Cl calculated points were grouped within Cl observed points.

From these points of view, the conduit flow in limestone aquifer and the confined flow in alluvial aquifer may be required to investigate in detail.

< Chloride and Water Level Calibration >

In the right side of Figure B.II-58, following chloride and water level calibrations were analyzed by the two dimensional distribution.

✓ Chloride (Cl) and Water Level (WL) observation points:	119 wells
✓ Acceptable Cl and WL calibration points:	48 wells
✓ Acceptable only Cl calibration points:	62 wells
✓ Poor Cl calibration points:	9 wells

Poor Cl calculation points are estimated at 9 (8%). However, poor water level calculation points are totaled at 62 wells (52%). One of the expected reasons in poor matching is pumping status at observation wells, MCWD and the study team could not identify the water level data whether it was static water level (SWL) or pumping water level (PWL). Groundwater in MCWD well fields has a high calcium contents because of limestone solubility.

Periodical pumping test (step drawdown) in every 2-3 years will be recommended to conduct for estimation of well efficiency. Currently, MCWD production wells may have large well loss that affects also wasteful electric consumptions.

Outskirts of MCWD wells in the model could not be calibrated because the observation data were not available at this moment. Finally, applying abstraction rate and chloride mass balance are presented in Figure B.II-60 as reference indicators during the calibrated period.

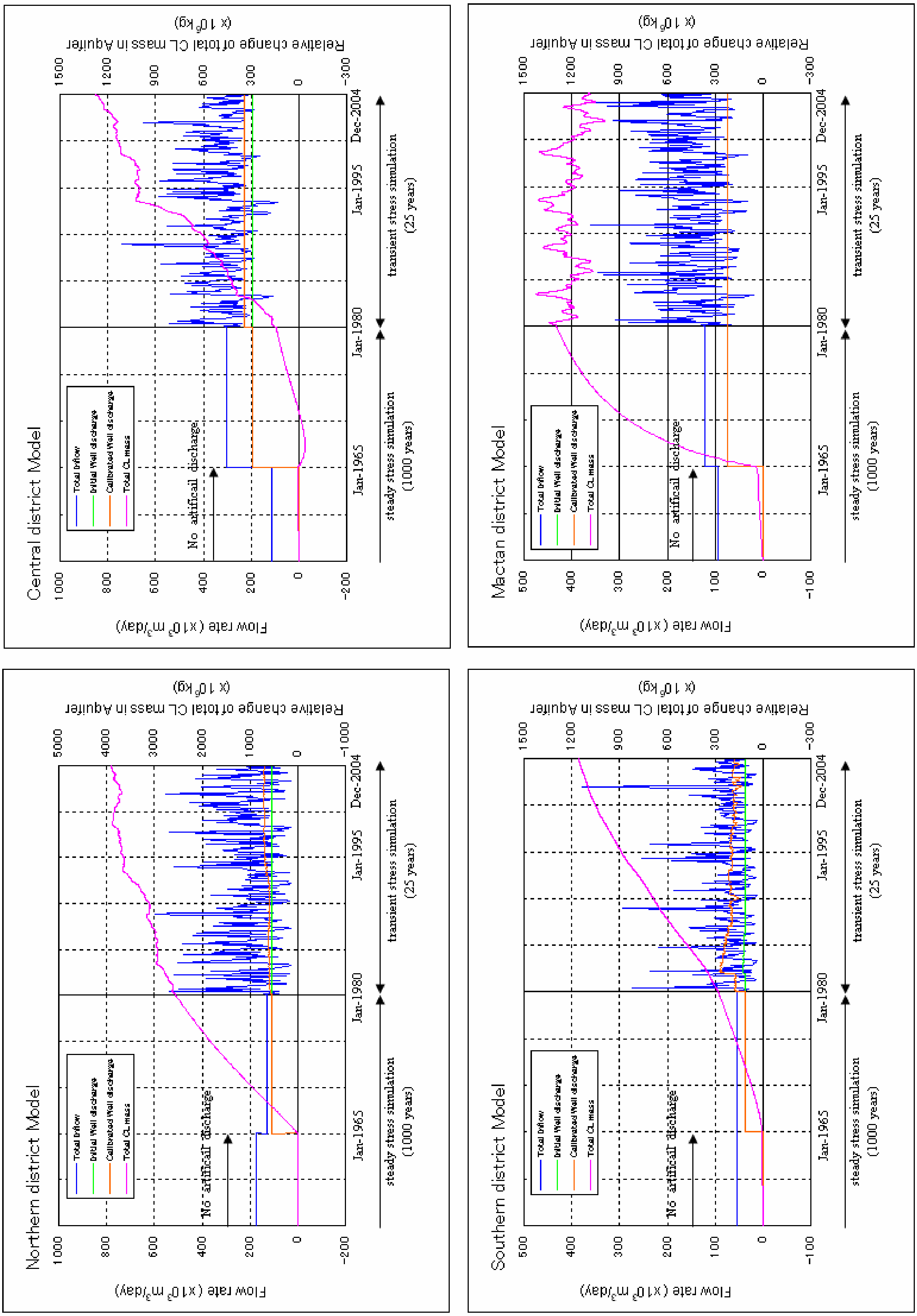


Figure B.II-60 Flow Rate and Chloride Mass Balance of Model Districts in Calibration Term

II-5.6 Model Limitation

It is noted that the model is not representation of actual replica and has following limitations.

(1) Soft-ware

Procurement of soft-ware was planned with due consideration of operability and modeling manifest. Solution on groundwater problems in Metropolitan Cebu has been put emphasis on sustainable freshwater development under controlling seawater intrusion in saturated porous aquifer. FDM (finite difference method) soft-ware was procured beyond the advantage of FEM (finite element method) such as unsaturated-flow, flexible boundary geometry, variable-scale meshing and so on.

(2) Due Scope of Work

It took about 8 months since the commencement of this study until completion of potential evaluation using the groundwater model. Among the said period, modeling works shared 2 months including model calibration. Sub-division of model structures may have more accurate representation.

- Plan on Procurement and Investigation: 3 months (mid-Jan to mid-Apr)
- Hydrogeological Investigation: 4 months (mid-Apr to mid-Aug)
- Modeling Works including Calibration: 2 months (mid-Jun to mid-Aug)
- Predict Simulation including Scenario Setting: 1 month (mid-Aug to mid-Sep)

(3) Reproductivity of Locality

Limestone is distributed in the study area as a dominant geology. Corroded limestone formation has been distinguished with topographic features of cone karst, sinkhole, cave, etc. The soft-ware being used for this study has no conduit flow model. Additionally, position and scale of such conduit flow could not be identified.

(4) Data Availability

Following items are feedback information from this study.

- Water Balance from Water Remind
- Non-MCWD Well Information
- Non-verification Area

Water components being reflected to this groundwater model were obtained from the Water Remind Project. It was so helpful but it was also difficult to verify (procedures were closed as black-box). Groundwater recharge rates against rainfall by WRMU were estimated at lowest 4% and highest 37% by the said project, additionally those are adjacent WRMUs.

Problem of non-MCWD well information has as yet been scarcely dealt with. The Water Remind Project estimated about 298,000 m^3/day at Dec-2004 by tank model, while the JICA study estimated about 391,000 m^3/day by flow model. About 60 to 70% of groundwater extraction may be occupied by non-MCWD wells.

Information of about 1,200 wells was encoded into the ArcGIS of MCWD. There is very limited information outside of MCWD franchise LGUs. Therefore, such area can not be calibrated during modeling period.

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