THE STUDY
ON SUSTAINABLE GROUNDWATER DEVELOPMENT
FOR BOGOTA PLAIN
IN THE REPUBLIC OF COLOMBIA

FINAL REPORT
SUPPORTING REPORT

PART 5

GROUNDWATER LEVEL OBSERVATION

Final Report
(Supporting Report)

Part 5 Groundwater Level Observation

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PART - 5 GROUNDWATER LEVEL OBSERVATION

Groundwater level of the Study Area was observed by simultaneous groundwater level observation and by automatic groundwater level recorder. Groundwater level and seasonal fluctuation of it were analyzed in this Study. The result is explained below.

CHAPTER 1 Simultaneous Groundwater Level Observation

(1) Simultaneous Groundwater Level Observation by CAR

CAR started simultaneous groundwater level observation for entire Study Area since 1998. Fourteen times groundwater observation campaigns for around 370 observation wells were carried out by CAR during 1998 and 2001. The wells used for these observations are currently in use for pumping. Owners of the wells measured groundwater level of wells after water level recovering by 1-day stop of pumping.

(2) Simultaneous Groundwater Level Observation by JICA Study Team

The Study Team carried out simultaneous groundwater level observation in February, August and December of 2001, in August and December of 2002. Total number of observed wells is around 100, which are currently not in use for pumping.

(3) Result of Simultaneous Groundwater Level Observation by

Groundwater level distribution and its fluctuation in the Study Area were examined from the result of simultaneous groundwater level observation carried out by CAR and the Study Team. The result of examination is explained below.

(4) Fluctuation of Groundwater level in the Study Area

Car carried out fourteen times of simultaneous groundwater level observation for four years during 1998 to 2001. Groundwater level fluctuation during this period was analyzed from CAR's result. Procedure for the analysis is explained below.

- Representative observation results of each year were selected from 14 times observation campaigns.
- In the selection of representative observation campaigns, season of observation campaigns and the number of observed wells of campaigns were taken into account: Season of observation campaign should be the same among selected campaigns, and number of the observation wells of selected campaign should be bigger. Representative observation campaigns were finally selected as shown below.

Observation Period	The number of wells
June, 1998	277
February, 1999	326
March, 2000	361
March, 2001	367

- Trend of groundwater fluctuation of each observation well during four years was estimated. Observed four groundwater levels at each observation well, one data/ one year, were approximated by one lines which was calculated by least squares method. It is assumed that approximated lines show trend of groundwater level fluctuation of each observation well. Gradient of this line can be called as "Average speed of groundwater level fluctuation".

Average speed of groundwater level fluctuation of observed wells was summarized in histogram shown in Figure-1.1. As shown in Figure-1.1, the average speed of groundwater level fluctuation show range of -20m/year to 15m/year, and most of them distribute between -6m/year and 6m/year. Shape of this distribution is similar to Gauss distribution. Observed data showing fluctuation speed of more than 6m seems abnormal, which has pumping effect, and these data were neglected. Then observed data, which has fluctuation speed of -6m/year to +6m/year, seems reliable without serious pumping effect. By examination of reliable data, matters below were concluded.

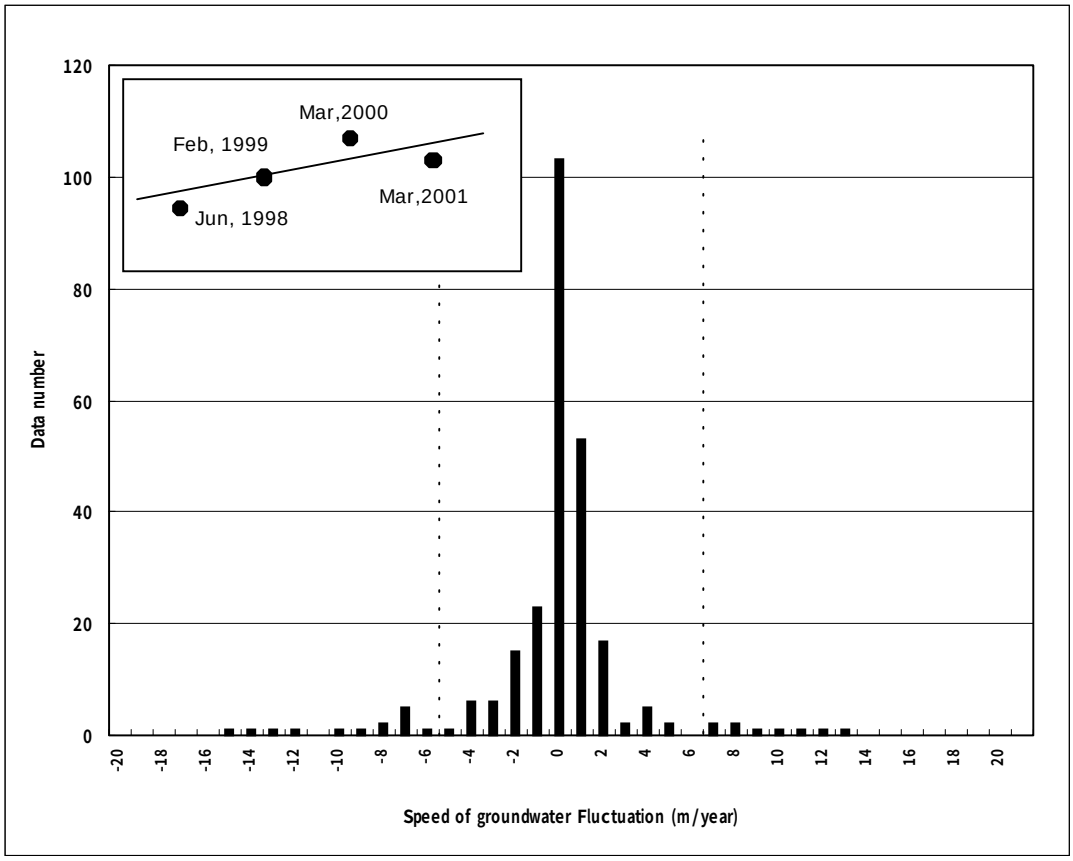

Figure-1.1 Histogram of Speed of Groundwater Fluctuation (m/year)

- In Figure-1.1, fluctuation speed ranging between -6m/year and 6m/year shows Gauss distribution, and the average of this distribution is -0.2m/year.
- Distribution above was caused by actual groundwater level fluctuation, pumping effect and errors in observation.
- Two interpretations for result above are possible. i) Groundwater level is being lowered by the average speed of -0.2m/year, ii) Fluctuation speed of -0.2m/year is negligible. It means that groundwater level is already in equilibrium state, and is not in big fluctuation.
- In order to observe precise groundwater level fluctuation, long term observation of well without pumping effect is necessary. It is difficult to know long-term groundwater level fluctuation only from CAR data. In the Study Area, large groundwater development started 20 years ago, since then lowering of groundwater level also started. From the result mentioned above, relation between pumping and the lowering of groundwater level has already reached equilibrium state, and serious lowering of groundwater level has already finished. If the amount of pumping is equal or less than the amount of

recharge on every specific basin.

CHAPTER 2 Continuous Groundwater Level Observation

The Study Team installed automatic groundwater level recorders to 11 existing wells, and groundwater level is currently being automatically observed in these wells. Wells where groundwater level recorders were installed are shown in Table-2.1 and Figure-2.1. Of wells in Table-2.1, No.1 to No.6 were drilled by JICA Study Team in Phase 1. No.6 was drilled by EAAB for this Study. No8 to No.11 are private wells selected for the monitoring.

Table-2.1 Wells for Groundwater Level Continuous Observation

Well No.	Well No.	Coordinates of well	
		E	N
No.1	Gibraltar (Soacha)	988,439	1,005,845
No.2	Tisquesusa (Facatativa)	976,639	1,022,020
No.3	Siberia (Tabio)	991,462	1,017,974
No.4	Sopo (Sopo)	1,011,020	1,037,638
No.5	Diana	1,013,170	1,038,429
No.6	Choconta	1,049,874	1,067,343
No.7	Suba	999,911	1,017,839
No.8	Guadarrama	1,014,772	1,053,702
No.9	Grasco	996,772	1,001,948
No.10	Santa Monica Flowers	977,203	1,014,760
No.11	Dersa	996,772	1,001,948

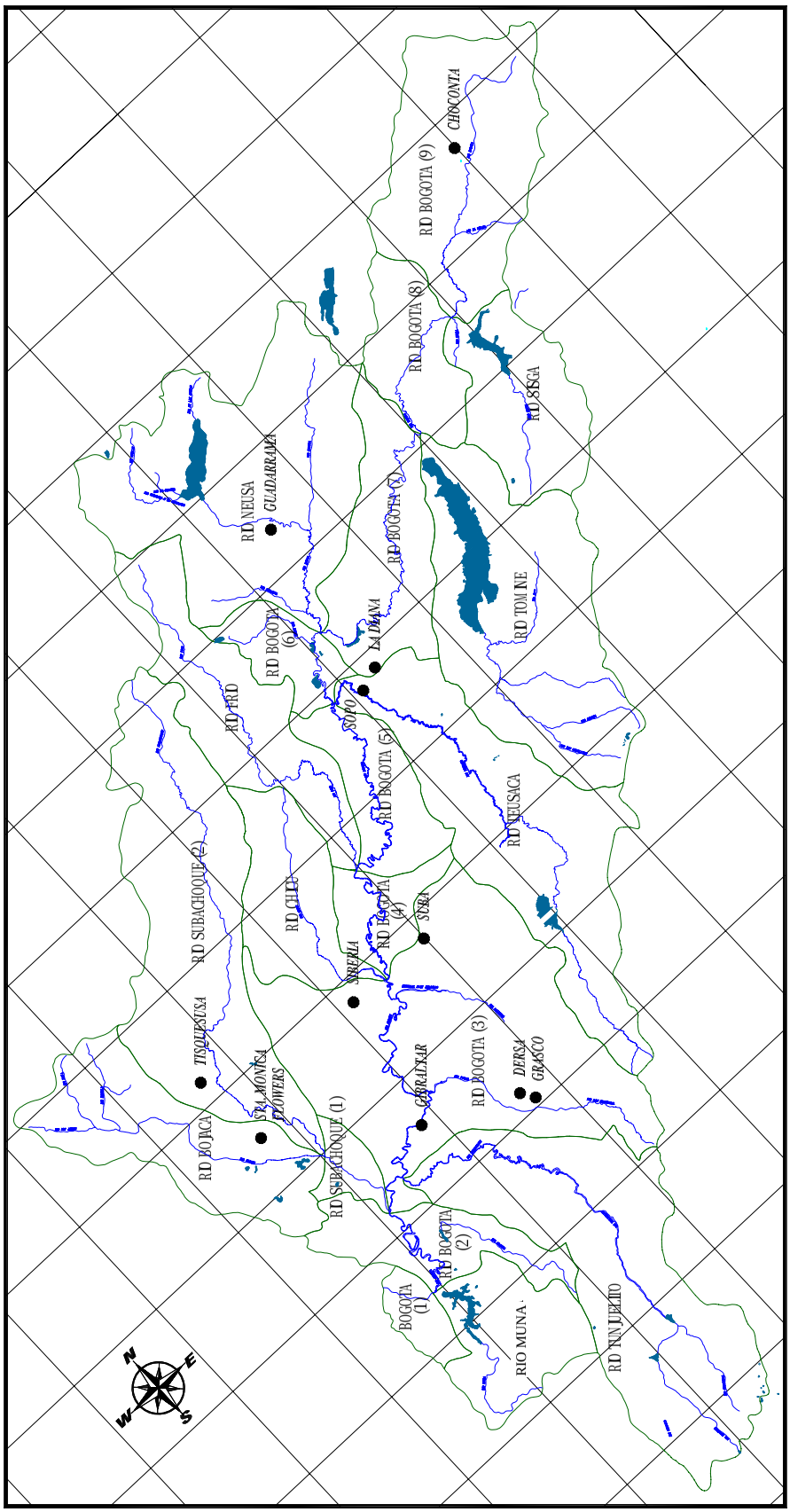

Figure-2.1 Site for Installation of Groundwater Level Recorders

Result of monitoring is shown in Figure-2.2 and Figure-2.3. Monitoring result is summarized as follows.

- The monitoring result shows seasonal groundwater fluctuation of Quaternary aquifer. Fluctuation pattern is different in each well, and seasonal fluctuation is not clear. It seems to be caused by effect of neighboring pumping wells.
- Pattern of groundwater level fluctuation in Study Area is generally complicated. This is caused by the existing pumping wells, which have influence on groundwater level by artificial yield control.
- From observation result, trend of long-term lowering and rising of groundwater level is not recognized. It is considered that lowering of groundwater level of Bogotá Plain by pumping has already reached equilibrium condition.
- Effect of the earth tide was also recorded in every monitoring result with regular vibration of groundwater level of several cm (two cycles per day).
- Groundwater level monitoring should be continued for long period. It is said that groundwater level of Quaternary aquifer is still declining. So far there is no information that proves directly this situation. Hence, groundwater level monitoring by automatic recorder is very important, and this monitoring should be continued after this Study.

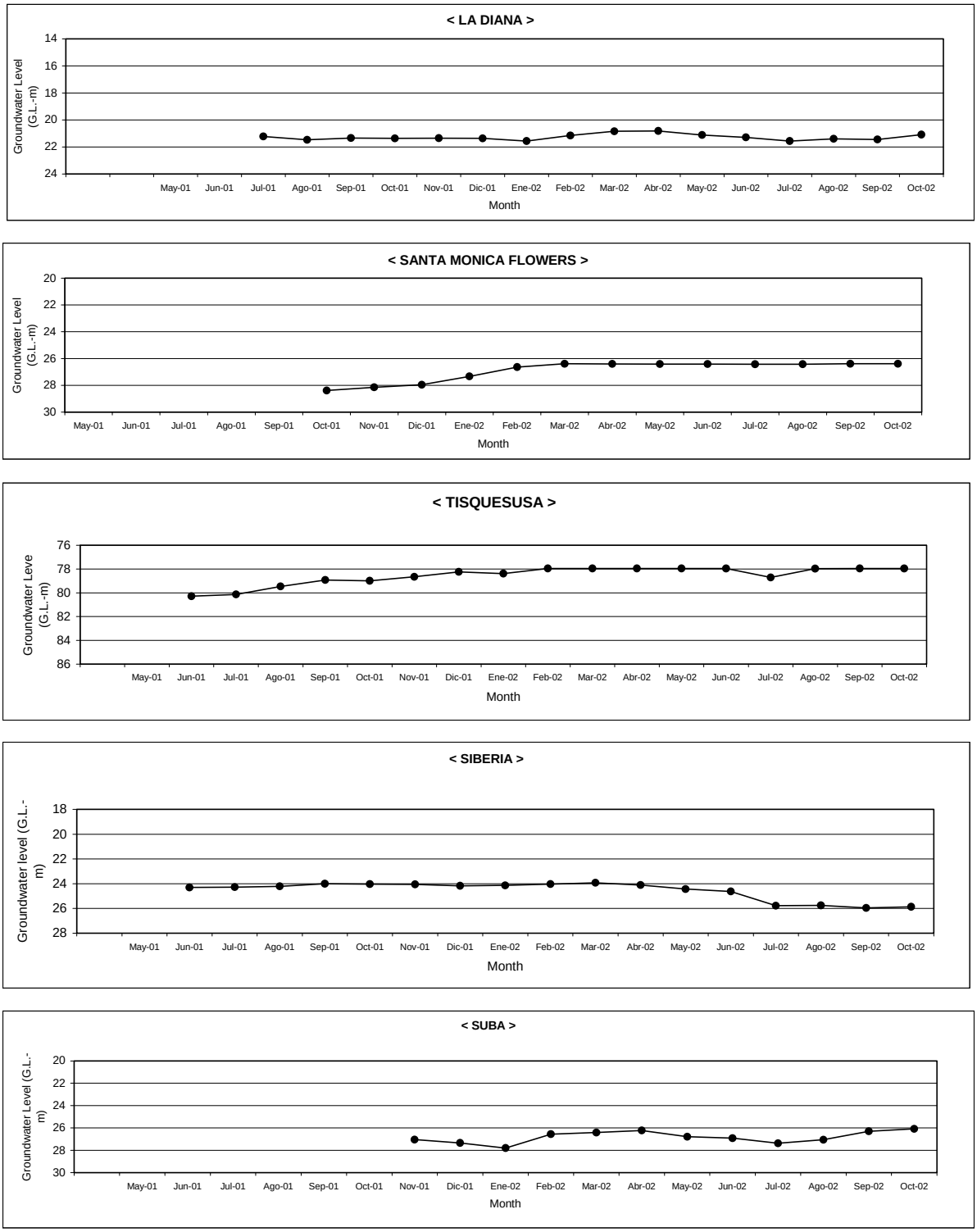

Figure-2.2 The Result of Groundwater Level Monitoring (1)

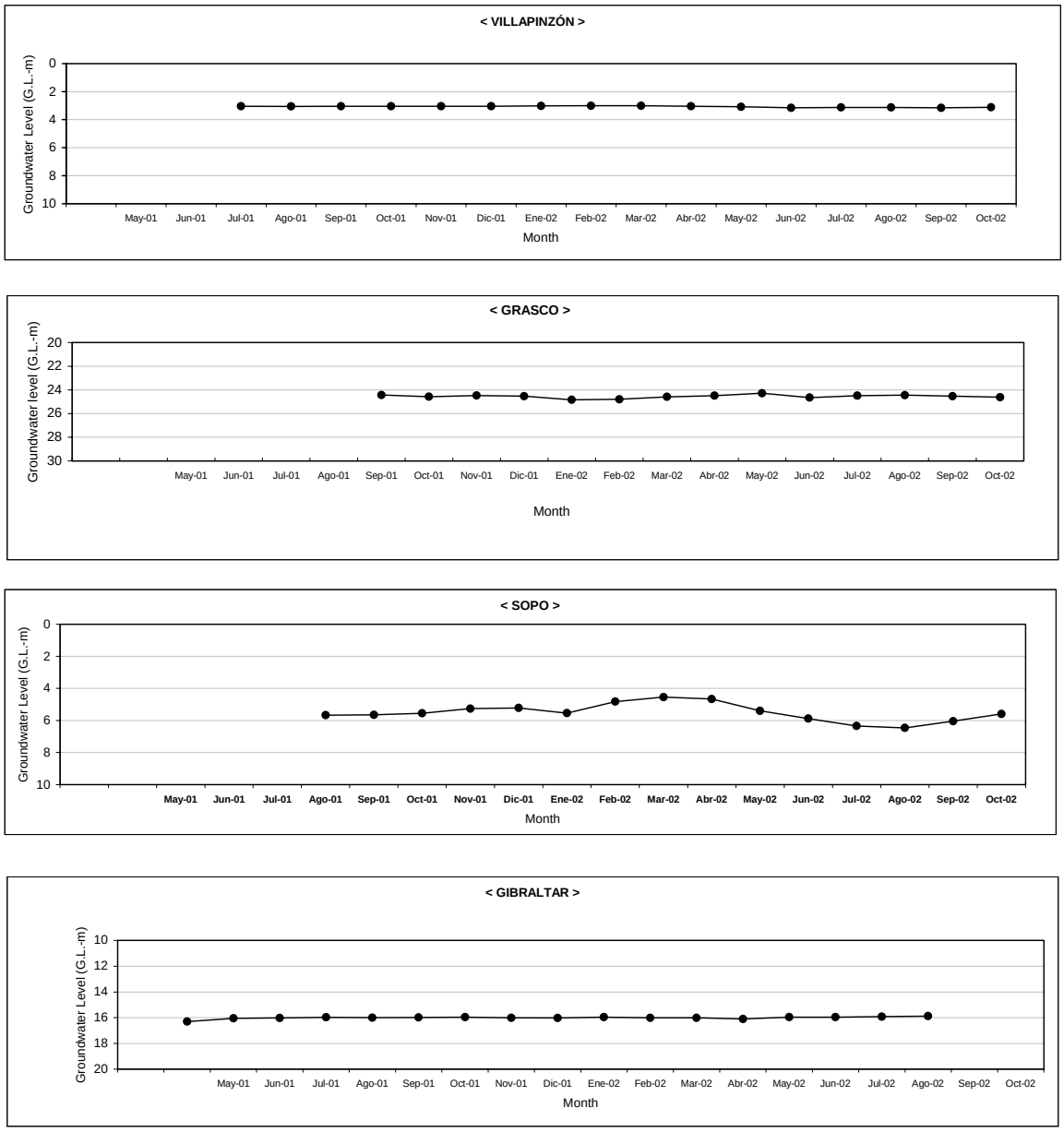

Figure-2.3 The Result of Groundwater Level Monitoring (2)

CHAPTER 3 Groundwater Tables in the Study Area

Groundwater level map was drawn from observation results by CAR and JICA Study Team. More than 90% wells, which were observed by CAR and the Study TEAM, have Quaternary aquifer, and wells with Cretaceous (Guadalupe) aquifer are few. Moreover, wells with Tertiary aquifer are rare.

(1) Groundwater Level of Quaternary

Groundwater level of Quaternary aquifer was analyzed and the result is explained below. Groundwater level of Quaternary aquifer is analyzed by procedure below.

- Observed groundwater levels of simultaneous groundwater level observation by CAR were averaged for each observation well. Observation data listed below was used for this analysis. As explained before, observed data with fluctuation speed more than 6m/year were neglected.

Period of observation Campaign	Number of Observed well
July, 1998	277
February, 1999	326
March, 2000	361
March, 2001	367

- From the result of simultaneous groundwater levels observation that was carried out three times by the Study Team, average groundwater level was obtained for each observation wells. In this operation, observed groundwater levels with fluctuation speed of more than 6m during three observation periods were neglected.
- Averaged groundwater level calculated from monitoring result by CAR and JICA Study Team was combined. Based on these data, groundwater level contour line covering all over the Study Area was drawn by interpolation. Program “Surfer” was used for this interpolation.
- In interpolation of groundwater level, it is assumed that groundwater level of boundary between Quaternary and base-rock (Cretaceous or Tertiary) is GL-15m. Groundwater level of Quaternary was interpolated by the assumed groundwater level and observed groundwater level.

As shown in Figure-3.1, groundwater of Quaternary aquifer flows from the border of Bogotá Plain (mountain and hill area) to the center of Bogotá Plain following the gradient of land slope. Groundwater level is low where there are many pumping wells, and it is expected that groundwater flows toward this area from surrounding area. Bojaca and Subachoque area shows this situation.

According to distribution of groundwater level shown in Figure-3.1, groundwater of Quaternary aquifer seems to be flowing within the Study Area. It is assumed that in course of flowing down, some groundwater is pumped up by wells, and other groundwater flows into rivers as base-flow. The remaining groundwater infiltrates into deep aquifer of Tertiary and Cretaceous, and finally flows away from the Study Area.

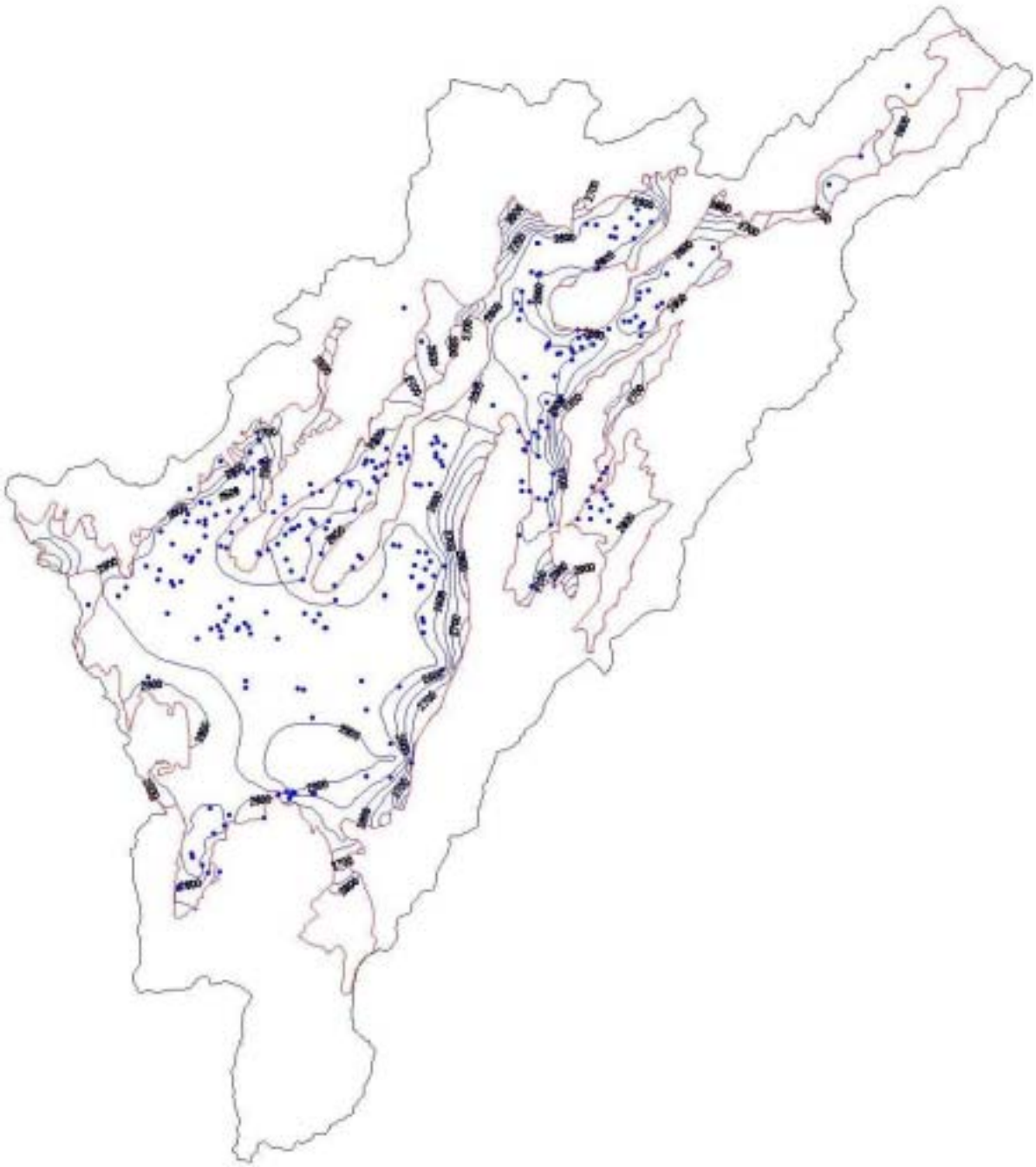

Figure-3.1 Groundwater Level of Quaternary

(2) Groundwater Level of Cretaceous Aquifer

Data of groundwater level of Cretaceous aquifer is few compared with those of Quaternary. Then, it is difficult to draw groundwater level contour-line covering all over the Study Area. In order to obtain concept of groundwater level distribution, groundwater level contour-line was drew based on some assumptions, and this is shown in Figure-3.2. Procedure of making groundwater level contour-line is explained below.

- Average groundwater level for each monitoring well was calculated from monitoring results of CAR and the Study Team. Data used for this operation was collected from the same monitoring result that was used for analyses of Quaternary groundwater level. As same as in case of Quaternary groundwater level analysis, groundwater level, which has fluctuation speed of more than 6m, were neglected.
- Averaged groundwater level calculated from monitoring result by CAR and JICA Study Team was combined. Based on these data, groundwater level contour line covering all over the Study Area was drawn by interpolation. Program "Surfer" was used for this interpolation.
- In interpolation of groundwater level, it is assumed that groundwater level of Cretaceous is GL-300m in the border of the Study Area. Groundwater level of Cretaceous was interpolated by the observed groundwater level and the assumed groundwater level.

As shown in Figure-3.2, groundwater of Cretaceous aquifer flows from mountain area bordering the Study Area to the center of Bogotá Plain. Then groundwater flows from NNE to SSW direction following gradient of land slope of Bogotá Plain, and finally flows away from the Study Area.

(3) Groundwater Level of Tertiary

Data of groundwater level of Tertiary aquifer is extremely few, then it is impossible to draw groundwater level contour-line covering all over the Study Area. Groundwater level of Tertiary aquifer should be assumed that groundwater level might be between groundwater level of Quaternary and Cretaceous.

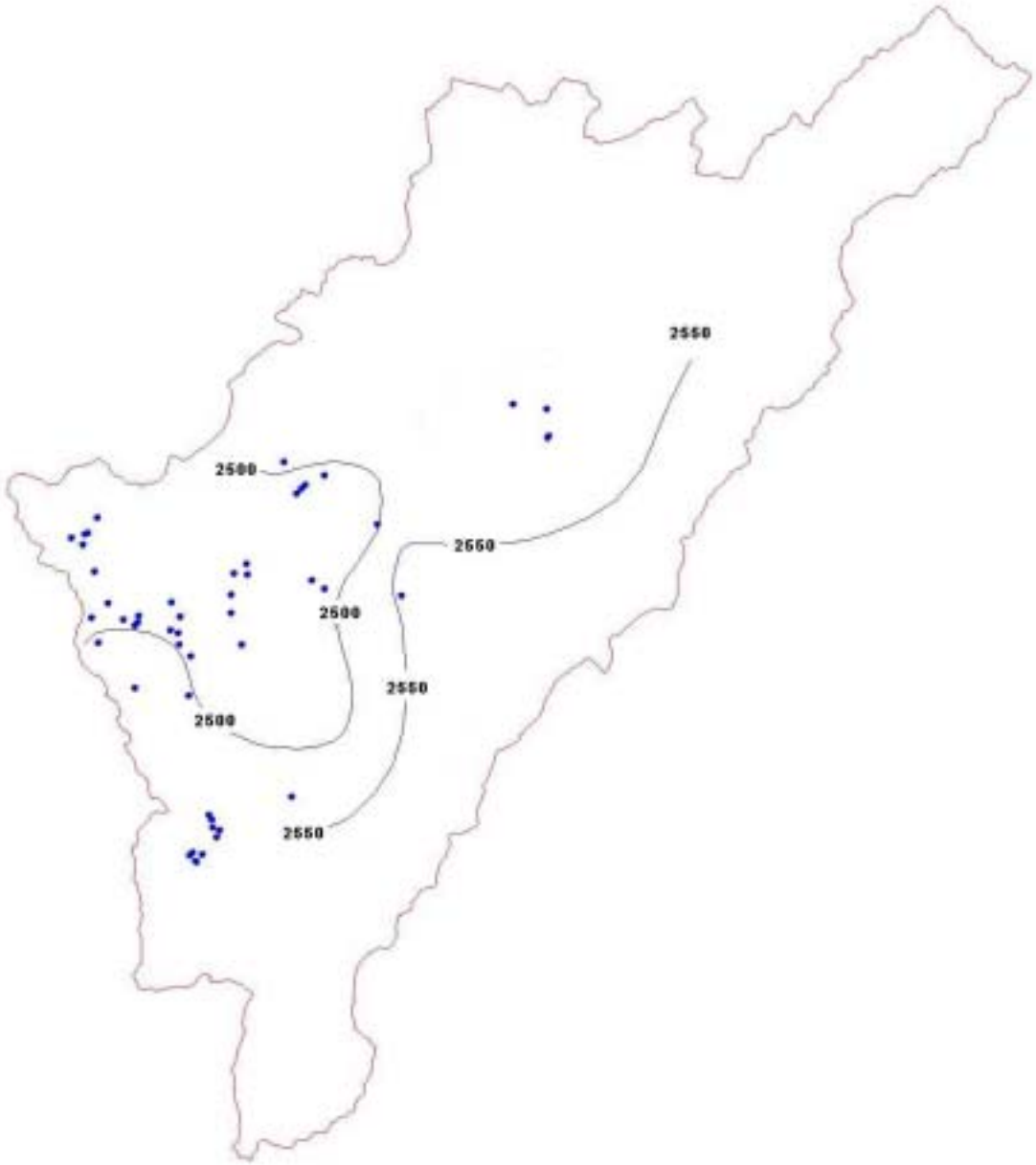

Figure-3.2 Groundwater Level of Cretaceous