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

FINAL REPORT
SUPPORTING REPORT

PART 7

ISOTOPIC ANALYSIS

Final Report
(Supporting Report)

Part 7 Isotopic Analysis

Table of Contents

List of Tables and Figures

PART - 7 ISOTOPIC ANALYSIS

Isotopic analysis was carried out based on the samples collected from existing 20 wells in February 2001 (Phase 1) and 10 wells in August 2002 (Phase 3) to estimate the groundwater recharge and its flow mechanism in the Bogotá Plain. An additional sample of superficial water in the birthing place of Bogotá River was collected and analyzed by the same manner.

CHAPTER 1 Sampling Points and Items for Analysis

Sampling wells for isotopic analysis were selected, as shown in Table 1.1 and Figure-1.1, from the wells of typical aquifers in the Bogotá Plain based on the existing database of approximately 7,000 wells.

Table 1.1 Selected sampling wells for isotopic well

Item		^{14}C	^{3}H	D and ^{1}H	^{18}O and ^{16}O
Aim for analysis		Age determination of ground water older than 5000 years	Confirmation of ground water of young age about 40 years	Examine the origin, mixture and flow of ground water	
Selection standard		・Selected in all aquifer mainly Cretaceous ・Selected wells in the central area of the basin	・Selected in all aquifer mainly Cretaceous ・Selected wells distributed widely in the study area		
Number of selected wells	Quaternary	1 (5)	14	14	14 (5)
	Tertiary	1	3	3	3
	Cretaceous	3 (4)	3	3	3 (4)
Total		5 (9)	20	20	20 (9)

( ) number of isotopic analysis in Phase 3

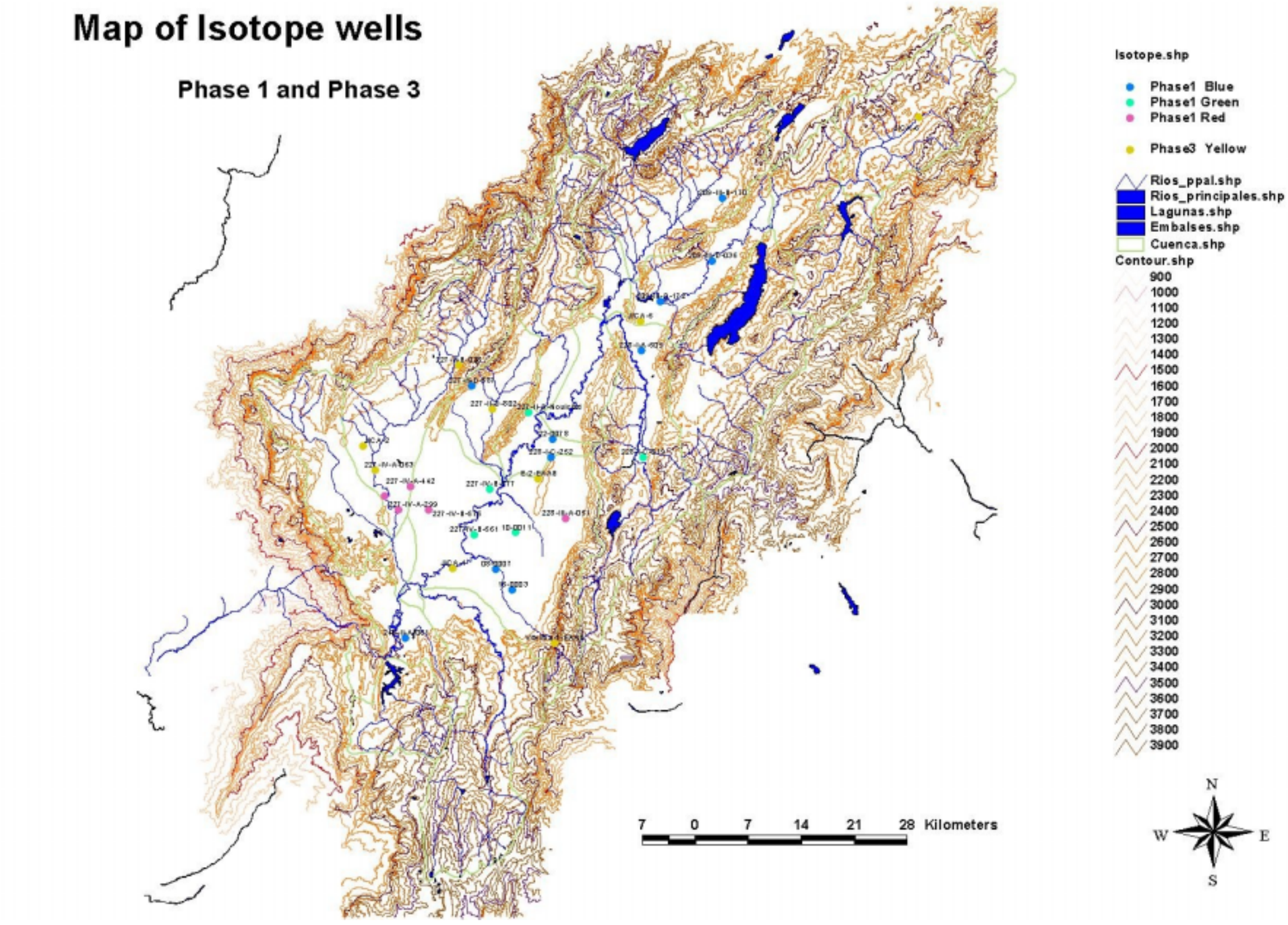

Figure-1.1 Distribution map of Isotopic Analysis wells

CHAPTER 2 Result of Analysis

Results of isotopic analysis are shown in Table 2.1 and summarized by items as follows.

In the Phase 3 study, the analysis of tritium was omitted. The reason is that it had been found from the Phase 1 study that there was no groundwater of the new age valid for analysis of tritium.

Table 2.1 Result of Isotopic Analysis

Phase	No.	Well	Basin	Aquifer	Water Depth m	^{14}Cyear	TR	δ^{18}O ‰	δD ‰
Ph-1	1	246-II-A-061	BOGOTA(1)	Saban-Gdlupe	357	14140±50	0.41	-10.67	-60.76
	2	227-II-D-587	CHICU	G. Guadalupe	1000	8230±40	0.50	-11.61	-78.50
	3	227-IV-A-233	SUBACHOQUE	G. Guadalupe	-	27150±150	0.37	-11.29	-74.16
	4	227 IV A-299	SUBACHOQUE	Sap-Subacho	500	23650±100	0.39	-8.82	-69.81
	5	228-I C-252	BOGOTA(2)	Tertiary	170	24180±110	0.38	-10.97	-63.66
	6	08-0007	BOGOTA(2)	Guadalupe	450	-	0.40	-11.77	-73.94
	7	227-IV-B-561	BOGOTA(2)	Sabana	115	-	Na	-10.95	-43.13
	8	11-0010	BOGOTA(2)	Sabana	251.8	-	0.45	-10.22	-86.52
	9	22-0078	BOGOTA(2)	Sabana	252	-	0.45	-10.36	-61.42
	10	228-I-C-019	TUESACA	F. Sabana	135	-	0.49	-10.82	-33.07
	11	209-III-D-172	BOGOTA(3)	F. Sabana	253	-	0.35	-10.78	-70.70
	12	228-I-A-509	TUESACA	Sabana	112	-	0.33	-11.00	-70.03
	13	209-III-D-036	BOGOTA(3)	F. Sabana	82	-	0.56	-11.47	-70.38
	14	209-III-B-170	NUESA	F. Cacho	-	-	0.42	-10.67	-66.14
	15	227-II-D-1115?	BOGOTA(2)	Guadalupe	-	-	0.44	-11.48	-41.79
	16	227-IV-A-442?	SUBACHOQUE	Sap-Subacho	353	-	0.57	-10.68	-73.77
	17	227-IV-B-577?	BOGOTA(2)	F. Sabana	526	-	0.44	-12.49	-68.08
	18	227 IV A-X6	SUBACHOQUE	Tilata	581	-	0.41	-11.91	-75.35
	19	16-0003	BOGOTA(2)	F. Sabana	192	-	0.47	-11.36	-66.90
	20	10-0011	BOGOTA(2)	F. Sabana	120	-	0.44	-11.55	-54.54
Ph-3	21	227-II-B-028	SUBACHOQUE(2)	G. Guadalupe	70	3630±40		-10.46	
	22	227-VI-A-063	SUBACHOQUE(2)	G. Guadalupe	448	33170±380		-10.71	
	23	227-II-D-802	CHICU	F. Sabana	100	32380±350		-10.51	
	24	Vitelma1 EAAB	BOGOTA(3)	Guadalupe ?		4620±40		-10.39	
	25	E-2 EAAB	BOGOTA(3)	Guadalupe	389	9430±40		-9.55	
	26	JICA1 EAAB	BOGOTA(3)	Sabana	196	29750±270		-10.31	
	27	JICA2	SUBACHOQUE(2)	Sabana	192	33110±380		-10.37	
	28	JICA5	BOGOTA(7)	Sabana	188	20640±90		-9.51	
	29	JICA6	BOGOTA(9)	Tilata	188	1690±40		-10.54	
	30	Nacimiento Rio BOGOTA				-		-9.99	

TR : Tritium Unit (1TR includes 1 tritium ion out of 1018 hydrogen ion.Before abbreviated TU)
Na : Lower than detectable value
δ : {(Isotopic ratio of sanmple data)-(Isotopic ratio of SMOW)} /(Isotopic ratio of SMOW)
δ value is shown in permillage(‰).

CHAPTER 3 Considerations on Isotopic Characteristics of Well Water

The considerations on each item of isotopic analysis are as follows.

(1) ^{14}C (Carbon 14)

The concentration of carbon 14 is affected by dissolved carbonic acid, which is provided by various reactions while rainwater penetrates and fluidizes. Since any carbon in carbon dioxide and hydrogen carbonate ions is “Dead carbon” from which ^{14}C is completely lost, the supply of these substances in aquifers lowers the ^{14}C concentration in the groundwater, and the groundwater might be older. Therefore, the age of groundwater can be younger than 1,690 to 33,170 years. It is concluded the groundwater in Cretaceous is relatively newer than the one in Quaternary when the both water is compared. The Cretaceous layer surveyed in this study locates in mountainous regions and is easily recharged by precipitation in a short period. On the contrary, the Quaternary layer places in the center of the plain and thick impermeable layer covers the aquifer. Therefore, it takes a long time that groundwater recharged by rainfall reaches in the aquifer. In addition, permeability and the activity of groundwater traveling in Cretaceous layer are higher than the ones in Quaternary strata. By contrasting to the result of

water quality test, Quaternary groundwater shows the characteristic of deep aquifer ($Na\text{-}HCO_3$ type) than Cretaceous water and this meets the result of the isotopic carbon analysis. The groundwater in Vitelma, where artificial recharge test have been conducted is categolozed as the newest water among 15 samples.

(2) ^{3}H (Tritium)

Twenty samples have been analyzed in order to determine the tritium concentration. The results showed that all the tritium concentration were less than 0.7 TU, the limit of detection. Considering that the half-life period of tritium is 12.35 years, the groundwater of Bogotá Plain is assumed to be older than 40 years. This result seems appropriate in view of the distance from the recharge area to the sampling wells and the depth of the aquifers (GL- 80m to GL-1,000 m). Generally, artificial tritium, generated in thermonuclear explosion test, is found more on the Northern Hemisphere and less on the Southern Hemisphere as the test fields are mostly located in the Northern Hemisphere. Also the higher the altitude from the sea level is, the lower the concentration will be. Considering that the Study Area is 2,600 m to 3,000 m above the sea level, since new information is unlikely to be obtained, the tritium analysis was omitted in the Phase 3 study.

(3) D and ^{18}O (Deuterium and Oxygen 18)

The analysis results of deuterium and oxygen 18 are shown in Figure-3.1. According to the results, water can be classified into the following three types.

It is evaluated only from the result of Phase 1, because in Phase 3 deuterium analysis has not been executed. In this diagram, three types of water can be distinguished. The isotope composition of water in Wells No. 1, 2, 5, 6, 9, 11, 12, 13, 14, and No. 19 are plotted along the approximate line $\delta D = 9.3868\ \delta 18O + 35.631$ which is nearly in parallel with the global meteorological line ($\delta D = 8\ \delta 18O + 10$) as shown in Figure-3.1. The global meteorological line in Bogotá Area is not clear, but it is estimated that this line is approximate to the global meteorological line in this area.

Wells No. 3, 4, 16 and No. 18 in Madrid district show the approximate line of $\delta D = 1.7844\ \delta 18O - 54.224$ that has a low inclination and intersects with the global meteorological line. As this district belongs to the subterranean heat zone, the rainwater that penetrated was warmed by the underground heat source and reacted with the surrounding rocks in isotopic exchange. (The rocks contain approximately 60% of oxygen in atomic composition. The reaction of isotopic exchange between water and rocks in this condition causes the isotopic ratio of oxygen in water to be drawn toward the value of rocks, resulting in an increase of 18O. On the other hand, the hydrogen content in the rocks is very low compared with that in water, so that the isotopic ratio of hydrogen in isotopic exchange reaction shows little change. The inclination of the approximate line is thus low.)

Moreover, water in Wells No. 7, 8, 10, 15, 17, and 20 is plotted far away in the above of the global meteorological line in the graph of Fifure-3.1. Wells No. 10 and 15 are located near recharge area, which are plotted at the top, and Wells No.7, 17, 20 and 8, which are plotted below them, are located in the city center. D and ^{18}O concentration has become high through filtering by minerals of groundwater during its movement in the geological layer and mixing with deeper groundwater.

Sampling locations for oxygen 18 analysis in Phase 3 was distributed in the rim of the Study Area in comparison to Phase 1 study. The result matches in Phase 3 to the one in Phase 1, but the average concentration of 18O is higher in Phase 3. This is probably because many sampling locations are in the area of rock layer of Cretaceous and the groundwater might be

under the influenced of rock-rainwater reaction.

Based on these results of isotopic analysis of hydrogen and oxygen, the possibility of mixture with the groundwater from the deep stratum is presumed, but basically, the groundwater originated from the rainwater is circulating to create a groundwater flow system. This supports the appropriateness of the groundwater flow analysis that is made on the groundwater originated from the rainwater based on the law of constancy of mass.

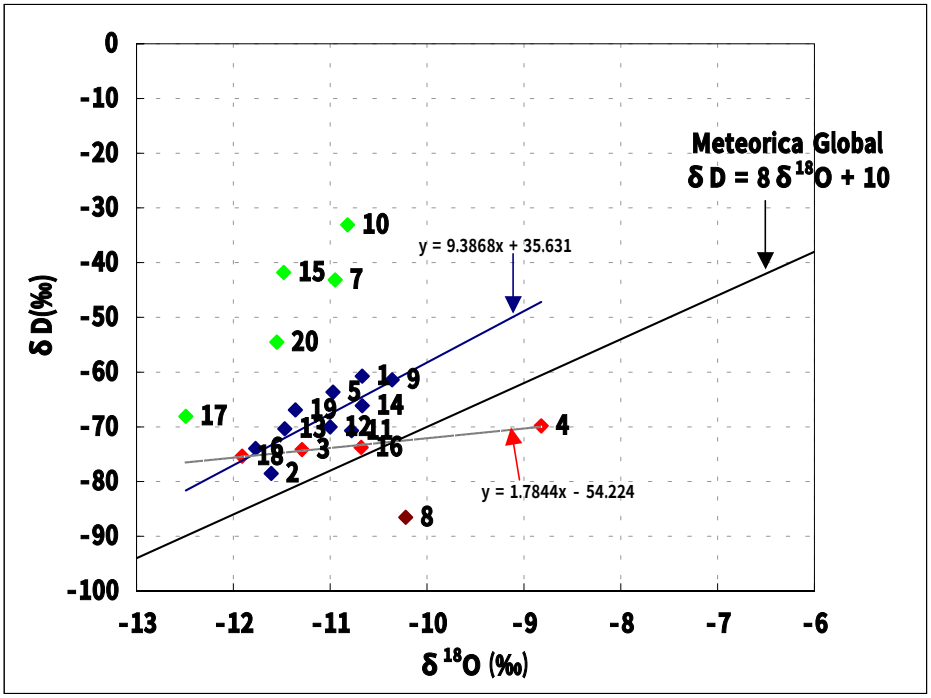

Figure-3.1 Analysis results of D and ^{18}O

Conclusion

- The age of the groundwater indicated by ^{14}C is 1,700 to 33,000 years old. However, the age of the groundwater can be younger because the analysed carbon may contain dead carbon extracted from *situ*.
- The tritium analysis shows that the age of the groundwater may be over 40 years older than the above.
- The isotopic ratio between hydrogen and oxygen shows that the source of groundwater is basically the rainwater though there is a possibility of change of the isotopic ratio due to reaction between groundwater and rocks.