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

**FINAL REPORT**
**SUPPORTING REPORT**

# PART 2

# ENVIRONMENTAL FIELD SURVEY

**Final Report**
**(Supporting Report)**

**Part 2 Environmental Field Survey**

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# PART - 2 ENVIRONMENTAL FIELD SURVEY

## CHAPTER 1 Contamination Sources of Groundwater

The groundwater quality in Bogotá plain is characterized with widely extended, highly concentrated $NH_4$-N and $H_2S$. It appears to be a very exceptional case of groundwater, hard to find same cases in other countries.

Regarding to a cause of this exceptional quality, first of all, we have to doubt the contaminations might come from ground surface by extensive human activities, such as a flow out of nitrogenous fertilizer, an infiltration of domestic, industrial and livestock wastes, because contaminations of the kinds has been commonly experienced all over the world. If the contamination has been occurred in limited places in the plain, above reasoning would be considerably persuasive and has a good possibility. However, the case of Bogotá plain is that, a widely extended contamination in groundwater has been confirmed, so that a huge amount of contaminants has been certainly stocked underground. Accordingly, without a quantitative approach to the relation between contaminants generated on the surface and stocked contaminants in the groundwater, we can't jump at the first reasoning.

Following description is, at first, to guess the amount of nitrogen and sulfur that generate on the surface and infiltrate into subsoil, second, to guess the amount of stocked N and S in underground and finally, to compare both amounts to give an obvious evidence that contaminants generated on the surface are too small and can't be a major source of stocked contaminants of the saturated zone.

### (1) A procedure of estimation

A procedure of estimation will be illustrated in Figure-1.1.

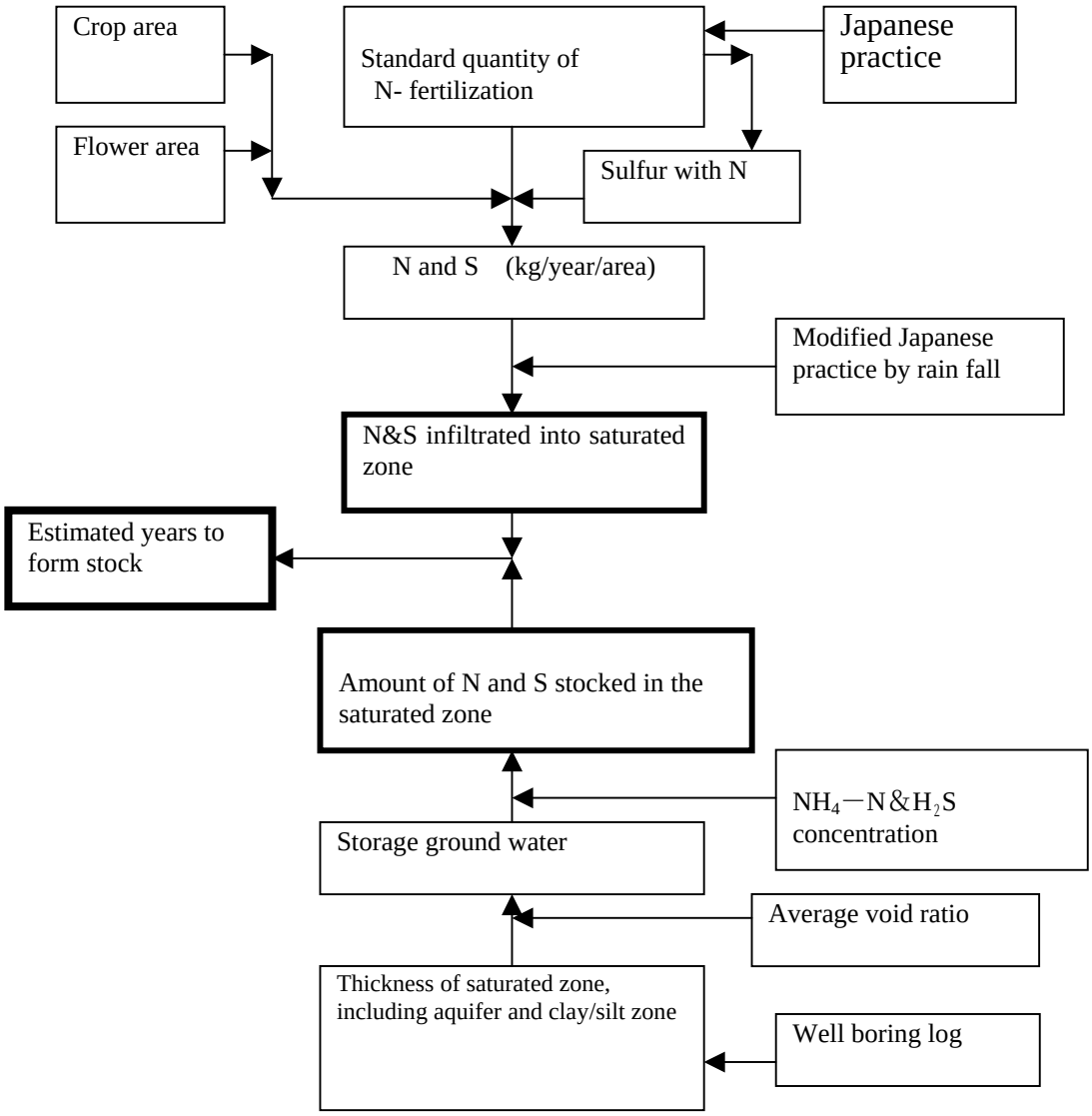


**Figure-1.1 The Estimation Procedure of Generation, Infiltration and Stock of N and S**

### (2) Data for estimation

Generating sources on the ground surface in the basin is listed in Table-1.1. N and S generating from ground surface is listed in Table-1.1. Stocks in saturated zone are listed in Table-1.2.

## Table-1.1 Generating Sources on the Ground Surface in the Basin

| Basin | Total area (ha) | Crop area (ha) | Flower farm area (ha) | Population (person) | Cattle (head) | Factory |
|---|---|---|---|---|---|---|
| Bogota(1) | 175 | 16.74 | 1 | | 154 | |
| Soacha R | 12,740 | 1,219 | 125 | 270,217 | 8,749 | |
| Bogota(2) | 11,136 | 1,065 | 110 | 5,232,730 | 4,378 | |
| Subachoque R(1) | 3,103 | 297 | 31 | | 814 | |
| Bojaca R | 21,546 | 2,062 | 212 | 171,874 | 10,896 | |
| Subachoque R(2) | 40,251 | 3,852 | 397 | 304,083 | 27,405 | |
| Tunjuelito | 38,305 | 3,665 | 377 | 5,205,790 | 14,447 | |
| Bogota(3) | 53,120 | 5,083 | 524 | 5,324,909 | 15,450 | |
| Chicu R | 13,298 | 1,273 | 131 | 5,113,493 | 6,255 | |
| Bogota(4) | 6,232 | 596 | 61 | 5,020,467 | 2,477 | |
| Neusaca R | 19,394 | 1,856 | 191 | 5,179,688 | 10,942 | |
| Bogota(5) | 10,430 | 998 | 102 | | 6,006 | |
| Teusaca R | 34,922 | 3,342 | 344 | | 27,855 | |
| Bogota(6) | 6,609 | 632 | 65 | | 2,525 | |
| Neusa R | 42,906 | 4,106 | 423 | | 24,958 | |
| Bogota(7) | 17,366 | 1,662 | 171 | 132,857 | 10,252 | |
| Tomine R | 36,697 | 3,512 | 362 | | 26,603 | |
| Bogota(8) | 10,263 | 982 | 101 | | 8,566 | |
| Sisga R | 15,196 | 1,454 | 150 | | 9,520 | |
| Bogota(9) | 27,153 | 2,598 | 268 | | 23,202 | |

Note: Flower farms has no possibility of the flow out of contaminations, because of closed cycle system.

## Table-1.1 N and S from Surface

| Basin | N (Fertilization / infiltration) | N from domestic wastewater (Generation / flow out) | N discharged by cattle | Total N discharged in ground water | S (Fertilization / Flow out) | S from domestic waste water | S discharged from cattle | Total S discharged in ground water |
|---|---|---|---|---|---|---|---|---|
| Bogota(1) | 167,400 / 16,740 | 289 | 7,700 / 385 | | | | | |
| Soacha R | 121,900 / 12,190 | 2,892 | 437,450 / 21,872 | 36,954 | 17,442 | 0 | 0 | 17,442 |
| Bogota(2) | 106,500 / 10,650 | 47,604 | 218,900 / 10,945 | 69,199 | 32,662 | 0 | 0 | 32,662 |
| Suba R(1) | 29,700 / 2,970 | 132 | 40,700 / 2,035 | | | | | |
| Bojaca R | 206,200 / 20,620 | 10,536 | 544,800 / 27,240 | 58,396 | 27,562 | 0 | 0 | 27,562 |
| Suba R(2) | 285,200 / 28,520 | 9,288 | 1,370,250 / 68,512 | 116,320 | 54,903 | 0 | 0 | 54,903 |
| Tunjuelito | 366,500 / 36,650 | 111,872 | 722,350 / 36,117 | 184,639 | 87,149 | 0 | 0 | 87,149 |
| Bogota(3) | 508,300 / 50,830 | 0 | 772,500 / 38,625 | 89,455 | 42,222 | 0 | 0 | 42,222 |
| Chicu R | 127,300 / 12,730 | 3,240 | 322,750 / 16,137 | 32,107 | 15,154 | 0 | 0 | 15,154 |
| Bogota(4) | 59,600 / 5,960 | 12,292 | 123,850 / 67,192 | 24,444 | 11,537 | 0 | 0 | 11,537 |
| Neusaca R | 185,600 / 18,560 | 3,456 | 547,100 / 27,350 | 24,751 | 11,682 | 0 | 0 | 11,682 |
| Bogota(5) | 99,800 / 9,980 | 24,804 | 300,300 / 15,015 | | | | | |
| Teusaca R | 334,200 / 33,420 | 12,590 | 1,392,750 / 69,637 | 115,647 | 54,585 | 0 | 0 | 54,584 |
| Bogota(6) | 63,200 / 6,320 | 9,348 | 126,250 / 6,312 | | | | | |
| Neusa R | 410,400 / 41,040 | 3,456 | 1,247,900 / 62,395 | 106,891 | 50,452 | 0 | 0 | 50,452 |
| Bogota(7) | 166,200 / 16,620 | 3,240 | 512,600 / 25,630 | 45,490 | 21,471 | 0 | 0 | 21,471 |
| Tomine R | 351,200 / 35,120 | 1,440 | 1,330,150 / 66,507 | | | | | |
| Bogota(8) | 98,200 / 9,820 | 1,032 | 428,300 / 21,415 | | | | | |
| Sisga R | 145,400 / 14,540 | 660 | 476,000 / 23,800 | | | | | |
| Bogota(9) | 259,800 / 25,980 | 2,496 | 1,160,100 / 58,005 | 86,481 | 40,819 | 0 | 0 | 40,819 |

Assumption:

(1) Average Fertilization 100 kg-N/ha
(2) Infiltrating Fertilizer 10% of Fertilization
(3) Generation Rate of Domestic wastewater, rural 60 l/c/d
(4) N Contents in Sewer 40mg/l
(5) Infiltration in subsoil urban= 0 Rural= 10%
(6) N from cattle : Dung 125g-N/head/d Urine 76g-N/head/d Total N ,50kg/head/year
(7) Infiltration of cattle waste: 5% of total
(8) S in (NH4)2SO4 : 41kg of N in 100kg of(NH4)2SO4 , S accompanied with N: 41x23.6/20.5=47.2kg

**Table-1.2 Stocks in Saturated Zone**

| Basin | Total area ( ha) | Thickness of saturated zone ( m) | Void ratio ( % ) | Net water storage ($1000M^3$) | Total-N Conc./N Stock ($g/m^3$)/kg | $H_2S-S$ conc. / Stock ($g/m^3$)/kg |
|---|---|---|---|---|---|---|
| Bogota(1) | 175 | | | | | |
| Soacha R | 12,740 | 69 | 0.4 | 3,516,240 | 0.615 / 2,173,036 | 1.84 / 6,094,776 |
| Bogota(2) | 11,136 | 69 | 0.4 | 3,073,536 | 3.78 / 11,611,819 | 1.32 / 3,823,484 |
| Subachoque R(1) | 3,103 | | | | | |
| Bojaca R | 21,546 | 69 | 0.4 | 5,946,696 | 2.14 / 12,779,449 | 2.20 / 12,310,850 |
| Subachoque R(2) | 40,251 | 69 | 0.4 | 11,109,276 | 3.29 / 36,582,845 | 2.04 / 21,325,810 |
| Tunjuelito | 38,305 | 69 | 0.4 | 10,572,180 | 6.25 / 66,076,125 | 2.03 / 20,155,501 |
| Bogota(3) | 53,120 | 93 | 0.4 | 19,760,640 | 4.91 / 97,024,742 | 1.52 / 28,114,369 |
| Chicu R | 13,298 | 93 | 0.4 | 4,946,856 | 2.23 / 11,031,488 | 1.75 / 8,164,855 |
| Bogota(4) | 6,232 | 93 | 0.4 | 2,318,304 | 4.57 / 10,594,649 | 1.60 / 3,499,164 |
| Neusaca R | 19,394 | 69 | 0.4 | 5,352,744 | 3.52 / 18,841,158 | 1.42 / 7,152,443 |
| Bogota(5) | 10,430 | | | | | |
| Teusaca R | 34,922 | 40 | 0.4 | 5,587,520 | 6.79 / 37,939,260 | 1.81 / 9,571,977 |
| Bogota(6) | 6,609 | | | | | |
| Neusa R | 42,906 | 106 | 0.4 | 18,192,144 | 3.52 / 64,036,346 | 1.27 / 21,655,291 |
| Bogota(7) | 17,366 | 106 | 0.4 | 7,363,184 | 3.43 / 25,255,721 | 1.38 / 9,540,895 |
| Tomine R | 36,697 | | | | | |
| Bogota(8) | 10,263 | | | | | |
| Sisga R | 15,196 | | | | | |
| Bogota(9) | 27,153 | 134 | 0.4 | 14,554,008 | 1.32 / 19,211,290 | 2.67 / 36,593,899 |

Assumption:
(1) Thickness of saturated zone is assumed, at least the distance from the top of the first sand layer to the bottom of the last sand layer that is recorded on test boring logs
(2) Average 40% of void ratio
(3) Storage water in the saturated zone is , at least, (1)x(2)

### (3) The result of trial calculation

We have selected 13 basins that have water analysis data, out of total 20 basins. The result of the trial calculation supports our consideration mentioned before, namely contaminants come from surface is too small in quantity to explain existing large accumulation in underground.

The summery of trial calculation indicates that, for total 13 basins, based on estimated generation rate of N and S on the surface and estimated accumulation of N and S in the groundwater, to achieve the accumulation by the generation rate, it requires 417 years for N and 402 years for S.

The trial calculation conducted by the Study team is based on several assumptions. It will be required a re-calculation based on more reliable data and assumption, but, in spite of re-calculation, the conclusion might be certain, from first to last. Stepped calculation is shown in the supporting report with basic data and assumption. The summarized results are shown in Table-1.3.

## Table-1.3 Summary of Calculation

| Basin | N from surface ( kg /y ) | Accumulated N in saturated zone ( kg ) | **Virtual years for accumulation ( y )** | S from surface ( kg/y ) | Accumulated S in saturated zone ( kg ) | **Virtual years for accumulation (y)** |
|---|---|---|---|---|---|---|
| Bogota(1) | -- | -- | -- | -- | -- | -- |
| Soacha R | 36,954 | 2,173,036 | **58** | 17,442 | 6,094,776 | **358** |
| Bogota(2) | 69,199 | 11,611,819 | **168** | 32,662 | 3,823,484 | **119** |
| SubachoqueR(1) | -- | -- | -- | -- | -- | -- |
| Bojaca R | 58,396 | 12,779,449 | **220** | 27,562 | 12,310,850 | **455** |
| Subachoque R(2) | 116,320 | 36,582,815 | **315** | 54,903 | 21,325,810 | **387** |
| Tunjuelito | 184,639 | 66,076,125 | **359** | 87,149 | 20,155,501 | **231** |
| Bogota(3) | 89,455 | 97,024,742 | **1,090** | 42,222 | 28,114,369 | **669** |
| Chicu R | 32,107 | 11,031,488 | **344** | 15,154 | 8,164,855 | **594** |
| Bogota(4) | 24,444 | 10,594,649 | **441** | 11,537 | 3,499,164 | **318** |
| Neusaca R | 24,751 | 18,841,658 | **785** | 11,682 | 7,152,443 | **650** |
| Bogota(5) | -- | -- | -- | -- | -- | -- |
| Teusaca R | 115,647 | 37,939,260 | **329** | 54,585 | 9,571,977 | **176** |
| Bogota(6) | -- | -- | -- | -- | -- | -- |
| Neusa R | 106,891 | 64,036,346 | **604** | 50,452 | 21,655,291 | **433** |
| Bogota(7) | 45,490 | 25,255,721 | **561** | 21,471 | 9,540,895 | **454** |
| Tomine R | -- | -- | -- | -- | -- | -- |
| Bogota(8) | -- | -- | -- | -- | -- | -- |
| Sisga R | -- | -- | -- | -- | -- | -- |
| Bogota(9) | 66,481 | 19,211,290 | **223** | 40,819 | 36,593,899 | **914** |
| **Total** | | 413,161,428 | **417** | | 188,003,314 | **402** |

## CHAPTER 2 Land Subsidence

Subsidence of surface land is occasionally referred in relation with excessive withdrawal of groundwater in Bogotá Plain and so called subsidence that can be observed in limited spots in Bogotá D.C. will be classified into following 3 cases.

i) "Waves" and cracks on the paved road
ii) Cracks on wall and floor of houses and buildings
iii) Land sink in parks and the likes with no upper load

As a matter of fact, "exposure" of well casing, which suggests just subsidence of ground around the well, is not observed anywhere. We shouldn't make any decisive conclusion at present, before detail observation and analysis is performed in this field. However, for the time being, following reasoning would be possible.

(a) Soft ground, with rich contents of clay and silt and poor bearing capacity of less than 3 tons, is widely extended in the study area. Thus, earth filling and installing structures on the ground, if any, may cause consolidation settlement in superficial soil zone (in superficial zone).

(b) The construction of housing or building on the ground of poor bearing capacity, without enough foundation work, might cause consolidation settlement by above load.

(c) However, consolidation settlement in the deep soil zone owing to excessive withdrawal of groundwater is not ever confirmed.

Since the water balance in the basin is not expected to be inclining on deficit side, the occurrence of subsidence relating to groundwater is hard to believe. However, according to a statistical analysis conducted by the study team, the lowering of water table in the basin is observed. Consequently, long-term observation and analysis of the subsidence (consolidation or elastic) related to the withdrawal of groundwater is most required.

## CHAPTER 3 Quality of River Water and River-Bed Material

The Study Team carried out environmental survey. This result is summarized in Table-4.1 to 4.2.

**Table-4.1 Result of analysis of Bogota River**

| | $NH_4$-N Mg/l | $NO_3$-N Mg/l | $NO_2$-N Mg/l | T-N Mg/l | Cl Mg/l | $SO_4$ Mg/l | $H_2S$ Mg/l | Cu µg/l | Cr µg/l | Fe Mg/l | Mn µg/l | TCU | Dissolved $O_2$ mg/l |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Origin | n.d | 0.1 | 6 | 6.1 | 0.2 | 2 | 2 | 1 | 1.5 | 0.2 | 4.8 | 20 | 7.8 |
| Choconta | 0.01 | 0.31 | 6 | 6.32 | 11.7 | 2 | 4 | 1 | 34 | 0.2 | 23 | 90 | 7.8 |
| Before Tibitoc | 0.74 | 0.24 | 14 | 15 | 6.75 | 2 | 2 | 4.9 | 1.7 | 0.5 | 28 | 120 | 2.6 |
| Amarillo | n.d | 0.86 | 51 | 51.9 | 19.2 | 2 | 2 | 5.1 | 1.6 | 0.3 | 30 | 70 | 1.4 |
| Tunjuero | 21.7 | 0.12 | 6 | 27.8 | 38.7 | 23.5 | 6 | 5.2 | 19 | 1.28 | 71 | 120 | 0.8 |
| Allcachin | 1.59 | 0.66 | 39 | 41.25 | 24.9 | 2.64 | 4 | 1 | 2.8 | 0.52 | 63 | 70 | 2.3 |
| Vargas | 21.7 | 0.1 | 6 | 27.8 | 3.55 | 2 | 8 | 2.5 | 6.2 | 0.68 | 81 | 200 | 0.4 |

**Table-4.2 Water Analysis of Bogota River at TIBITOC Purification Unit**

| | D.O, mg/l | TCU | T-Fe, mg/l | $No_3$-N,mg/l | Mn, µg/l |
|---|---|---|---|---|---|
| TOCANCIPA | | | | | |
| Jan. | 3.81 | 66 | 1.73 | 0.4 | 0.03 |
| Apr | 3.31 | 91 | 1.7 | 0.6 | 0.051 |
| Jul | 4.04 | 58 | 1.94 | 0.53 | 0.02 |
| Oct | 4.26 | 64 | 1.58 | 0.5 | 0.029 |
| BOCA TOMA(S) | | | | | |
| Jan. | 3.18 | 66 | 1.77 | 0.31 | |
| Apr | 3.57 | 90 | 2.05 | 0.69 | |
| Jul | 3.83 | 63 | 1.99 | 0.54 | |
| Oct | 3.66 | 66 | 1.66 | 0.58 | |
| BOCA TOMA(N) | | | | | |
| Jan. | 3.45 | 62 | 1.93 | 0.45 | 0.37 |
| Apr | 3.94 | 85 | 2.05 | 0.83 | 0.038 |
| Jul | 3.83 | 64 | 2.03 | 0.54 | 0.027 |
| Oct | 4.11 | 67 | 1.53 | 0.46 | 0.46 |