APPENDIX C

WATER RESOURCES AND USE MANAGEMENT

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APPENDIX C WATER RESOURCES AND USE MANAGEMENT

CHAPTER I EXISTING WATER USE

1.1 Farmland and Crops of the Study Area

Land use in the Study Area predominates in agricultural use. These farmlands extend on flat planes as well as mountain/hill areas. Almost all farmlands on mountain/hill areas are rainfed. On the other hand, irrigation and drainage system of CAR locates on flat planes.

Pastures are dominant crops and stock raising is priority agriculture in the Study Area. In addition to this, animal husbandry utilizes natural grasses growing on mountain/hill areas.

1.1.1 Farmland Distribution

Understanding location of non-agricultural lands of the Study Area is the most efficient way to grasp the distribution of farmlands. The non-agricultural lands consist of primeval forests, reforestation areas, natural bushes and paramo areas. The other areas fall in farmlands consequently. The farmland here means area that is fully and/or partially utilized for agriculture including natural grass land grazed by cattle. The locations of major non-agricultural lands are, as follows:

(1) Primeval Forests

Primeval forests locate along the basin boundaries of Suarez river, downstream of Tolon gate. Other small primeval forests are scattering in mountain area.

(2) Reforestation Areas

Reforestation areas are covered by eucalyptuses and pine trees in the Study Area. One of these areas locates along the northern basin boundary of Susa river, northeast of Susa urban area. The other locates surrounding Sutatausa urban area.

(3) Natural Bushes

There are natural bush areas in mountain/hill areas sporadically. The one in Cucunuba lake basin is notable.

(4) Paramo Areas

The largest paramo area extends on eastern part of Lenguazaque river basin. However, considerable part of this area produces potato and poa grass (pasture). The others locate in the basins of Suta, Ubate, Susa and Simijaca rivers.

1.1.2 Crops

Present crops in the Study Area are pastures (mejorados, kikuyo, poa, gramineous), wheat, barley, maize, potato, tomato, kidney bean, etc. Of these crops, pastures are dominant crops in irrigated areas as well as rainfed areas.

1.2 Irrigation Water Use

In this Study, irrigation water use means the irrigation water used by CAR irrigation and drainage system. This is because that the CAR system is the only irrigation system in the Study Area.

1.2.1 Irrigated Area and Cropping Pattern

The CAR system extends on the flat plane of the Study Area. This plane locates along river-lake systems. The major river-lake system is Palacio/Cucunuba lakes - Ubate river - Fuquene lake - Suarez river.

(1) Irrigated Area

The irrigation and drainage system of CAR covers 19,444.3638 ha (the number of registered plots is 4,186) as of October 1999 based on CAR tariff list ("*factores que intervienen en la liquidacion de la cuota de reembolso en los distritos de riego*"). This registered figure does not include small lots (less than 6,400 m2) which are covered by the system (although tariffs are collected from these small lots). However, it is judged that this figure represents the present irrigated area of the Study Area.

CAR divides the system into 12 sub-zones considering each zone's water sources, etc. In this Study, the system is divided into 15 irrigation blocks considering water balance analysis and operation simulation (Fig. C.1.1). Present net irrigated area (CAR registered area) and present gross irrigated area (irrigation block area) of each irrigation block are shown below (total gross irrigated area is 21,603 ha). In the estimation of the irrigation block areas, the ratio of net area to gross area is assumed at 0.9. This figure is determined through comparison of registered area and measured area on cadastral maps (s=1/10,000) using the selected several sample areas.

Block No.	Irrigation Block Name	Net Irrigated Area (ha)	Gross Irrigated Area (ha)	Remarks
1	Suta	749	832	
2	Cap-1	571	634	
3	Cucunuba	1,703	1,892	
4	Lenguazaque	1,576	1,751	
5	Cap-2	1,424	1,582	This block is not fully irrigated because capacities of its irrigation canals are insufficient.
6	Mariño	630	700	
7	Mariño-Ubate	348	387	
8	Fuquene	2,283	2,537	
9	Honda	458	509	
10	Susa	507	563	
11	Suarez	7,478	8,309	
12	Simijaca	0	0	This block is future extension area for irrigation. However, block No.12 is given considering its location.
13	Old-Suarez	205	228	
14	Madron	1,223	1,359	
15	Merchan	288	320	
	Total	19,443	21,603	

(2) Major Crops

Present cultivated crops in the CAR system are pastures (mejorados, kikuyo, gramineous), wheat, barley, maize, potato, tomato, etc. Among these crops pastures are the dominant crops.

Cultivated areas of these major crops are necessary in order to calculate water demand of irrigation. However it is not available to utilize the existing data in question, so hearing survey was conducted at relating municipal offices. From this hearing survey, it is found that only in Simijaca municipality vegetables are cultivated in a non-negligible scale. Irrigation blocks relating to Simijaca municipality are No.11 and No.12. Therefore, only pastures are considered in the other blocks. The following table shows cultivated areas of major crops in block No.11.

Present pastures and vegetable areas (represented by maize) are estimated at 18,462 ha and 3,141 ha in the CAR system respectively. Vegetable area is equivalent to 15% of present irrigated area.

Block No.	Irrigation Block Name	Cultivated Crops	Present Irrigated Area (Gross ha)
11	Suarez	Pastures	5,168
		Maize	3,141
		Total	8,309

(3) Cropping Pattern

Modules for irrigation consumption (Tables C.1.1 to C.1.5) inform the cropping patterns in the irrigated area. CAR established these modules to grant water users the required discharges in a technical and adequate way. Cropping patterns of the major crops are, as follows:

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pastures	■	■	■	■	■	■	■	■	■	■	■	■
Maize	■		■	■	■	■	■		■	■	■	■

Note) ■ : Cultivated Month.

1.2.2 Irrigation System

Salient features of present irrigation system by each irrigation block are, as follows:

(1) Suta Irrigation Block

Water source of this block is Suta river. Irrigation water is taken by gravity in the upper portion of this block. There are no reservoir and gate for this block.

(2) Cap-1 Irrigation Block

Water source of this block is Hato dam and Ubate river. Irrigation water for this block is taken at intake weir, Captacion No.1.

(3) Cucunuba Irrigation Block

Water source of this block is streams and Cucunuba lake. There are Cartagena gate and one (1) pump station at the end of this block. Cartagena gate controls water level of Cucunuba lake, and this pump station returns residual surface water to Cucunuba lake. Thus water resources are effectively utilized in this block.

(4) Lenguazaque Irrigation Block

Water source of this block is Lenguazaque river. There are no reservoir and gate for this block.

(5) Cap-2 Irrigation Block

Water source of this block is Hato dam and neighboring watershed. Intake weir, Captacion No.2, locates downstream of Captacion No.1. Due to insufficient capacities of irrigation canals in this block, irrigation water can not cover whole area. Actual irrigated area is estimated at around 20% of this block area (gross area 316 ha).

(6) Mariño Irrigation Block

Water source of this block is Mariño canal. This block does not utilize Ubate river. There are no reservoir and gate for this block.

(7) Mariño- Ubate Irrigation Block

Water source of this block is Mariño canal and Ubate river. There are no reservoir and gate for this block.

(8) Fuquene Irrigation Block

This block surrounds Fuquene lake. Water source of this block is neighboring watershed and Fuquene lake.

(9) Honda Irrigation Block

Water source of this block is Fuquene lake and Honda river. There are no reservoir and gate for this block.

(10) Susa Irrigation Block

Water source of this block is Susa river. There are no reservoir and gate for this block.

(11) Suarez Irrigation Block

Water source of this block is Suarez river and Fuquene lake. There is Tolon gate at the end of this block. Tolon gate controls water level of Fuquene lake.

(12) Simijaca Block

This irrigation block is not irrigated yet.

(13) Old-Suarez Irrigation Block

Water source of this block is original Suarez river and neighboring watershed. There are no reservoir and gate for this block. There is pipeline system (ϕ=16”) connecting Tolon gate and this block for supplying irrigation water. However, this pipeline is clogged at present.

(14) Madron Irrigation Block

Water source of this block is Madron river. There are no reservoir and gate for this block.

(15) Merchan Irrigation Block

Water source of this block is neighboring watershed. There was Merchan gate in Suarez river. However, this gate was destructed by flash flood from Chiquinquira river about ten (10) years ago. Therefore, this block can not utilize Suarez and Chiquinquira rivers at present.

1.2.3 Water Requirement on Farm

Water requirements on farm level are derived from the existing CAR irrigation modules (Tables C.1.1 to C.1.5). These CAR irrigation modules are determined by basins (Fuquene, Susa, Simijaca, Chiquinquira and Suarez). The following table summarizes water requirement on farm level in the irrigated area:

Irrigation Block	Gross Area (ha)	Adopted Irrigation Module			Net Water Req. ('000m^3/year)
		Basin Name	Crop	Net Irrigation Requirement (m^3/ha/year)	
1. Suta	832	Fuquene	Pastures	3,898	3,243
2. Cap-1	634	Fuquene	Pastures	3,898	2,471
3. Cucunuba	1,892	Fuquene	Pastures	3,898	7,374
4. Lenguazaque	1,751	Fuquene	Pastures	3,898	6,825
5. Cap-2	1,582 (316)	Fuquene	Pastures	3,898	6,166 (1,232)
6. Mariño	700	Fuquene	Pastures	3,898	2,728
7. Mariño -Ubate	387	Fuquene	Pastures	3,898	1,508
8. Fuquene	2,537	Fuquene	Pastures	3,898	9,889
9. Honda	509	Fuquene	Pastures	3,898	1,984
10. Susa	563	Susa	Pastures	3,044	1,714
11. Suarez	5,168	Suarez	Pastures	2,757	14,248
	1,149	Suarez	Maize	1,389	1,595
	1,992	Simijaca	Maize	1,788	3,561
Sub Total	8,309	--	--	--	19,404
12. Simijaca	0	Simijaca	Pastures	3,385	0
	0	Simijaca	Maize	1,788	0
Sub Total	0	--	--	--	0
13. Old-Suarez	228	Suarez	Pastures	2,757	629
14. Madron	1,359	Suarez	Pastures	2,757	3,747
15. Merchan	320	Suarez	Pastures	2,757	882
Total	21,603 (20,337)	--	--	--	68,564 (63,630)

1.2.4 Surface Water Use

In the estimation of surface water use, understandings of large area water balance are necessary in addition to the water requirement on farm level. Water required on farm level of pastures, which is the net irrigation requirement of the major cultivation of the CAR system, originates in groundwater, which moves up to their effective root zones (depth around 0.4 – 0.6 m) by a capillary action (around 0.6 – 1.0 m). The said consumed groundwater links to surface water flowed/stored in rivers and canals in irrigated area. In line with this idea, irrigation water demand is evaluated as surface water use.

In this Study, the surface water use is estimated using irrigation efficiency. Irrigation efficiency comprises conveyance efficiency, field canal efficiency and field application efficiency. In the study of these efficiencies, standard values are referred from existing authorized data (FAO irrigation series and so on). Water balance study under present conditions leads the following irrigation efficiencies as the possible feature:

Irrigation Block	Gross Area (ha)	Main Water Source	Ec	Eb	Ea	Ep
1. Suta	832	Suta River	1.0	0.8	0.8	0.640
2. Cap-1	634	Hato Dam	0.9	0.8	0.8	0.576
3. Cucunuba	1,892	Cucunuba Lake	1.0	1.0	0.8	0.800
4. Lenguazaque	1,751	Lenguazaque River	1.0	0.8	0.8	0.640
5. Cap-2	1,582 (316)	Hato Dam	0.9	0.8	0.8	0.576
6. Mariño	700	Mariño Canal	1.0	0.8	0.8	0.640
7. Mariño -Ubate	387	Mariño Canal, Ubate River	1.0	0.8	0.8	0.640
8. Fuquene	2,537	Fuquene Lake	1.0	0.8	0.8	0.640
9. Honda	509	Honda River	1.0	0.8	0.8	0.640
10. Susa	563	Susa River	1.0	0.8	0.8	0.640
11. Suarez	8,309	Fuquene Lake, Susa River	1.0	0.8	0.8	0.640
12. Simijaca	0	Simijaca River	1.0	0.8	0.8	0.640
13. Old-Suarez	228	Streams	1.0	0.8	0.8	0.640
14. Madron	1,359	Madron River	1.0	0.8	0.8	0.640
15. Merchan	320	Streams	1.0	0.8	0.8	0.640

Note) Ec = Conveyance Efficiency, Eb = Field Canal Efficiency,
Ea = Field Application Efficiency, Ep = Irrigation Efficiency (=Ea.Eb.Ec)

The following table shows surface water use of the irrigated area:

Irrigation Block	Gross Area (ha)	Net Water Req. ('000m^3/year)	Ep	Gross Water Req. ('000m^3/year)
1. Suta	832	3,243	0.640	5,067
2. Cap-1	634	2,471	0.576	4,290
3. Cucunuba	1,892	7,374	0.800	9,218
4. Lenguazaque	1,751	6,825	0.640	10,664
5. Cap-2*	1,582 (316)	6,166 (1,232)	0.576	10,705 (2,138)
6. Mariño	700	2,728	0.640	4,263
7. Mariño -Ubate	387	1,508	0.640	2,357
8. Fuquene	2,537	9,889	0.640	15,451
9. Honda	509	1,984	0.640	3,100
10. Susa	563	1,714	0.640	2,678
11. Suarez	8,309	19,404	0.640	30,319
12. Simijaca	0	0	0.640	0
13. Old-Suarez	228	629	0.640	982
14. Madron	1,359	3,747	0.640	5,854
15. Merchan	320	882	0.640	1,378
Total	21,603 (20,337)	68,564 (63,630) = 2.17 (2.02) m^3/s		106,326 (97,759) = 3.37 (3.10) m^3/s

Note) (Gross Water Requirement) = (Net Water Requirement)/ Ep.
*Figure in parentheses shows the case of actual irrigated area.

1.3 Livestock Water Use

CAR prepared water consumption rates of livestock, as follows:

Species	Consumption (litters/per head day)
Bovine	25
Equine	20
Ovine	15
Porcine	10
Poultry (100 units)	15

Source: Ref. 1)

Multiplying present cattle numbers by consumption rates makes the following livestock water use in the Study Area:

Species	Number of Heads (1998)	Consumption (litters/per head day)	Source Demand (m^3/day)
Bovine	171,402	25	4,285
Porcine	29,562	10	296
Ovine	64,400	15	966
Total	265,364	--	5,547 (0.06 m^3/s)

In the CAR system, 50,000 heads of bovine are estimated (2.7 heads per ha of pastures). Porcine and ovine are negligible in the system.

1.4 Municipal Water Use

1.4.1 Water Source and Treatment System

Small portion of industrial water use for milk product fabrication and some part of rural water supply come from underground water. The remaining water uses (domestic, institutional and other industrial water demand) utilize surface water from rivers and streams in the Study Area.

For surface water source, dominant components of treatment process are sedimentation, flocculation, filtering and chlorination. The underground water for milk product fabrication is utilized without treatment.

1.4.2 Water Use

Table C.1.6 shows the results of questionnaire survey for public water supply systems in the Study Area. These public water supply systems cover domestic, commercial, institutional, slaughtering, and large portion of milk product fabrication water uses. This is because these water uses share same water supply system in each municipality. Among those public water supply systems, only those of Ubate and Chiquinquira municipalities have direct relationship with CAR system. There are also rural water supply systems (vereda water supply systems) in the Study Area. However these vereda systems do not cover whole rural population.

Based on this survey, intake volume of raw water results in 914,704 m^3/month in the Study Area (11.0 million m^3/year).

(1) Domestic Water Demand

The following table shows modules for domestic consumption prepared by CAR:

Item	Consumption (litters/per capita day)		
[Urban Zone] Population Size	Minimum	Medium	Maximum
<= 5,000	130	150	180
5,001 – 10,000	150	165	185
10,001 – 20,000	170	180	190
> 20,001	185	195	205
[Rural Zone]		125	

Source: Ref. 1)

From this CAR module, domestic consumption (medium level) ranges 150 to 195 litters per capita per day in accordance with population size. Tables C.1.7 shows estimated present domestic water demand of the Study Area. From this table, total customer demand in question results in 27,000 m^3/day (urban 14,000 m^3/day and rural 13,000 m^3/day; public 15,000 m^3/day and vereda 12,000 m^3/day) in the Study Area (9.9 million m^3/year).

(2) Institutional Water Demand

Institutional water demand of the Study Area is estimated at 10% of domestic water demand. This figure is estimated based on the modules for institutional consumption prepared by CAR. As the result, the present institutional water demand of the Study

Area is estimated at 2,700 m^3/day.

(3) Industrial Water Demand

Cattle slaughtering and milk product fabrication are dominant industries in the Study Area. The following table shows modules for industrial consumption established by CAR:

[C.I.I.U Code] Type of Industry	Type of Plant	Production Unit	Module (litters)
[3.1.1.1] Cattle Slaughtering (preparation and conservation)	Slaughterhouse	per bovine	500
		per porcine	250
		per ovine or caprice	200
		per poultry	30
	Packing Factories	per ton of alive animals	5,000
[3.1.1.2] Milk Product Fabrication	Milk Collecting Station	per ton of milk	1,500
	Pasteurized Milk Production	per ton of milk	2,000
	Cheese Production	per ton of cheese	15,000
	Butter Production	per ton of butter	20,000

Source: Ref. 1)

Using this CAR module, present water demands for slaughtering and milk product fabrication are estimated at 250 m^3/week (public) and 2,600 m^3/day (public 2,200 m^3/day and vereda 400 m^3/day) respectively (Tables C.2.2 and C.2.3).

(4) Ratio of Source Demand to Customer Demand

Ratio of source demand (water demand abstracted at river intake points) to customer demand of the Study Area is estimated as shown below. Resulted figure 1.6 is high comparing CAR standard value (1.2).

Item		Quantity (‘000 m^3/year)
Source Demand	914,704 m^3/month x 12 month =	10,976
Customer Demand		
Domestic	15,000 m^3/day x 365.25 day =	5,479
Institutional	10% of Domestic	548
Industrial (slaughtering)	250 m^3/week x 52 week =	13
Industrial (milk product)	2,200 m^3/day x 365.25 day =	804
Sub Total		6,844
Ratio	10,976/ 6,844 =	1.6

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CHAPTER II FUTURE PROJECTED WATER USE

2.1 Irrigation Water Use

Multiplying the projected irrigation area by the CAR irrigation consumption module (Tables C.1.1 to C.1.5) outputs future irrigation water use.

2.1.1 Irrigated Area and Major Crops

(1) Irrigated Area

Judging from CAR information ("*Predial Actualizado A Diciembre 31/92, Contrato 086/92*"), CAR has intention to extend the existing system area to neighboring flat areas. Therefore, future irrigated area of the CAR system is estimated through adding these extension areas to the present irrigated areas. Gross irrigation area of each extension area is determined through measurement on existing cadastral maps (s=1/10,000). The future irrigated areas are shown below (total gross area is 24,849 ha).

Block No.	Irrigation Block Name	Present Gross Irrigated Area (ha)	Gross Extension Area (ha)	Future Gross Irrigation Area (ha)
1	Suta	832	101	933
2	Cap-1	634	731	1,365
3	Cucunuba	1,892	0	1,892
4	Lenguazaque	1,751	902	2,653
5	Cap-2	1,582	0	1,582
6	Mariño	700	0	700
7	Mariño-Ubate	387	0	387
8	Fuquene	2,537	0	2,537
9	Honda	509	349	858
10	Susa	563	426	989
11	Suarez	8,309	0	8,309
12	Simijaca	0	417	417
13	Old-Suarez	228	0	228
14	Madron	1,359	0	1,359
15	Marchan	320	320	640
	Total	21,603	3,246	24,849

It is expected that the above extension (3,246 ha, 15% increase to the present area) will be realized at least until 2010. In order to realize this extension, the construction/rehabilitation of canals and gates, etc. is necessary.

(2) Major Crops

Based on the hearing survey on present major crops, vegetables are cultivated only in Simijaca municipality in a non-negligible scale. This situation will continue up to 2010. Irrigation blocks relating to Simijaca municipality are No.11 and No.12. In the other blocks, only pastures are considered. The following table shows the future cultivated areas of major crops in block No.11 and No.12.

Future pastures and vegetable areas (represented by maize) are estimated at 21,625 ha and 3,224 ha (3,141+ 83), respectively. Vegetable area is equivalent to 13% of future irrigation area.

Block No.	Irrigation Block Name	Cultivated Crops	Future Irrigated Area (Gross ha)
11	Suarez	Pastures	5,168
		Maize	3,141
		Total	8,309
12	Simijaca	Pastures	334
		Maize	83
		Total	417

2.1.2 Surface Water Use

Future water requirement on farm is calculated, as follows:

Irrigation Block	Gross Area (ha)	Adopted Irrigation Module			Net Water Req. ('000m^3/year)
		Basin Name	Crop	Net Irrigation Requirement (m^3/ha/year)	
Suta. Present	832	Fuquene	Pastures	3,898	3,243
Suta. Extension	101	Fuquene	Pastures	3,898	394
Cap-1. Present	634	Fuquene	Pastures	3,898	2,471
Cap-1. Extension	731	Fuquene	Pastures	3,898	2,849
Cucunuba. Present	1,892	Fuquene	Pastures	3,898	7,374
Lenguazaque. Present	1,751	Fuquene	Pastures	3,898	6,825
Lenguazaque. Extension	902	Fuquene	Pastures	3,898	3,516
Cap-2. Present	1,582	Fuquene	Pastures	3,898	6,166
Mariño. Present	700	Fuquene	Pastures	3,898	2,728
Mariño –Ubate. Present	387	Fuquene	Pastures	3,898	1,508
Fuquene. Present	2,537	Fuquene	Pastures	3,898	9,889
Honda. Present	509	Fuquene	Pastures	3,898	1,984
Honda. Extension	349	Fuquene	Pastures	3,898	1,360
Susa. Present	563	Susa	Pastures	3,044	1,714
Susa. Extension	426	Susa	Pastures	3,044	1,297
Suarez. Present	5,168	Suarez	Pastures	2,757	14,248
	1,149	Suarez	Maize	1,389	1,595
	1,992	Simijaca	Maize	1,788	3,561
Sub Total	8,309	--	--	--	19,404
Simijaca. Extension	334	Simijaca	Pastures	3,385	1,131
	83	Simijaca	Maize	1,788	148
Sub Total	417	--	--	--	1,279
Old-Suarez. Present	228	Suarez	Pastures	2,757	629
Madron. Present	1,359	Suarez	Pastures	2,757	3,747
Merchan. Present	320	Suarez	Pastures	2,757	882
Merchan. Extension	320	Suarez	Pastures	2,757	882
Total	24,849	--	--	--	80,141

Using same idea as present conditions, future surface water use is estimated at 125.5 million m^3 (3.98 m^3/s) as below. Comparing those figures of present condition (106.3 million m^3, 3.37 m^3/s), gross water requirement will increase 18%.

Irrigation Block	Gross Area (ha)		Net Water Req. ('000m^3/year)		Ep	Gross Water Req. ('000m^3/year)	
Suta. Present*	832	(1,176)	3,243	(4,584)	0.576	5,630	(7,958)
Suta. Extension*	101		394		0.576	683	
Cap-1. Present	634		2,471		0.576	4,290	
Cap-1. Extension	731		2,849		0.576	4,947	
Cucunuba. Present	1,892		7,374		0.800	9,218	
Lenguazaque. Present	1,751	(1,407)	6,825	(5,484)	0.640	10,664	(8,569)
Lenguazaque. Extension	902		3,516		0.640	5,493	
Cap-2. Present	1,582		6,166		0.576	10,705	
Mariño. Present	700		2,728		0.640	4,263	
Mariño –Ubate. Present	387		1,508		0.640	2,357	
Fuquene Present	2,537		9,889		0.640	15,451	
Honda. Present	509		1,984		0.640	3,100	
Honda. Extension	349		1,360		0.640	2,125	
Susa. Present	563		1,714		0.640	2,678	
Susa. Extension	426		1,297		0.640	2,026	
Suarez. Present	8,309		19,404		0.640	30,319	
Simijaca. Extension	417		1,279		0.640	1,998	
Old-Suarez. Present	228		629		0.640	982	
Madron. Present	1,359		3,747		0.640	5,854	
Merchan. Present	320		882		0.640	1,379	
Merchan. Extension	320		882		0.640	1,379	
Total	24,849		80,141 = 2.54 m^3/s			125,541 (125,774) = 3.98 m^3/s (3.99 m^3/s)	

*) Hato dam will command these blocks in future.

1. Figures in parentheses: case of transferring 344 ha from Lenguazaque. Present to Suta. Present.

2.2 Livestock Water Use

Multiplying projected number of livestock by the module of cattle consumption fore mentioned results in future livestock water use of the Study Area, as follows:

Species	Projected Number of Heads (2010)	Consumption (litters/per head day)	Source Demand (m^3/day)
Bovine	195,324	25	4,883
Porcine	29,562	10	296
Ovine	69,360	15	1,040
Total	294,246	--	6,219 (0.07 m^3/s)

2.3 Municipal Water Use

Future municipal water use can be estimated based on the CAR module fore mentioned.

(1) Domestic Water Demand

Table C.2.1 shows projection of domestic water demand of the Study Area. From this table, total customer demand in question results in 31,000 m^3/day (urban 17,000 m^3/day and rural 14,000 m^3/day; public 19,000 m^3/day and vereda 12,000 m^3/day) in the Study Area (11.3 million m^3/year). Based on this result, the domestic water demand will increase 15%.

(2) Institutional Water Demand

Future institutional water demand of the Study Area is estimated at 10% of domestic water demand. This figure is estimated based on the module for institutional consumption prepared by CAR. As the result, projected institutional water demand of the Study Area is estimated at 3,100 m^3/day.

(3) Industrial Water Demand

Using the CAR module, the future water demands for slaughtering and milk product fabrication are projected at 300 m^3/week (public) and 2,700 m^3/day (public 2,300 m^3/day and vereda 400 m^3/day), respectively (Tables C.2.2 and C.2.3).

(4) Source Demand

Source demand of public water supply system is estimated by the following method:

S.D.(source demand) = C.D.(customer demand) x (R)

As for (R), figure 1.2 is standard value of CAR. This value includes treatment plant water use and unaccounted-for water. As described before, this figure is 1.6 at present. In this Study, R = 1.2 is adopted in future projection.

CHAPTER III SIMULATION UNDER PRESENT CONDITIONS

3.1 Water Storage and Water Intake System

Salient features of major water storage and intake facilities of the CAR system are, as follows:

System Name	Description
Hato Dam	• Water storage for irrigation in Ubate river basin and municipal water supply for Ubate. • Flood regulation for Fuquene lake. • Center cored rock fill dam (dam height 33 m) completed in 1992. • Area-Capacity Curve (Fig. C.3.1), - H.H.W.L. 2847.29 m: Area 0.96 km^2, Volume 14.4 million m^3 - N.H.W.L. 2842.70 m: Area 0.76 km^2, Volume 9.7 million m^3 - L.W.L. 2828.00 m: Area 0.33 km^2, Volume 2.0 million m^3
Palacio Lake	• Peripheral ring canal functioning as water intake system. - W.L. 2544 m: Area 0.4 km^2, Volume $290x10^3$ m^3 - W.L. 2542.5 m: Area 0 km^2, Volume 0 m^3
Cucunuba Lake	• Water storage for Cucunuba irrigation block. • Area-Capacity Curve, 1984 (Fig. C.3.1), - W.L. 2544 m: Area 2.5 km^2, Volume 6.8 million m^3 - W.L. 2539 m: Area 0 km^2, Volume 0 million m^3
Fuquene Lake	• Water storage for irrigation, and municipal water supply for Ciquinquira. • Area-Capacity Curve, 1984 (Fig. C.3.1), - W.L. 2540.0 m: Area 32.6 km^2, Volume 82.5 million m^3 - W.L. 2532.5 m: Area 0 km^2, Volume 0 million m^3
Cartagena Gate	• Control gate for Cucunuba lake. • Slide Gates - Gate Base El. 2542.90 m - Gate Height 1.74 m
Cubio Gate	• Control gate for Cucunuba lake. • Slide Gates - Gate Base El. 2540.90 m - Gate Height 2.53 m
Tolon Gate	• Control gate for Fuquene lake and Chiquinquira pumping station. • Slide Gates - Gate Base El. 2537.39 - Gate Height 2.52 m
Merchan Gate	• Destroyed by the flush flood from Chiquinquira river in around 1990.

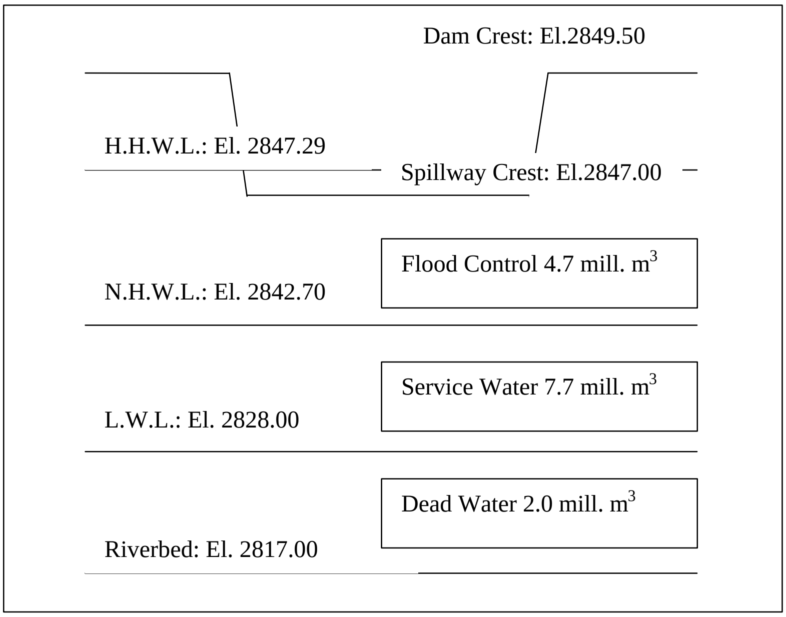
Note) H.H.W.L.: Highest High Water Level
N.H.W.L.: Normal High Water Level
L.W.L.: Low Water Level

3.2 Existing Operation Rules of the Reservoir and Gates

Existing operation rules of the reservoir and gates above mentioned are, as follows:

(1) Reservoir

Following profile shows operation concept of Hato reservoir. Hato reservoir did not experience its H.H.W.L. since its construction. Water level of the reservoir lowers as dry season proceeds, and raises as rainy season proceeds. When the water level exceeds N.H.W.L (El. 2842.7 m), outlet valve of the dam is opened to lower its water level.



Note) H.H.W.L.: Highest High Water Level
N.H.W.L.: Normal High Water Level
L.W.L.: Low Water Level

Stored water in the reservoir is released based on user's request. This released discharge is usually 500 to 600 litter/s. During severe drought period, 800 litter/s is released. As typical operation of Hato dam, it is closed during April, May, September, October and November.

(2) Gates

The following table shows basic concept of existing operation rules of gates:

Gates	Operation Rule		Remarks
	Rainy Season	Dry Season	
Cartagena	Closed	Opened	• Water flow from Cucunuba lake to Palacio lake is scarce.
Cubio	Opened	Closed	• When Cartagena gate is closed, Cubio gate must be opened, vice versa.
Tolon	Opened	Closed	• If Merchan gate exists, this gate maintains upper water level of Merchan gate during dry season.
Merchan	Opened	Closed	• This is operation rule when this gate existed.

The details of existing operation rule of each gate are described below:

(a) Cartagena Gate

Top and bottom elevations of this gate are El.2544.64 m and El.2542.90 m respectively.

During rainy season, Cartagena gate is closed and Cubio gate is opened. This operation is carried out during March to May and August to October usually. As Cartagena gate is closed during rainy season, flow water of Lenguazaque and Ubate rivers can not enter to Cucunuba lake. When water level of Cucunuba lake becomes higher than El.2542.90 m and water level of Cartagena gate (Cubio gate side) is lower than that of Cucunuba lake, Cartagena gate is opened.

During dry season, Cartagena gate is opened and Cubio gate is closed. Through this operation, only flood flows of Lenguazaque and Ubate rivers enter to Cucunuba lake. This reverse flow to Cucunuba lake occurs during June, July, February and January (not frequent) usually.

(b) Cubio Gate

Top and bottom elevations of this gate are El.2543.43 m and El.2540.90 m respectively.

During rainy season, Cubio gate is opened. This operation is carried out in accordance with upper water level of this gate (not fully opened usually).

On the other hand, during dry season, Cubio gate is closed and maintain water level of 2.5 m. This figure is reading of staff gage installed at Cubio gate. However, this figure is not linked with ground elevation.

(c) Tolon Gate

Top and bottom elevations of this gate are El.2539.91 m and El.2537.39 m respectively.

When upper water level of Tolon gate raises at El.2539.4, Tolon gate begins to open. On the other hand, this water level lowers at El.2539.0, Tolon gate begins to close. In practical operation, the allowable lowest upstream water level is El.2538.7 m, because less than this figure there occurs a problem (cavitation) in pumping up for Chiquinquira municipal water supply. The staff gauge reading at Tolon gate is equal to ground elevation.

In typical operation, Tolon gate is closed during June to September, and latter half of December to February.

3.3 Construction of Water Balance Simulation Model

Figure C.3.2 shows water balance simulation model of the present CAR system. Based on this schematic model, a mathematical model is constructed as described below:

(1) Simulation Period

20 years can be acceptable as term of calculation. Unit periods of the calculation are five (5) days for dry season and one (1) day for rainy season in principle.

(2) Irrigation Block

Basic equation of water balance of each irrigation block (including livestock and municipal water uses) is, as follows:

Deficit = (Demand – (River runoff) – (Residual watershed discharge)) ≧ 0.0

Surplus = ((River runoff) + (Residual watershed discharge) – Demand) ≧ 0.0

(3) Hato Dam

Hato dam is multipurpose having flood control and service water capacities. When its water level reaches at N.H.W.L. (El. 2842.7 m), CAR controls its water level by operating a valve. The valve in the model has the following capacity:

Water Level (base=2800 m. s .n. m)	42.7	42.8	42.9	43.0	43.1	43.2	43.3	43.4	43.5	43.6	43.7
Discharge (m^3/sec)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0

The model considers evaporation from reservoir surface in calculation of water level. The following table shows evaporation rates adopted:

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Eva. (mm/day)	2.1	2.1	2.0	1.7	1.6	1.7	1.6	1.9	1.9	1.8	1.7	1.8

(4) Cucunuba Lake

The model considers the following evaporation from water surface of the lake:

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Eva. (mm/day)	2.0	2.1	2.0	1.8	1.6	1.4	1.6	1.6	1.7	1.6	1.5	1.7

(5) Cartagena Gate

This gate is closed during March to May and August to October. When water level of Cucunuba lake exceeds El.2544.0 m, overflowing water discharges to Cubio gate.

(6) Cubio Gate

Only floods discharge into Cucunuba lake when Cubio gate is closed. This gate maintains upper water level. Therefore, a parameter (Qcc) is introduced in the model. The basic equation of this gate is, as follows:

Inflow to Cucunuba lake = Qcc (designed at 1.0 m^3/s)

Discharge at Cubio gate = (Ubate, Suta and Lenguazaque river discharge) - Qcc ≧ 0.0

(7) Fuquene Lake

The model adopts the following water balance equation of the lake:

$$\Delta Sw = (Dwi - Dwo) + Pw - Ew$$

Where,

ΔSw = change of stored water volume,

Dwi = inflow into the lake,

Dwo = outflow from the lake,

The following table shows present outflow capacity of the lake when Tolon gate is opened, which capacity accrues from non-uniform flow calculation of Suarez river:

Water Level (base = 2500 m.s.n.m)	37.5	38.7	39.1	39.3	39.6	39.9	40.2
Discharge (m^3/sec)	0.0	2.7	5.7	8.4	11.1	13.9	16.8

Pw = rainfall on water surface,

Ew = evaporation from water surface, the following table indicates values:

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Eva. (mm/day)	2.4	2.5	2.3	1.9	1.9	2.0	2.2	2.1	2.2	1.9	1.9	2.1

(8) Tolon Gate

Under the present operation rule, this gate is operated in accordance with its upstream water level, as follows:

Water Level (El. m)	Operation
more than 2539.4	Opening
2539.0 – 2539.4	Partial Operation
less than 2539.0	Closed

In the study of optimum operation rule, however, Tolon gate is operated in accordance with water level of Fuquene lake.

When Tolon gate is opened, passing discharge is converted into water level using the following rating curve. This curve is derived from hydraulic study of Suarez river and Tolon gate:

Water Level (base=2500 m.s.n.m)	37.4	38.0	38.5	39.0	39.5	40.0
Discharge (m^3/sec)	0.0	0.2	1.2	7.0	17.5	31.0

(9) Return Flow

In the simulation, return flow is assumed. Source of the return flow is irrigation loss. Irrigation efficiency (Ep) is studied in Section 1.2.4, and its value varies 0.576 – 0.80 by irrigation blocks. This means there is irrigation loss, and a part of this loss is assumed to return to downstream. The details of return flow is, as follows:

(a) Return Flow Volume

Return flow volume is assumed to be zero with Ep = 0.8. Then, 10% of the difference between (loss with Ep < 0.8) and (loss with Ep = 0.8) is assumed to be the volume of return flow. Return flow is not counted when blocks are of deficit. Return flow volume is expressed, as follows:

(Return flow) = ((Gross water requirement) – (Deficit)) x (1.0 – 1.25Ep) x 0.1

(b) Place to where Return Flow gathers

Return flow is assumed to gather in lake or river which locates downstream of each irrigation block.

(c) Timing of Return Flow

Return flow in calculation period (t_i) is assumed to become surface water in the next period (t_{i+1}).

(10) Adequacy of Model

Adequacy of the model is judged based on water level of Fuquene lake. Figure C.3.3 shows comparison results of the said water levels of calculated and observed ones during 1992 – 1997, after completion of Hato dam. Simulated water level of the lake is judged to be acceptable keeping in mind the limit of this simulation model.

3.4 Water Balance Analysis

Table C.3.1 shows result of water balance analysis under present conditions (20 years, 1978 – 1997). In this calculation, water demand is considered as gross irrigation area of 20,337 ha (actual irrigated area is adopted for Cap-2 block), 50,000 heads of bovine and municipal water use (Ubate 196,992 m^3/month = 0.076 m^3/s, Chiquinquira 518,400 m^3/month = 0.2 m^3/s based on the questionnaire survey).

Based on the results of this analysis, water balance situation of the present CAR system is, as follows:

- Water deficit exists in blocks for which supplementary irrigation water from dam/lake etc. is not supplied. This is because natural discharges during dry season become negligible. Drought prone blocks are Suta, Lenguazaque, Mariño, Susa, Old-Suarez, Madron, Merchan.

- Among those blocks, severe drought prone area is Mariño, Old-Suarez, Suta and Madron blocks. Under the average conditions, amount of deficit reaches 2,000 – 5,000 m^3/ha in these blocks. Comparing this figure to their irrigation water demands, ratio of water deficit to its water demand is estimated at more than 30%. In the other drought prone blocks, this ratio becomes less than 30%.

- With 5-year return period, more than 50% of water demand becomes deficit in severe blocks and Merchan block. With 20-year return period, deficit reaches more than 50% of demand in drought prone blocks except for Lenguazaque block.

- On the other hand, Cap-1, Cap-2, Cucunuba, Mariño-Ubate, Fuquene, Honda and Suarez blocks are benefited by water resources (Hato dam, Cucunuba and Fuquene lakes, Ubate and Suarez rivers) to have no water deficit.

3.5 Optimum Operation Rule

In order to operate CAR system rationally, optimum operation rule is studied hereunder. This study is carried out under the present system conditions focussing on Hato dam and Fuquene lake. Existing water use of Cucunuba lake is already efficient.

3.5.1 Hato Dam

One of the purposes of Hato dam is to supply irrigation and municipal water. The other is flood mitigation for Fuquene lake. In order to realize these purposes, this dam is expected to store floods during rainy season, and utilize this stored floods during dry season. This is the basic concept of optimization of dam operation. Fig. C.3.4 shows observed and simulated water levels of the dam under present operation rule.

(1) Water Supply

(a) Supply Rule

Optimization of water supply means to release water without deficit and surplus in demand. But irrigation water demand varies with hydrological and meteorological conditions. However, the necessary release water (without deficit and surplus) can be calculated for 20 years (Table C.3.2). The most rational method to establish water supply rule is to utilize these data.

If release water in specific period is determined as the biggest volume within 20 years, this release water can cope with severe drought conditions, and this probability is evaluated at 20-year return period (exceedance probability). Water supply rule can be determined likewise.

Considering features shown in Table C.3.2 and present operation of the dam, constant release with about 100% room is adopted in proposed rule.

Based on the above approach, water supply discharges with return period 5, 10 and 20 years are determined, as follows:

(unit: upper litter/s, lower ‘000 m^3/month)

Return Period	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1/20	400	400	400	0	400	400	400	400	0	0	0	400
	1,000	1,000	1,000	0	1,000	1,000	1,000	1,000	0	0	0	1,000
1/10	200	200	200	0	200	200	200	200	0	0	0	200
	500	500	500	0	500	500	500	500	0	0	0	500
1/5	100	100	100	0	100	100	100	100	0	0	0	100
	250	250	250	0	250	250	250	250	0	0	0	250

The following table shows ratio of total water shortage to total gross irrigation water requirement (Cap-1 and Cap-2 irrigation blocks), and ratio of total water shortage period to total irrigation period (excluding April, October and November) in 20 years. Based on these results, water supply with 5-year return period is judged to have no problem.

Ratio	Return Period (year)	
	1/5	1/10
Water Shortage Volume	less than 1 %	less than 1 %
Water Shortage Period	less than 1 %	less than 1 %

(b) Supply Reduction Rule

When water level of the dam is expected to down to L.W.L, regulation on water supply and uses become necessary. Under the present conditions, water level of the dam will not fall to L.W.L. This rule is studied under future conditions.

(2) Flood Rule

Flood rule is studied under the above optimum supply rule. Flood rule is designed with concept that flood water level of the dam raises at around El.2847.0 m (spillway crest elevation) once in 20 years. Spillway of the dam is designed with MPF (Maximum Probable Flood). Therefore, the dam is still safe even with this situation. After try and error, the flood rule of the dam is determined, as follows:

Water Level (base=2800 m. s. n. m)	42.7	42.8	42.9	43.0	43.1	43.2	43.3	43.4	43.5	43.6	43.7
Optimum (m^3/sec)	0.0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
Present (m^3/sec)	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0

Fig. C.3.5 shows calculated water level of the dam. The water level raises at around 2847.0 m in October 1979. Magnitude of this flood is estimated at about 100-year return period.

3.5.2 Fuquene Lake

Optimum operation rule of Fuquene lake is studied under the optimized dam operation rule above mentioned.

Optimization of the lake operation aims to keep lake water level high in order to improve lake environment, and to mitigate inundation damages around the lake. This is basic concept of the optimization.

To keep lake water level high and to mitigate inundation damages are paired viewpoints in terms of evaluating high water level of the lake. On the other hand, low water level of the lake is also important in its operation. Therefore, the operation rule should be evaluated using high and low water levels at the same time.

(1) Conditions of Optimization

(a) Control Water Level

At present, Fuquene lake is controlled by Tolon gate based on gate water level. The lake and gate are connected by Suarez river (length 17.5 km), and when the gate is opened, there exists water level difference between the lake and the gate. This operation system is complicated hydraulically. Therefore, in this Study, water level of Fuquene lake is adopted as control water level.

Inundation around the lake occurs from W.L. 2539.75 m. In this Study, W.L. 2539.5 m is designed at 2-year return period (exceedance probability of annual maximum water level). Referring to the following table, annual maximum water level of 1/2 probability was El. 2539.64 m in the past.

Probability of Recorded Water Level of Fequene Lake	
Probable Annual Maximum W.L. (El. m)	
1/2	2539.64
1/5	2539.95
1/10	2540.15
1/20	2540.35
Probable Annual Minimum W.L. (El. m)	
1/2	2538.55
1/5	2538.39
1/10	2538.32
1/20	2538.27
Distribution (Mode)	2539.1-2539.2 (16 %)

(b) Optimization Cases

Optimization of the operation is studied under four (4) cases based on Suarez river condition, as follows (for hydraulic details, refer to Appendix B):

- (Case-1) Present conditions,
- (Case-2) Lowered roughness coefficient (0.036 to 0.025) through removal of aquatic plants,
- (Case-3) Riverbed dredging (0.5 m depth from existing riverbed), and
- (Case-4) Combination of Case 2 and Case 3.

Corresponding discharge capacity from the lake to Suarez river is prepared for each case respectively.

(c) Basic Pattern of Operation Rule

Under present conditions, Tolon gate is usually closed from June to September and from latter half of December to February (dry season operation). On the other hand, the gate is usually opened from March to May and from October to former half of December (rainy season operation).

In this Study, referring to the above annual pattern, periods from June to September and from December to February are designed as dry season operation period. The other months are designed as rainy season operation period.

(2) Optimization Simulation

(a) Optimization Method

Optimization is carried out using the simulation model. Method of the optimization is, as follows:

(i) Water level of Fuquene lake is determined by combination of operation water levels during dry and rainy season operation periods.

(ii) Tolon gate is opened when the lake water level is higher than the operation water levels, and closed when the lake water level is lower.

(iii) The lake water level is simulated for 20 years under various combinations of the operation water levels (for each simulation case, probable annual maximum and minimum water levels and water level distribution are calculated using simulated lake water level).

(iv) Optimum operation rule, a combination of operation water levels, is chosen from simulation cases whose values are less than 2539.5 m (probable annual maximum water level of 2-year return period).

(b) Calculation Results

Tables C.3.3 to C.3.6 show probable annual maximum and minimum water levels (using Gumbel Method) and the mode of water level distribution by simulation cases.

(c) Effect of Suarez River Improvement

Effect of Suarez river improvement is evaluated as difference between Case-1 and other Cases under same operation rule, using 1/2 probable annual maximum water level, as follows:

Optimization Case	Rule (Dry – Rainy W.L.: El. m)	1/2 Pro. Max. Value (m)	Effect (m)
Case-1 (present condition)	2538.9 – 2538.7*	2539.50	----
Case-2 (aquatic plants removal)	same to Case-1	2539.39	0.11
Case-3 (dredging)	same to Case-1	2539.33	0.17
Case-4 (aquatic plants and dredging)	same to Case-1	2539.26	0.24

Note) * Optimum operation rule.

(3) Optimum Operation Rule

Based on the simulation results, the optimum operation rule is studied, as follows (Figs. C.3.6 to C.3.9):

(a) Case-1 (present condition)

Optimum operation rule is W.L. 2538.9 m as dry season operation water level, and W.L. 2538.7 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.50 m, and mode of water level distribution is W.L. 2538.8 – 38.9 m (19 %).

(b) Case-2 (aquatic plants removal)

Optimum operation rule is W.L. 2539.1 m as dry season operation water level, and W.L. 2538.9 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.46 m, and mode of water level distribution is W.L. 2539.0 – 39.1 m (14 %).

(c) Case-3 (dredging)

Optimum operation rule is W.L. 2539.3 m as dry season operation water level, and W.L. 2538.9 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.49 m, and mode of water level distribution is W.L. 2539.1 – 39.2 m (17 %).

(d) Case-4 (aquatic plants remove and dredging)

Optimum operation rule is W.L. 2539.1 m as dry and rainy season operation water levels. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.44 m, and mode of water level distribution is W.L. 2539.0 – 39.1 m (30 %).

3.6 Cavitation Problem at Chiquinquira Pumping Station

In general, water source for municipal water supply should be secured more than 95 % in terms of its service period.

On the other hand, cavitation occurs at Chiquinquira pumping station when its water level is less than 2538.7 m. During cavitation period, pump can not lift water satisfactorily. In line with this idea, ratio of cavitation period is adopted as a indicator for safety of Chiquinquira municipal water supply.

Based on the simulation results under each optimum operation rule, it is expected that cavitation problem occurs at the pumping station with the said frequency more than 5 % (Tables C.3.3 to C.3.6)

Therefore, a countermeasure is necessary in order to introduce the optimum operation rule.

CHAPTER IV SIMULATION UNDER FUTURE CONDITIONS

4.1 Proposed Irrigation System

Based on the water balance analysis under present conditions, drought prone blocks are identified. On the other hand, the system will expand in future. Therefore, it is necessary to change present irrigation system in order to reduce foreseeable water shortage. In other words, existing water resources should be utilized as much as possible under the future conditions. In line with this idea, future irrigation system is formulated, as follows (locations and salient features of intake facilities are shown in Figs. C.4.1. and C.4.2.):

(1) Suta. Present Block

Two (2) gates (G-ST1 and G-ST2) will be constructed along Suta river. Irrigation water from Hato dam will inflow upstream of these gates, and will be conveyed into this block. A part of Lenguazaque Block (344 ha), between Suta and Lenguazaque rivers, will be irrigated under this system.

(2) Suta. Extension Block

One (1) gate (G-ST3) will be constructed along Suta river. Irrigation water will be supplemented from Hato dam.

(3) Cap-1. Present Block

Same to present system.

(4) Cap-1. Extension Block

Extensive ditch system will be constructed, and irrigation water from Hato dam will be conveyed into this block through this ditch system.

(5) Cucunuba. Present Block

Same to present system.

(6) Lenguazaque. Present Block

A part of this block (344 ha) will be irrigated through the system of Suta. Present block.

(7) Lenguazaque. Extension Block

Three (3) gates (G-LG1, G-LG2 and G-LG3) will be constructed along Lenguazaque river.

(8) Cap-2. Present Block

Existing canal will be excavated to increase its flow capacity. Through this rehabilitation, supplied water from Hato dam will irrigate all area.

(9) Mariño. Present Block

One (1) turnout (T-MA1) will be constructed along Ubate river, upstream of Cubio gate. In addition to this, one (1) small gate (G-MA1) will be constructed in the right bank of Mariño canal.

(10) Mariño- Ubate. Present Block

Same to present system.

(11) Fuquene Present Block

Same to present system.

(12) Honda. Present Block

Same to present system.

(13) Honda Extension Block

One (1) gate (G-HO1) will be constructed along Honda river.

(14) Susa. Present Block

One (1) pumping station (P-SS1) will be constructed beside Fuquene lake to irrigate this block. In addition to this, one (1) gate (G-SS1) will be constructed along Susa river. Lifted water from the new pumping station will inflow upstream of this gate, and will be conveyed into this block.

(15) Susa. Extension Block

One (1) gate (G-SS2) will be constructed along Susa river. In addition to this, another gate (G-SS3) will be constructed in the north area of this block. These two (2) gates will be connected.

(16) Suarez. Present Block

Same to present system.

(17) Simijaca. Extension Block

Two (2) gates (G-SI1 and G-SI2) will be constructed along Simijaca river.

(18) Old-Suarez. Present Block

One (1) turnout (T-OS1) will be constructed along Suarez river, after confluence of Chiquiquira river. Water level of this turnout will be maintained by La Copetona gate described below.

(19) Madron. Present Block

Same to present system.

(20) Merchan. Present Block

This block will be irrigated with the construction of La Copetona gate described below.

(21) Merchan. Extension Block

One (1) gate, La Copetona gate (G-ME1), will be constructed along Suarez river. Water resources of Chiquinquira river and Fuquene lake will be able to be utilized with this gate.

In this Study, construction of Merchan gate is not considered based on the existing study, "Estudio Hidraulico, Topografico e Hidrologico del Canal Paris–Rio Suarez y Diseño de las Estructuras de Control, CAR, 1992"

4.2 Construction of Water Balance Simulation Model

Based on the proposed irrigation system, new water balance simulation model is constructed (Fig. C.4.3). In this model, following block names are used (Fig. C.4.1):

Block No. and Name in Future Model	Gross Area (ha)	Composition of Irrigation Block
1. Suta	1,277	Suta. Present + Suta. Extension + Lenguazaque 344 ha
2. Cap-1	1,365	Cap-1. Present + Cap-1. Extension
3. Cucunuba	1,892	Cucunuba. Present
4. Lenguazaque	2,309	Lenguazaque. Present + Lenguazaque. Extension – 344 ha
5. Cap-2	1,582	Cap-2. Present
6. Mariño	700	Mariño. Present
7. Mariño-Ubate	387	Mariño-Ubate. Present
8. Fuquene	2,537	Fuquene. Present
9. Honda	509	Honda. Present
10. Susa	563	Susa. Present
11. Suarez	8,309	Suarez. Present
12. Simijaca	417	Simijaca. Extension
13. Old-Suarez	228	Old-Suarez. Present
14. Madron	1,359	Madron. Present
15. Merchan	640	Merchan . Present + Merchan. Extension
16. Honda. Ext.	349	Honda. Extension
17. Susa. Ext.	426	Susa. Extension
Total	24,849	----

4.3 Water Balance Analysis

Table C.4.1 and Fig. C.4.4 show the result of water balance analysis under future conditions (20 years, 1978 – 1997). In this calculation, counted water demands consist of gross irrigation area of 24,849 ha, 66,740 heads of bovine (about 3 heads per pasture ha), and municipal water use (Ubate 0.1 m^3/s and Chiquinquira 0.2 m^3/s). These livestock and municipal water uses are estimated based on the results of water use projection. Based on this analysis, water balance situation of future CAR system is, as follows:

Irrigation Blocks of Hato Dam

Suta, Cap-1 and Cap-2 are planned as irrigation blocks of Hato dam. The dam will experience water shortage four (4) years in 20 years. However, amounts of water shortage in three (3) years are negligible, and for the biggest water shortage, its ratio to annual irrigation demand is estimated at less than 10 %. This level of under-irrigation is acceptable.

Irrigation Block of Cucunuba Lake

In Cucunuba irrigation block, water shortage will occur once in 20 years, which shortage will be negligible.

Irrigation Blocks of Fuquene Lake and Suarez River

Fuquene, Honda, Susa, Suarez, Old-Suarez and Merchan are planned as irrigation blocks of Fuquene lake and Suarez river. No water shortage will occur in these blocks.

Irrigation Blocks in upper Fuquene Lake Basin

Lenguazaque, Mariño, Mariño-Ubate and Honda.Extension blocks locate in this basin.

As for Honda.Extension block, its average water deficit is estimated at 10 % of irrigation demand, and 20 % and 15 % in drought years of 10 and 5 years return period, respectively. In Lenguazaque block, its drought condition will slightly worsen. This is because its extension area will begin to take water in the upstream.

In the right bank of lower Ubate river, there exist Mariño and Mariño-Ubate blocks, and they will be drought prone areas. Under the future conditions, their water sources are to be same (Mariño canal and Ubate river), and, as a whole, future drought condition of these blocks will better slightly in comparison with present one.

Water resource development in Lenguazaque river is one (1) solution to cope with the drought problem in Lenguazaque, Mariño and Mariño-Ubate blocks.

Irrigation Blocks in lower Fuquene Lake Basin

Simijaca, Madron and Susa.Extension blocks locate in this basin.

As for Simijaca block, its water shortages in 10 and 5 years return period are estimated at 20 % and 10 % of irrigation demand, respectively. Madron block will be drought prone area same as present conditions. As for Susa.Extension block, its water shortages with 10 and 5 years return periods are estimated at more than 30 % of its irrigation demand.

4.4 Optimum Operation Rule

Basic concept of rule formulation under future conditions is same to one under present conditions. Same approach and method described in Chapter III are adopted here.

4.4.1 Hato Dam

(1) Water Supply

(a) Supply Rule

Necessary dam supplies (without surplus and deficit) are shown in Table C.4.2. Under future conditions, water level of Hato dam is expected to down to its L.W.L. (2828.0 m). Therefore, no room is considered in supply rule under future conditions. Based on this idea, water supply discharges with return period 5, 10 and 20 years are determined, as follows:

(unit: upper litter/s, lower '000 m^3/month)

Return Period	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1/20	1,750	1,300	800	0	100	100	1,000	1,100	550	0	0	1,100
	4,600	3,050	2,050	0	200	250	2,600	2,900	1,350	0	0	3,050
1/10	1,650	1,100	650	0	100	100	1,000	1,100	500	0	0	850
	4,400	2,700	1,700	0	150	150	2,550	2,850	1,250	0	0	2,200
1/5	1,500	950	500	0	50	50	500	800	350	0	0	600
	3,950	2,250	1,350	0	50	100	1,300	2,100	900	0	0	1,600

The following table shows ratio of total water shortage to total gross irrigation water requirement (Suta, Cap-1 and Cap-2 irrigation blocks), and ratio of total water shortage period to total irrigation period (excluding April, October and November) in 20 years. Based on these results, water supply with 5-year return period is judged to be acceptable.

Ratio	Return Period (year)	
	1/5	1/10
Water Shortage Volume	less than 5 %	5 %
Water Shortage Period	16 %	14 %

(b) Supply Reduction Rule

Under future conditions, water level of the dam will fall to its L.W.L. Therefore, shortage rule is necessary for future operation. Water supply from the dam and water demand to the dam will be reduced in accordance with shortage rule.

The following is the proposed shortage rule, which is designed with idea that the water level falls near to L.W.L once in 20 years under the above supply rule:

Water Level (base=2800 m. s. n. m)	higher than 32	32 – 30	30 - 28
Reduction Rate of Water Supply and Demand (%)	0	40	50

(2) Flood Rule

Flood rule of the dam is studied under the optimum operation rules above mentioned. The flood rule is shown below, and simulated water level of the dam is shown in Fig. C.4.5.

Water Level (base=2800 m.s.n.m)	42.7	42.8	42.9	43.0	43.1	43.2	43.3	43.4	43.5	43.6	43.7
Optimum (m^3/sec)	0.0	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50

(3) Effectiveness of Integral Operation of Hato Dam and Fuquene Lake

Integral operation of Hato dam and Fuquene lake is not considered effective from the following facts and consideration:

(a) Supplemental Water Supply to Fuquene Lake

Hato dam is designed to have storage capacity of 7.7 million m^3 for water supply, from L.W.L. 2828.0 m to N.H.W.L. 2842.7 m. However, as described above, this storage capacity will be completely used to supply irrigation water in the future. Therefore, integral operation, supplemental water supply to the lake to raise its water level during dry season, will be difficult in the future.

(b) Reducing Flood Release from Hato Dam

Hato dam is designed to have flood control capacity of 4.7 million m^3, from N.H.W.L. 2842.70 m to H.H.W.L. 2847.29 m. When a medium scale flood occurs, water level of the dam reaches at 2,845.0 m (Fig. C.4.5), filling half of the allocated capacity (50 % of 4.7 million m^3). The remaining capacity can be used for flood control of the lake by reducing flood release from the dam. However, effect on the lake is lowering its water level by 7-8 cm. On the other hand, this integral operation will increase risk of the dam at such a large flood as 1979 flood.

4.4.2 Fuquene Lake

Optimum operation rule of Fuquene lake under future conditions is studied under the optimized dam operation rules above mentioned. Optimization approach and method here are same to those under present conditions. Results of simulation are shown in Tables C.4.3 to C.4.6.

(1) Effect of Suarez River Improvement

Effect of Suarez river improvement is evaluated, as follows:

Optimization Case	Rule (Dry – Rainy W.L.: El. m)	1/2 Pro. Max. Value (m)	Effect (m)
Case-1 (present condition)	2539.1 – 2538.9*	2539.49	----
Case-2 (aquatic plants removal)	same to Case-1	2539.41	0.08
Case-3 (dredging)	same to Case-1	2539.37	0.12
Case-4 (aquatic plants and dredging)	same to Case-1	2539.34	0.15

Note) * Optimum operation rule.

(2) Optimum Operation Rule

Based on the simulation results, the optimum operation rule is studied, as follows (Figs. C.4.6 to C.4.9):

(a) Case-1 (present condition)

Optimum operation rule is W.L. 2539.1 m as dry season operation water level, and W.L. 2538.9 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.49 m, and mode of water level distribution is W.L. 2539.0 – 39.1 m (25 %).

(b) Case-2 (aquatic plants removal)

Optimum operation rule is W.L. 2539.1 m as dry season operation water level, and W.L. 2538.9 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.41 m, and mode of water level distribution is W.L. 2539.0 – 39.1 m (27 %).

(c) Case-3 (dredging)

Optimum operation rule is W.L. 2539.3 m as dry season operation water level, and W.L. 2538.9 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.49 m, and mode of water level distribution is W.L. 2539.2 – 39.3 m (19 %).

(d) Case-4 (aquatic plants remove and dredging)

Optimum operation rule is W.L. 2539.3 m as dry season operation water level, and W.L. 2539.1 m as rainy season operation water level. With this rule, 1/2 probable annual maximum water level is calculated at W.L. 2539.50 m, and mode of water level distribution is W.L. 2539.1 – 39.2 m (29 %).

4.5 Cavitation Problem at Chiquinquira Pumping Station

Under future conditions, with present Hato dam and Fuquene lake operation rules (however, Hato dam supplies water in accordance with block demands), it is expected that cavitation occurs with 13 % frequency at Chiquinquira pumping station for municipal water supply.

On the other hand, based on the simulation results above mentioned, cavitation will occur with more than 5 % frequency in each Suarez river conditions (Tables C.4.3 to C.4.6).

Consequently, a countermeasure will be necessary at the pumping station in future.

CHAPTER V IMPROVEMENT OF CAR SYSTEM

5.1 Contents of Improvement

(1) Irrigation

Based on the water balance analysis under present conditions, it becomes clear that several irrigation blocks are drought prone because of the luck of irrigation facilities. In addition to this, the system will expand in future. Therefore, there is a need of system improvement in order to strengthen its irrigation function.

(2) Drainage

There are drainage problems in the system. The major one is observed around Fuquene lake. Others are observed along some rivers/canals due to thick of aquatic plants, etc. Inundation problem around the lake can be mitigated with Suarez river improvement and introduction of lake optimum operation.

(3) Municipal Water Supply

There is no severe problems on Ubate municipal water supply. On the other hand, countermeasure against cavitation is necessary at Chiquiquira pumping station. This subject is treated in the next chapter.

5.2 Effects of Improvement

(1) Irrigation

Effects of irrigation improvement consist of expansion of irrigation area and upgrading of irrigation level. Future without project conditions are deemed to be same as present conditions, and future with project conditions are of improved irrigation system under future conditions. Based on this idea, beneficial areas are identified and summarized in the table below.

In the table, beneficial areas are classified into four (4) types, Type-A, Type-B, Type-C and Type-D. Those types are established based on irrigation levels, rainfed, under-irrigation and optimum irrigation. In optimum irrigation level, water applications are calculated based on consumptive use data, and calculated irrigation water is supplied. In under-irrigation level, lower applications are supplied because of no availability of water storage facilities. In rainfed level, only rainfall is utilized because of no irrigation facilities.

Under-irrigation is possible in traditional agriculture, with its local varieties and its low input levels. Major agriculture in the system is traditional pasture cultivation. Therefore, system improvement fell into Type-A is significant in the Study Area.

Irrigation Block	Gross Area (ha)	Beneficial Area (ha) Type -A	Type -B	Type -C	Type -D	Total	Remarks
Suta. Present	1,176	0	0	1,176	0	1,176	344 ha: from Lenguazaque
Suta. Extension	101	0	101	0	0	101	
Cap-1.Extension	731	0	731	0	0	731	
Lenguazaque	2,309	761	0	0	0	761	adjusted area
Cap-2. Present	1,582	0	1,266	0	0	1,266	316 ha: already irrigated
Mariño/ Mariño-Ubate	1,087	0	0	0	313	313	adjusted area
Honda. Extension	349	349	0	0	0	349	
Susa. Present	563	0	0	563	0	563	
Susa. Extension	426	426	0	0	0	426	
Simijaca. Extension	417	417	0	0	0	417	
Old-Suarez. Present	228	0	0	228	0	228	
Merchan. Present	320	0	0	320	0	320	
Merchan. Extension	320	0	320	0	0	320	
Total	9,609	1,953	2,418	2,287	313	6,971	

Note) Type-A: from rainfed to under-irrigation.
Type-B: from rainfed to optimum irrigation.
Type-C: from under-irrigation to optimum irrigation.
Type-D: upgraded level within under-irrigation.

(2) Drainage

Reduction of inundation area around Fuquene lake, accrues from Suarez river improvement and introduction of optimum operation rule of the lake, is summarized in the table below. As for future with project conditions, Case-2 (optimum operation under removal of aquatic plants from Suarez river) is adopted in this calculation.

Fuquene Lake W.L. (m. s. n. m)	Inundation Area # (ha)	Future w/o Conditions* Exceedance Probability	Occurrence Probability	Expectation (ha)	Future w/ Conditions** Exceedance Probability	Occurrence Probability	Expectation (ha)
2539.75	0	0.400	0.260	0.0	0.145	0.095	0.0
2540.00	500	0.140	0.095	47.5	0.050	0.040	20.0
2540.25	3,250	0.045	0.034	110.5	0.010	0.008	26.0
2540.50	6,000	0.011	0.009	54.0	0.002	0.0018	10.8
2540.75	8,000	0.002	0.002	16.0	0.0002	0.0002	1.6
Total	----	----	----	228.0	----	----	58.4
Reduction of Inundation Area (ha) =				169.6 170			

*) Future system with Hato dam optimum operation rule with Fuquene lake present operation rule,
**) Future system with Hato dam optimum operation rule with Fuquene lake optimum operation rule (Case-2)
#) Inundation Area: refer to Fig. B.2.5,
1. Exceedance Probability: readings from plotting positions,
2. Occurrence Probability: difference between exceedance probabilities,
3. Expectation = (Inundation Area) X (Occurrence Probability),
4. Reduction of Inundation Area: difference between Total Expectation (w/o) and Total Expectation (w/).

5.3 Quantity of Improvement

(1) Irrigation

Improvement works comprise construction and rehabilitation of irrigation facilities, which consist of intake facility and ditch system. Item and quantity of the works are summarized below.

Irrigation Block	Ditch (km)	Intake (nos.)		
		Gate	Pump	Turnout
1. Suta. Present	9.5	2	0	0
2. Suta. Extension	1.0	1	0	0
3. Cap-1. Present*	15.7	0	0	0
4. Cap-1.Extension	12.3	0	0	0
5. Lenguazaque. Extension	21.4	3	0	0
6. Cap-2. Present	31.8	0	0	0
7. Mariño. Present	7.6	1	0	1
8. Honda. Extension	9.1	1	0	0
9. Susa. Present	11.9	1	1	0
10. Susa. Extension	8.9	2	0	0
11. Simijaca. Extension	9.0	2	0	0
12. Old-Suarez. Present	6.2	0	0	1
13. Merchan. Present	1.0	0	0	0
14. Merchan. Extension	6.6	1	0	0
Total	152.0	14	1	2

*: Ditch works in this block are necessary for improvement of Suta.Present and Suta.Extension blocks.

(2) Drainage

Suarez river improvement aims to lower roughness coefficient through removal of aquatic plants. Therefore, this improvement requires yearly activity, and falls to maintenance activity of the river (length 17.5 km).

In addition to this, another item is introduction of the optimum operation rule of Fuquene lake.

5.4 Cost Estimate

(1) Irrigation

Improvement cost comprises direct construction cost, land acquisition and compensation, engineering and administration cost and physical contingency. Cost estimate is executed under contract basis, as of October 1999. Result of cost estimate is, as follows (Table C.5.1):

(unit: million Colombian Pesos)

Irrigation Block	Direct Construction Cost			Land Acquisition	Engin. & Ad-ministration	Physical Contin.	Total	
	Intake	Ditch	Total				(million Col$)	('000 US$)
1. Suta. Present	552	174	726	150	175	88	1,139	593
2. Suta. Extension	276	42	318	16	67	33	434	226
3. Cap-1. Present	0	518	518	247	153	77	995	518
4. Cap-1.Extension	0	258	258	194	90	45	587	306
5. Lenguazaque. Ext.	1,423	344	1,767	337	421	210	2,735	1,424
6. Cap-2. Present	0	931	931	501	286	143	1,861	969
7. Mariño. Present	236	145	381	120	100	50	651	339
8. Honda. Extension	435	212	647	143	158	79	1,027	535
9. Susa. Present	312	213	525	187	142	71	925	482
10. Susa. Extension	436	192	628	140	154	77	999	520
11. Simijaca. Ext.	552	162	714	142	171	86	1,113	580
12. Old-Suarez. Present	18	109	127	98	45	23	293	153
13. Merchan. Present	0	42	42	16	12	6	76	40
14. Merchan. Extension	1,450	149	1,599	104	341	170	2,214	1,153
Total	5,690	3,491	9,181	2,395	2,315	1,158	15,049	7,838

Note) Exchange Rate: 1 US$ = 1,920 Colombian Pesos (1999 October)
1. Value added tax (I.V.A) is not included.

(2) Drainage

Improvement cost of Suarez river is counted as annual maintenance cost of the river. The annual maintenance cost is estimated, as follows:

Maintenance cost (as of 1999 October): 17,500 m x 2,200 Col$/m/year = 38,500,000 Col$

Cost for introduction of the optimum operation of Fuquene lake is negligible.

5.5 Operation and Maintenance Cost

(1) Irrigation

Annual operation and maintenance cost (O/M cost) of the CAR system was 974.5 million Colombian Pesos in 1998 fiscal year. Based on this data, the annual O/M cost as of 1999 October is estimated at 50,000 Colombian Pesos per gross ha.

The O/M cost comprises administration wages 10%, operation wages 50 %, material (spare parts and fuel, etc.) 10 %, system maintenance (canal/river clearing, road/gate/bridge repair) 20 %, others (survey/investigation, utilities, mechanical works, water charge collection, etc.) 10 %.

Beneficial area of the system is 6,971 ha in total. Therefore, the incremental O/M cost by irrigation improvement is estimated at 348.6 million Colombian Pesos in total.

(2) Drainage

As shown before, incremental O/M cost from this improvement is estimated at 38.5 million Pesos.

5.6 Implementation Program

Implementation program of the system improvement consists of two (2) stages, Detailed Design Stage (year 2002) and Construction Stage (year 2003 to 2010). Construction Stage comprises Phase I (year 2003 to 2006) and Phase II (year 2007 to 2010). Implementation program of the system improvement is shown in Table C.5.2.

(1) Irrigation

Five (5) blocks (Suta.Present, Suta.Extension, Cap-1.Present, Cap-1.Extension and Cap-2.Present) will be improved during Phase I. This is because these blocks will be irrigated by Hato dam, and this dam is not fully utilized at present. The other nine (9) blocks will be implemented during Phase II.

Hato dam optimum operation rule should be implemented from year 2002.

(2) Drainage

Suarez river improvement and Fuquene lake optimum operation are recommended to start with Hato dam optimum operation concurrently.

CHAPTER VI WATER SUPPLY IMPROVEMENT IN CHIQUINQUIRA

6.1 Pumping Station

(1) Effect of Improvement

Effect of pumping station improvement is to secure municipal water supply for Chiquinquira through preventing cavitation.

(2) Method of Improvement

There are two (2) methods for this improvement, as follows:

1st: Replacement of existing pumps (3 nos.) with new ones (3 nos.) using existing motors.

2nd: Lowering (about 2.9 m) pump installation position using existing pumps and motors.

Through preliminary comparison study, 1st method is recommended because of its lower cost and easier water supply during construction.

(3) Cost Estimate

Improvement cost by the said method, as of October 1999, is estimated, as follows:

Item	Work Quantity		Unit Price	Total	
	Amount	Unit	(‘000 Col$)	(million Col$)	(‘000 US$)
1. Direct Construction Cost					
1.1 Building	1	L. S.		7.5	
1.2 Pump	3	nos.	30,000	90.0	
1.3 Electrical & Mechanical Works	1	L. S.		32.6	
Sub-total				130.1	67.8
2. Engineering and Administration Cost				26.0	
3. Physical Contingency				13.0	
Total				169.1	88.1

Note) Exchange Rate: 1 US$ = 1,920 Colombian Pesos (1999 October)
1. Value added tax (I.V.A) is not included.

(4) Operation and Maintenance Cost

Incremental O/M cost accrues from this improvement is negligible.

6.2 Water Purification Plant

6.2.1 General

A water-supply system is necessary for supplying a sufficient quantity of portable water with suitable quality. The principal contaminants of concern below is the target parameter in the purification plant.

(1) Pathogenic bacteria

(2) Turbidity and suspended materials

(3) Color

(4) Tastes and odors

(5) Hardness

(6) Natural and synthetic organic compounds

(7) Selected inorganic constituent such as aluminum, arsenic, barium, cadmium, chromium, fluoride, lead mercury, nitrate, selenium, and sliver

(8) Total dissolved solids

The purification processes consists of physical methods such as screening and simple sedimentation, chemical methods such as adsorption and physicochemical techniques in which contaminant are altered chemically to enhance their removal by physical processes.

6.2.2 National Standard

The Government of Columbia stipulated the national standard of portable water criteria through the Decree 475 de 19 on 10th March in 1998. The value of each parameter is shown in Table C.6.1.

6.2.3 Inventory

(1) Water Supply System in Each Municipality

The public water supply system of 14 municipalities in the Study Area is surveyed by questionnaire and the result of them is already shown in Table C.1.6. Most municipalities except Fuquene and Susa have the purification plant.

(2) Water Purification Plant in Chiquinquira

Water pollution problem will have little influence the water supply system of 14 municipalities except Chiquinquira. In Chiquinquira, the intake point is just located before the Tolon Gate in the Suarez River. Water quality deterioration due to water pollution in Fuquene Lake will directly influence the water quality of intake for water supply system.

The water purification plant in Chiquinquira was originally constructed in 1928, and additional plant was installed in 1976. The water is taken from the Suarez River, about 1,800 m far from the purification plant. The water is pumped up at about 90 m, aerated and divided into new and old plants. In each plant, the water is at first coagulated with chemicals in the mixing tank, flocculated, sedimented and filtered.

After filtration, the water is stored in the reservoir and then distributed to each household and establishments.

The size of each facilities are as follows:

Facilities	New Plant	Old Plant
Aerator	L4.65 m×W4.10 m×H4.20 m	
Flocculation Tank	L13.95 m×W8.09 m×H1.23 m×2	L4.40 m×W5.47 m×H4.75 m×3
Sedimentation Tank	L12.65 m×W5.29 m×H5.00 m×2	L6.40 m×W28.00 m×H5.00 m×1
Filtration Tank	L4.39 m×W6.93 m×H4.8 m×4	L6.95 m×W6.00 m×H3.40 m×2

(3) Water Quality

(a) Water at Intake Point

The water quality at intake point in Suarez River was analyzed in rainy and dry seasons by JICA Study Team in 1999. The result is shown in Table C.6.2. The characteristics of water quality at intake point (before purification) are as follows:

(i) The value of COD, Fe, humic acid and turbidity is high.

(ii) DO is nearly 0 mg/l.

(iii) Heavy metal is not detected.

(iv) The number of coliforms (Total and Fecal) is high due to the wastes of human and livestock.

$Al_2(SO_4)_3$, CaO, NAClO are added before flocculation tank in order to remove contaminants and adjust pH. Cl_2 is also added after filtration for disinfection.

The consumption of chemicals is as follows:

Kind of Chemicals	Consumption Quantity (kg/month)
$Al_2(SO_4)_3$	20,000 – 30,000
CaO	2,000 – 2,200
NAClO	1,000 – 1,200
Cl_2	80 – 100

The daily consumption rate and weight in September, 1999 are shown in Table C.6.3.

(b) Water after Purification

The daily water quality before and after purification in September, 1999 is shown in Table C.6.4. The monthly average quality of major parameter, day number and the rate of meeting after purification are shown below. The number of day where the analysis results of water quality meets the national standard counts “day number” and rate of meeting is calculated by dividing the day number by 30.

Parameter	Unit	Monthly Average	National Standard	Day Number	Rate of meeting (%)
Turbidity	UNT	6.7	<5	11	37
NO_2^-	mg/l	0.0285	0.1	30	100
PH	-	5.3	6.5-9.0	0	0
Fe	mg/l	0.33	0.3	11	37
Cl^-	mg/l	9.9	250	30	100

The rate of meeting the national standard on turbidity and iron is nearly one third. The value of pH is always out of allowable range. The improvement of purification plant is required to meet the national standard.

6.2.4 Future Projection

(1) Water Quantity

Intake water quantity for purification plant is about 12,800 m^3/day on the average in 1999. In 2010, the water quantity will increase in proportion to the growth of population. It is estimated that the water volume will be 15,000 m^3/day.

(2) Water Quality

It is assumed that the most serious parameters in water quality will be iron, turbidity and dissolved oxygen. As shown above, the iron concentration at intake site is extremely high, which is sometimes over 10 mg/l, and dissolved oxygen is nearly 0 mg/l. There is a close connection between two parameters.

Iron concentration will increase in inverse proportion to dissolved oxygen. Dissolved oxygen in the Suarez River will decrease due to progressing the decaying/decomposition of aquatic plant. Consequently iron concentration will become higher even in the future.

However, the estimation of iron concentration are very difficult. Then, iron concentration is assumed to be 20 mg/l in this study because the worst value at present is 18.3 mg/l.

6.2.5 Improvement Plan

(1) Target Parameter

As described above, the most serious parameter is iron, turbidity and dissolved oxygen. Since dissolved problem will be solved through iron and turbidity improvement, the removal of iron and turbidity is studied hereunder.

(2) Methods of Removing Iron

Though iron is most commonly found in groundwater, surface water may also contains significant amounts at times. Concentration in excess of 0.3 mg/l, which is also the value of national standard, may produce detectable taste and odor, red-colored water which may stain clothes, cooling utensils and plumbing fixtures, accumulations of precipitated iron in the distribution system, and growth of

Crenothrix (an iron bacteria) in the pipes. The bacterial growth can produce additional taste and odor problems.

Although the iron is removed by the combination of aerator and chlorine at present in Chiquinquira, the iron concentration often exceeds the criteria. The average of iron concentration is shown below. (The daily data is shown in Table C.6.2 and C.6.4).

(unit: mg/l)

Sampling Point		Date	Value	National Standard
Suarez River	Before Tolon Gate near Intake Point	Rainy season	18.3	-
		Dry season	5.9	-
Purification Plant	Inlet	Average of 1999.9	7.3	-
	Outlet	Average of 1999.9	0.33	<0.3

The methods used for removing iron are (1) precipitation after oxidation by aeration, (2) chemical addition and settling or filtration, (3) filtration through manganese zeolite, and (4) ion exchange. Of the above mentioned methods, (1) and (2) are the most popular methods. The outline of each method is as follows:

(a) Precipitation after Oxidation by Aeration

Precipitation after oxidation by aeration is used very often. The removal can be enhanced by oxidizing them to a higher valence state in which their solubility is reduced. The oxidation reactions of interests are as follows:

$$4\ Fe(HCO_3)_2 + O_2 + 2H_2O \rightarrow 4\ Fe(OH)_3 \downarrow + 8CO_2$$

As shown above, ion in the ferrous form (2+) is oxidized to insoluble ferric hydroxide (3+), which can be removed as a precipitate in the sedimentation tank and filtration.

The aeration has also the following effects in addition to the iron removal since aeration is a form of gas transfer.

(i) Addition of oxygen to oxidize dissolved manganese,

(ii) Removal of carbon dioxide,

(iii) Removal of hydrogen sulfide to eliminate odors and tastes,

(iv) Removal of volatile oils and similar odor and taste, which produces substances released by algae and similar microorganisms.

Aeration techniques consists of spray, cascade, diffused-air, multiple-tray and packed-column systems. The purification plant in Chiquinquira adopts multiple-tray aerator. This process is composed of a series of trays formed of wooden slats, perforated plates or screen, which is spaced about 500 mm apart. The water is applied at the top of the structure through sprays or a perforated pan. Airflow through the trays is provided by open louvers on the sides, normally with natural draft.

(b) Oxidation with Chemicals

Oxidation with chemicals is a process in which the oxidation state of a substance is increased by means of chemical reaction. The most popular oxidizing agents are chlorine, chlorine dioxide, ozone, permanganate, or any other oxidant, which will not leave an unwanted residue. The formula using chlorine is as follows:

$$2\ Fe^{2+} + Cl_2 \rightarrow 2\ Fe^{3+} + 2\ Cl^-$$

The application of strong oxidizing agents can serve to oxidize iron more rapidly and can also modify or destroy the present organic materials so they do not interfere with the reaction.

(c) Proposed Improvement

In Chiquinquira, the iron is removed by the combination of oxidation with aerator and chlorine. It would be possible to meet the water criteria by adding more chlorine. Although 0.635 mg of chlorine is required to oxidize 1 mg of iron theoretically, more chlorine is necessary because organic and reducible matter consume chlorine actually, resulting in the a large number of consumption of chlorine for removing iron. This method is not recommendable by the following reasons.

(i) High cost

(ii) Carcinogenic possible risk associated with chlorinating by hydrocarbons

Since chlorine has the potential of forming trihalomethanes, this must be applied with care. The trihalometfhanes are single-carbon organics with three of the carbon bonds being occupied by halogen family - chlorine, bromine and iodine. The formation of trihalomethane occurs when members of the halogen family react with organic compounds. The trihalomethanes are carcinogenic, hence their presence in public water supplies is undesirable. Trihalomethanes are especially formed during chlorination of water containing organics such as humic and fulvic acid.

(iii) Preferential uptake of chlorine by BOD, resulting in a high dosing rate and wastage of chlorine.

(iv) Maintenance of the dosing system and continuity of supplies are considered difficult.

Therefore, oxidation by aerator is proposed. Since the efficiency of the existing aerator will not be sufficient, another aerator will be required.

(3) The Methods of Removing Turbidity

The average of turbidity are shown below (the daily data is shown in Table C.6.2 and C.6.4). Turbidity does not always meet the national standard due to poor efficiency of sedimentation tank and high filtration rate.

(unit: UNT)

Sampling Point		Date	Value	National
Suarez River	Before Tolon Gate near Intake Point	Rainy season	61.8	-
		Dry season	333.0	-
Purification Plant	Inlet	Average of	118.9	-
	Sedimentation Tank	Average of	14.0	-
	Outlet	Average of	6.7	<5

The improvement of sedimentation tank is required. At the same time, installation of one more filter should be necessary because the filtration rate is higher than the allowable range.

(4) The Improvement Facilities

(a) One more aerator should be installed. The size of the proposed facilities is as same as that of the existing one.

(b) Inclined parallel plate will be inserted in the existing sedimentation tank to improve the efficiency of sedimentation.

(c) One more filtration tank will be necessary in the new plant to reduce the filtration rate for removing the turbidity. The structure of filtration tank is as same as the existing one.

Th size of each facilities are as follows:

Facilities	Size
Aerator	L4.65 m×W4.10 m×H4.20 m×1
Sedimentation Tank (Improvement)	Insertion of inclined parallel plate
Filtration Tank	L14.8 m×W23.3 m×H6.2 m (The number of pond is 2)

The flow chart and the improved facilities of the sedimentation tank are shown in Fig.C.6.1.

(5) Cost Estimate

(a) Construction Cost

The improvement cost above mentioned is estimated as follows:

Item	Total Cost		Remarks
	(Million Col$)	(×10^3 US$)	
Direct Cost	470	245	
Indirect Cost	94	49	20 % of Direct Cost (Engineering Service and Administration)
Physical Contingency	47	24	10 % of Direct Cost
Total	611	318	

Note) Cost estimate: as of 1999 October.

The direct cost of each facilities are broken down as follows:

Facilities		Total Cost	
		(Million Col$)	(×10^3 US$)
Aerator		45	23
Sedimentation Tank (Installing of Inclined Parallel Plate)		40	21
Filtration Tank	Machinery	115	60
	Civil Engineering	210	109
	Sub-total	325	169
Pipe Installation, Electricity, Supplements		60	31
Total		470	245

(b) Operation and Maintenance Cost

The total maintenance and operation cost will be high with the increase of the quantity to be purified. However, the supplementary cost of operation and maintenance cost resulting from installing the facilities above mentioned will be neglected because little electricity and no chemicals are required.

6.3 Implementation Program

Implementation program of water supply improvement for Chiquinquira municipality is shown in Table. C.6.5. This program is prepared based on the following concept:

(1) Pumping Station

Pumping station will be improved in the first year of Construction Stage.

(2) Purification Plant

Purification plant will be implemented after improving the pumping station. The plant will be improved in consideration of the annual investment cost. At first one more aerator will be installed, followed by improving the sedimentation tank and installing one more filter.

REFERENCES

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2) Estudio Regional Integrado del Altiplano Cundiboyacense, IGAC, 1984.

3) Estudio de Factibilidad y Diseño de la Presa El Hato y Distrito de Riego, Contrato 093/84, Informe Final, Capítulo I–Resumen, Volumen I, CAR, Bogotá–Colombia, Noviembre de 1986.

4) Estudios Hidrológicos e Hidráulicos en los Ríos Suta y Susa y el Diseño de Estructuras con sus Compuertas en los mismos Ríos, Informe Final, CAR, Nov./1990.

5) Acuerdo 031 de 1991, CAR.

6) Contrato de Consultoria 227–CAR, Presa El Hato, Manual de Instrumentación de la Presa, Informe Técnico IT–07, Bogotá, Colombia, Agosto, 1992.

7) Estudio Hidráulico, Topográfico e Hidrológico del Canal Paris–Río Suárez y Diseño de las Estructuras de Control, Informe Final & Anexos, CAR, Santafé de Bogotá, Noviembre de 1992.

8) Estudio para la Determinación de Módulos de Consumo para Beneficio Hídrico, Contrato CAR–467–93, Informe Final, Volúmen II, Tomo II 2a Copia, CAR.

9) Revisión y Actualización del Sistema Tarifario del Distrito de Riego y Drenaje de Fúquene y Cucunubá, Contrato 086/92, Informe Final, CAR, Santafé de Bogotá, D.C. Diciembre 1994.

10) Factores que Intervienen en la Liquidación de la Cuota de Reembolso en los Distritos de Riego, CAR.

Table C.1.1 Modules for Irrigation Consumption for Lake Fuquene Basin

	Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Crops	Precipitation (mm)	29	45	67	119	84	68	42	38	61	119	100	42	814
	Evapotranspiration (mm)	93	89	93	86	85	77	83	83	81	86	85	84	1,025
	Effective Rainfall, RE (mm)	16	37	54	86	73	58	34	30	51	86	85	33	643
Pastures	Crop Coefficient (K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Consumptive Use, UC (mm)	93	89	93	86	85	77	83	83	81	86	85	84	1,025
	UC-RE (mm)	77	52	39	0	12	19	49	53	30	0	0	51	382
	Net Irrigation Requirement (m^3/ha)	770	520	390	0	120	190	490	530	300	0	0	510	3,898
	Irrigation Module (l/s/ha)	0.29	0.21	0.15	0.00	0.05	0.07	0.19	0.20	0.12	0.00	0.00	0.20	--
Potato	Crop Coefficient (K)	0.4		0.4	0.9	1.0	0.9	0.4		0.4	0.9	1.0	0.9	
	Consumptive Use, UC (mm)	37		37	77	85	69	33		32	77	85	76	608
	UC-RE (mm)	21		(17)	(9)	12	11	(1)		(19)	(9)	0	43	32
	Net Irrigation Requirement (m^3/ha)	210				120	110					0	430	870
	Irrigation Module (l/s/ha)	0.08				0.05	0.04					0.00	0.17	--
Maize	Crop Coefficient (K)	0.9		0.4	0.7	1.0	1.0	0.9		0.4	0.7	1.0	1.0	
	Consumptive Use, UC (mm)	84		37	60	85	77	75		32	60	85	84	679
	UC-RE (mm)	68		(17)	(26)	12	19	41		(19)	(26)	0	51	103
	Net Irrigation Requirement (m^3/ha)	680				120	190	410				0	510	1,910
	Irrigation Module (l/s/ha)	0.26				0.05	0.07	0.16				0.00	0.20	--
Wheat/ Barley	Crop Coefficient (K)	0.7		0.2	0.4	0.7	0.9	0.7		0.2	0.4	0.7	0.9	
	Consumptive Use, UC (mm)	65		19	34	59	69	58		16	34	59	76	489
	UC-RE (mm)	49		(35)	(52)	(14)	11	24		(35)	(52)	(26)	43	(87)
	Net Irrigation Requirement (m^3/ha)	490					110	240					430	1,270
	Irrigation Module (l/s/ha)	0.19					0.04	0.09					0.17	--

Source: Ref. 1)

Table C.1.2 Modules for Irrigation Consumption for Susa River Basin

	Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
	Precipitation (mm)	24	39	95	166	122	75	45	53	80	159	141	51	1,050
	Evapotranspiration (mm)	89	79	82	81	80	74	82	81	80	78	78	82	966
Crops	Effective Rainfall, RE (mm)	15	28	78	81	80	57	32	40	60	78	78	42	669
	Crop Coefficient (K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Consumptive Use, UC (mm)	89	79	82	81	80	74	82	81	80	78	78	82	966
	UC-RE (mm)	74	51	4	0	0	17	50	41	20	0	0	40	297
	Net Irrigation Requirement (m^3/ha)	740	510	40	0	0	170	500	410	200	0	0	400	3,044
Pastures	Irrigation Module (l/s/ha)	0.28	0.21	0.02	0.00	0.00	0.07	0.19	0.16	0.08	0.00	0.00	0.15	--
	Crop Coefficient (K)	0.4		0.4	0.9	1.0	0.9	0.4		0.4	0.9	1.0	0.9	
	Consumptive Use, UC (mm)	36		33	73	80	67	33		32	70	78	74	576
	UC-RE (mm)	21		(45)	(8)	0	10	1		(28)	(8)	0	32	(25)
	Net Irrigation Requirement (m^3/ha)	210				0	100	10				0	320	640
Potato	Irrigation Module (l/s/ha)	0.08				0.00	0.04	0.00				0.00	0.12	--
	Crop Coefficient (K)	0.9		0.4	0.7	1.0	1.0	0.9		0.4	0.7	1.0	1.0	
	Consumptive Use, UC (mm)	80		33	57	80	74	74		32	55	78	82	645
	UC-RE (mm)	65		(45)	(24)	0	17	42		(28)	(23)	0	40	44
	Net Irrigation Requirement (m^3/ha)	650				0	170	420				0	400	1,640
Maize	Irrigation Module (l/s/ha)	0.25				0.00	0.07	0.16				0.00	0.15	--
	Crop Coefficient (K)	0.7		0.2	0.4	0.7	0.9	0.7		0.2	0.4	0.7	0.9	
	Consumptive Use, UC (mm)	62		16	32	56	67	57		16	31	55	74	466
	UC-RE (mm)	47		(62)	(49)	(24)	10	25		(44)	(47)	(23)	32	(135)
Wheat/ Barley	Net Irrigation Requirement (m^3/ha)	470					100	250					320	1,140
	Irrigation Module (l/s/ha)	0.18					0.04	0.10					0.12	--

Source: Ref. 1)

Table C.1.3 Modules for Irrigation Consumption for Simijaca River Basin

	Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Crops	Precipitation (mm)	24	38	93	164	120	73	44	52	78	157	138	51	1,032
	Evapotranspiration (mm)	92	82	85	84	83	76	85	84	83	81	81	85	1,001
	Effective Rainfall, RE (mm)	15	26	76	84	83	55	30	38	58	81	81	42	669
Pastures	Crop Coefficient (K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Consumptive Use, UC (mm)	92	82	85	84	83	76	85	84	83	81	81	85	1,001
	UC-RE (mm)	77	56	9	0	0	21	55	46	25	0	0	43	332
	Net Irrigation Requirement (m^3/ha)	770	560	90	0	0	210	550	460	250	0	0	430	3,385
	Irrigation Module (l/s/ha)	0.29	0.23	0.03	0.00	0.00	0.08	0.21	0.18	0.10	0.00	0.00	0.17	--
Potato	Crop Coefficient (K)	0.4		0.4	0.9	1.0	0.9	0.4		0.4	0.9	1.0	0.9	
	Consumptive Use, UC (mm)	37		34	76	83	68	34		33	73	81	77	595
	UC-RE (mm)	22		(42)	(8)	0	13	4		(25)	(8)	0	35	(9)
	Net Irrigation Requirement (m^3/ha)	220				0	130	40				0	350	740
	Irrigation Module (l/s/ha)	0.08				0.00	0.05	0.02				0.00	0.13	--
Maize	Crop Coefficient (K)	0.9		0.4	0.7	1.0	1.0	0.9		0.4	0.7	1.0	1.0	
	Consumptive Use, UC (mm)	83		34	59	83	76	77		33	57	81	85	667
	UC-RE (mm)	68		(42)	(25)	0	21	47		(25)	(24)	0	43	63
	Net Irrigation Requirement (m^3/ha)	680				0	210	470				0	430	1,788
	Irrigation Module (l/s/ha)	0.25				0.00	0.08	0.18				0.00	0.16	--
Wheat/ Barley	Crop Coefficient (K)	0.7		0.2	0.4	0.7	0.9	0.7		0.2	0.4	0.7	0.9	
	Consumptive Use, UC (mm)	64		17	34	58	68	59		17	32	57	77	483
	UC-RE (mm)	49		(59)	(50)	(25)	13	29		(41)	(49)	(24)	35	(122)
	Net Irrigation Requirement (m^3/ha)	490					130	290					350	1,260
	Irrigation Module (l/s/ha)	0.18					0.05	0.11					0.13	--

Source: Ref. 1)

Table C.1.4 Modules for Irrigation Consumption for Chiquinquira River Basin

	Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Crops	Precipitation (mm)	38	47	93	150	113	79	57	50	83	141	136	60	1,047
	Evapotranspiration (mm)	85	82	91	81	82	76	82	82	79	82	79	81	982
	Effective Rainfall, RE (mm)	28	36	81	81	82	64	43	38	66	82	79	47	727
Pastures	Crop Coefficient (K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Consumptive Use, UC (mm)	85	82	91	81	82	76	82	82	79	82	79	81	982
	UC-RE (mm)	57	46	10	0	0	12	39	44	13	0	0	34	255
	Net Irrigation Requirement (m^3/ha)	570	460	100	0	0	120	390	440	130	0	0	340	2,550
	Irrigation Module (l/s/ha)	0.21	0.19	0.04	0.00	0.00	0.05	0.15	0.17	0.05	0.00	0.00	0.13	--
Potato	Crop Coefficient (K)	0.4		0.4	0.9	1.0	0.9	0.4		0.4	0.9	1.0	0.9	
	Consumptive Use, UC (mm)	34		36	73	82	68	33		32	74	79	73	584
	UC-RE (mm)	6		(45)	(8)	0	4	(10)		(34)	(8)	0	26	(69)
	Net Irrigation Requirement (m^3/ha)	60				0	40					0	260	360
	Irrigation Module (l/s/ha)	0.02				0.00	0.02					0.00	0.10	--
Maize	Crop Coefficient (K)	0.9		0.4	0.7	1.0	1.0	0.9		0.4	0.7	1.0	1.0	
	Consumptive Use, UC (mm)	77		36	57	82	76	74		32	57	79	81	651
	UC-RE (mm)	49		(45)	(24)	0	12	31		(34)	(25)	0	34	(2)
	Net Irrigation Requirement (m^3/ha)	490				0	120	310				0	340	1,260
	Irrigation Module (l/s/ha)	0.19				0.00	0.05	0.12				0.00	0.13	--
Wheat/ Barley	Crop Coefficient (K)	0.7		0.2	0.4	0.7	0.9	0.7		0.2	0.4	0.7	0.9	
	Consumptive Use, UC (mm)	59		18	32	57	68	57		16	33	55	73	468
	UC-RE (mm)	31		(63)	(49)	(25)	4	14		(50)	(49)	(24)	26	(185)
	Net Irrigation Requirement (m^3/ha)	310					40	140					260	750
	Irrigation Module (l/s/ha)	0.12					0.02	0.05					0.10	--

Source: Ref. 1)

Table C.1.5 Modules for Irrigation Consumption for Suarez River Basin

	Month	Jun	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Crops	Precipitation (mm)	40	50	98	159	119	83	60	53	87	149	144	62	1,104
	Evapotranspiration (mm)	90	87	97	85	86	79	87	86	81	86	81	85	1,030
	Effective Rainfall, RE (mm)	29	38	85	85	86	67	43	41	70	86	81	49	760
Pastures	Crop Coefficient (K)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	
	Consumptive Use, UC (mm)	90	87	97	85	86	79	87	86	81	86	81	85	1,030
	UC-RE (mm)	61	49	12	0	0	12	44	45	11	0	0	36	270
	Net Irrigation Requirement (m^3/ha)	610	490	120	0	0	120	440	450	110	0	0	360	2,757
	Irrigation Module (l/s/ha)	0.23	0.20	0.05	0.00	0.00	0.05	0.17	0.17	0.04	0.00	0.00	0.14	--
Maize	Crop Coefficient (K)	0.9		0.4	0.7	1.0	1.0	0.9		0.4	0.7	1.0	1.0	
	Consumptive Use, UC (mm)	81		39	59	86	79	78		32	60	81	85	681
	UC-RE (mm)	52		(46)	(26)	0	12	35		(38)	(26)	0	36	(1)
	Net Irrigation Requirement (m^3/ha)	520				0	120	350				0	360	1,389
	Irrigation Module (l/s/ha)	0.19				0.00	0.05	0.14				0.00	0.14	--

Source: Ref. 1)

Table C.1.6 Results of Questionnaire Survey for Public Water Supply System

Municipalities (Organization)	Intake System	Water Source	Treatment *) Process	Urban Zone		Rural Zone		Monthly Average Raw Water Intake Volume (m³) [lit./per capita day]
				Population (habitants)	Served (%)	Population (habitants)	Served (%)	
1. Carmen de Carupa (Public Service Office)	Diversion	R. Playa	Se, Ar	1,500	100	6,000	0	15,000 [330]
2. Ubate (Public Service Office)	Diversion	R. Ubate	Se, Fl, Fi, Ch	17,500	100	4,500	31	196,992 [350]
3. Tausa (Municipality)	Diversion	Q. Chapeton	Se, Fi, Ch	700	100	n. d.	n. d.	7,350 [350]
4. Sutatausa (Public Service Office)	Diversion	Surface	Se, Fl, Fi, Ch	1,104	98	3,438	1	18,144 [540]
5. Cucunuba (Municipality)	Diversion	Q. Lachorrera	Se, Fl, Fi, Ch	927	100	7,514**)	7	5,068 [120]
6.Lenguazaque (Municipality)	Diversion	R. Lenguazaque	Se, Fl, Fi, Ch	1,780	100	8,700	1	31,104 [560]
7. Guacheta (Municipal Planning Office)	Diversion	Q. Honda	Se, Fl, Fi, Ch	3,365	100	8,463	71	31,120 (urban) [310]
8. San Miguel de Sema (Municipal Planning Office)	Diversion	Q. La Cortadera	Se, Fl, Fi, Ch	536	100	4,500	72	49,065 [430]
9. Fuquene (Municipality Planning Office)	Diversion	Q.El Páramo	Nothing	495	100	5,000	0	9,338 [144]
10. Susa (Municipality)	Diversion	Q. Nutrias	Nothing	1,368	100	4,900	20	12,798 [180]
11. Simijaca (Municipality)	Diversion	R.Simijaca	Se, Fl, Fi, Ch	4,215	35	5,600	0.5	7,988 [150]
12. Caldas (Municipality)	Diversion	Q. Ojo de Agua	Se.	285	100	5,500	23	6,187 [134]
13. Chiquinquira (Empochiquinquira***)	Pumping Sta.	R. Suarez	Se, Fl, Fi, Ch, Ar	46,566	94	n. d.	n. d.	518,400 [400]
14. Saboya (Municipality)	Diversion	Q. Cantoco	Se.	1,225	100	16,500	10	6,150 [74]
Total								914,704

Note) 1. Survey Date: May & October 1999.
2. n. d.: no data.
3. *) Se.: Sedimentation, Ar: Aeration, Fl.: Flocculation, Fi.: Filtering, Ch.: Chlorination/ Disinfection.
4. **): 1993 data.
5. ***): Municipal enterprise.

Table C.1.7 Estimation of Present Domestic Water Demand

Municipalities	Area	1988 Population (persons)	Municipal Water Supply System: Service Factor	Municipal Water Supply System: Consumption (l/capita day)	Municipal Water Supply System: Customer Demand (l/day)	Vereda Water Supply System: Service Factor	Vereda Water Supply System: Consumption (l/capita day)	Vereda Water Supply System: Customer Demand (l/day)	Total Customer Demand (m^3/day)
C.Carupa	Urban	1,511	1.00	150	226,650	0.00	150	0	227
	Rural	6,130	0.00	125	0	1.00	125	766,250	766
Sub-total		7,641			226,650			766,250	993
Ubate	Urban	16,883	1.00	180	3,038,940	0.00	180	0	3,039
	Rural	22,592	0.31	125	875,440	0.69	125	1,948,560	2,824
Sub-total		39,475			3,914,380			1,948,560	5,863
Tausa	Urban	635	1.00	150	95,250	0.00	150	0	95
	Rural	911	0.00	125	0	1.00	125	113,875	114
Sub-total		1,546			95,250			113,875	209
Sutatausa	Urban	1,104	0.98	150	162,288	0.02	150	3,312	166
	Rural	3,438	0.01	125	4,298	0.99	125	425,453	430
Sub-total		4,542			166,586			428,765	596
Cucunuba	Urban	1,226	1.00	150	183,900	0.00	150	0	184
	Rural	5,996	0.07	125	52,465	0.93	125	697,035	750
Sub-total		7,222			236,365			697,035	934
Suesca	Urban	0	1.00	150	0	0.00	150	0	0
	Rural	2,136	0.00	125	0	1.00	125	267,000	267
Sub-total		2,136			0			267,000	267
Villapinzon	Urban	0	1.00	165	0	0.00	165	0	0
	Rural	1,330	0.00	125	0	1.00	125	166,250	166
Sub-total		1,330			0			166,250	166
Lenguazaque	Urban	2,133	1.00	150	319,950	0.00	150	0	320
	Rural	7,764	0.01	125	9,705	0.99	125	960,795	971
Sub-total		9,897			329,655			960,795	1,291
Guacheta	Urban	3,621	1.00	150	543,150	0.00	150	0	543
	Rural	8,717	0.71	125	773,634	0.29	125	315,991	1,090
Sub-total		12,338			1,316,784			315,991	1,633
S. M. de Sem:	Urban	525	1.00	150	78,750	0.00	150	0	79
	Rural	3,967	0.72	125	357,030	0.28	125	138,845	496
Sub-total		4,492			435,780			138,845	575
Raquira	Urban	0	1.00	150	0	0.00	150	0	0
	Rural	2,325	0.00	125	0	1.00	125	290,625	291
Sub-total		2,325			0			290,625	291
Fuquene	Urban	348	1.00	150	52,200	0.00	150	0	52
	Rural	5,129	0.00	125	0	1.00	125	641,125	641
Sub-total		5,477			52,200			641,125	693
Susa	Urban	1,368	1.00	150	205,200	0.00	150	0	205
	Rural	4,893	0.20	125	122,325	0.80	125	489,300	612
Sub-total		6,261			327,525			489,300	817
Simijaca	Urban	4,215	0.35	150	221,288	0.65	150	410,963	632
	Rural	5,556	0.005	125	3,473	0.995	125	691,028	695
Sub-total		9,771			224,761			1,101,991	1,327
Caldas	Urban	275	1.00	150	41,250	0.00	150	0	41
	Rural	5,501	0.23	125	158,154	0.77	125	529,471	688
Sub-total		5,776			199,404			529,471	729
Chiquinquira	Urban	41,021	0.94	195	7,519,149	0.06	195	479,946	7,999
	Rural	6,609	0.00	125	0	1.00	125	826,125	826
Sub-total		47,630			7,519,149			1,306,071	8,825
Saboya	Urban	979	1.00	150	146,850	0.00	150	0	147
	Rural	12,101	0.10	125	151,263	0.90	125	1,361,363	1,513
Sub-total		13,080			298,113			1,361,363	1,660
Urban		75,844			12,834,815			894,221	13,729
Rural		105,095			2,507,787			10,629,091	13,140
Total		180,939			15,342,602			11,523,312	26,869

Table C.2.1 Projection of Domestic Water Demand

Municipalities	Area	2010 Population (persons)	Municipal Water Supply System: Service Factor	Municipal Water Supply System: Consumption (l/capita day)	Municipal Water Supply System: Customer Demand (l/day)	Vereda Water Supply System: Service Factor	Vereda Water Supply System: Consumption (l/capita day)	Vereda Water Supply System: Customer Demand (l/day)	Total Customer Demand (m^3/day)
C.Carupa	Urban	2,192	1.00	150	328,800	0.00	150	0	329
	Rural	6,358	0.00	125	0	1.00	125	794,750	795
Sub-total		8,550			328,800			794,750	1,124
Ubate	Urban	22,883	1.00	195	4,462,185	0.00	195	0	4,462
	Rural	26,499	0.31	125	1,026,836	0.69	125	2,285,539	3,312
Sub-total		49,382			5,489,021			2,285,539	7,774
Tausa	Urban	1,074	1.00	150	161,100	0.00	150	0	161
	Rural	911	0.00	125	0	1.00	125	113,875	114
Sub-total		1,985			161,100			113,875	275
Sutatausa	Urban	1,476	0.98	150	216,972	0.02	150	4,428	221
	Rural	3,646	0.01	125	4,558	0.99	125	451,193	456
Sub-total		5,122			221,530			455,621	677
Cucunuba	Urban	2,048	1.00	150	307,200	0.00	150	0	307
	Rural	6,822	0.07	125	59,693	0.93	125	793,058	853
Sub-total		8,870			366,893			793,058	1,160
Suesca	Urban	0	1.00	165	0	0.00	165	0	0
	Rural	2,660	0.00	125	0	1.00	125	332,500	333
Sub-total		2,660			0			332,500	333
Villapinzon	Urban	0	1.00	165	0	0.00	165	0	0
	Rural	1,346	0.00	125	0	1.00	125	168,250	168
Sub-total		1,346			0			168,250	168
Lenguazaque	Urban	2,800	1.00	150	420,000	0.00	150	0	420
	Rural	7,913	0.01	125	9,891	0.99	125	979,234	989
Sub-total		10,713			429,891			979,234	1,409
Guacheta	Urban	4,602	1.00	150	690,300	0.00	150	0	690
	Rural	9,113	0.71	125	808,779	0.29	125	330,346	1,139
Sub-total		13,715			1,499,079			330,346	1,829
S. M. de Sema	Urban	730	1.00	150	109,500	0.00	150	0	110
	Rural	3,936	0.72	125	354,240	0.28	125	137,760	492
Sub-total		4,666			463,740			137,760	602
Raquira	Urban	0	1.00	150	0	0.00	150	0	0
	Rural	2,674	0.00	125	0	1.00	125	334,250	334
Sub-total		2,674			0			334,250	334
Fuquene	Urban	713	1.00	150	106,950	0.00	150	0	107
	Rural	5,308	0.00	125	0	1.00	125	663,500	664
Sub-total		6,021			106,950			663,500	771
Susa	Urban	1,765	1.00	150	264,750	0.00	150	0	265
	Rural	4,903	0.20	125	122,575	0.80	125	490,300	613
Sub-total		6,668			387,325			490,300	878
Simijaca	Urban	5,048	0.35	165	291,522	0.65	165	541,398	833
	Rural	5,761	0.005	125	3,601	0.995	125	716,524	720
Sub-total		10,809			295,123			1,257,922	1,553
Caldas	Urban	621	1.00	150	93,150	0.00	150	0	93
	Rural	5,351	0.23	125	153,841	0.77	125	515,034	669
Sub-total		5,972			246,991			515,034	762
Chiquinquira	Urban	48,364	0.94	195	8,865,121	0.06	195	565,859	9,431
	Rural	6,887	0.00	125	0	1.00	125	860,875	861
Sub-total		55,251			8,865,121			1,426,734	10,292
Saboya	Urban	1,616	1.00	150	242,400	0.00	150	0	242
	Rural	10,480	0.10	125	131,000	0.90	125	1,179,000	1,310
Sub-total		12,096			373,400			1,179,000	1,552
Urban		95,932			16,559,950			1,111,685	17,671
Rural		110,568			2,675,014			11,145,988	13,822
Total		206,500			19,234,964			12,257,673	31,493

Table C.2.2 Present and Projected Slaughtering Water Demand

Municipalities	1998 Population (persons)	2010 Population (persons)	Increae Ratio	1999 Municipal Water Supply System				2010 Municipal System
				Animal	Slaughtering (head/week)	Consumption (l/head)	Customer Demand (l/week)	Customer Demand (m^3/week)
C.Carupa	7,641	8,550	1.12	Bovine	15	500	7,500	8
Ubate	39,475	49,382	1.25	Bovine	150	500	75,000	
				Porcine	72	250	18,000	
				Ovine	72	200	14,400	
				Sub-total	294		107,400	134
Tausa	1,546	1,985	1.28	--				0
Sutatausa	4,542	5,122	1.13	Bovine	11	500	5,500	6
Cucunuba	7,222	8,870	1.23	Bovine	5	500	2,500	3
Suesca	2,136	2,660	1.25	--				0
Villapinzon	1,330	1,346	1.01	--				0
Lenguazaque	9,897	10,713	1.08	Bovine	24	500	12,000	13
Guacheta	12,338	13,715	1.11	Bovine	21	500	10,500	12
S. M. de Sema	4,492	4,666	1.04	Bovine	2	500	1,000	1
Raquira	2,325	2,674	1.15	--				0
Fuquene	5,477	6,021	1.10	Bovine	21	500	10,500	12
Susa	6,261	6,668	1.07	Bovine	22	500	11,000	12
Simijaca	9,771	10,809	1.11	Bovine	35	500	17,500	19
Caldas	5,776	5,972	1.03	Bovine	4	500	2,000	2
Chiquinquira	47,630	55,251	1.16	Bovine	115	500	57,500	67
Saboya	13,080	12,096	0.92	Bovine	21	500	10,500	10
Total	180,939	206,500	1.14		884		249,900	299

Table C.2.3 Present and Projected Milk Product Fabrication Water Demand

Municipalities	1998 Production		(Unit)	Consumption	(Unit)	1998 Customer demand (m^3/day)	1998 Customer Demand (m^3/day) *Municipal System	1998 Customer Demand (m^3/day) **Vereda System, Wells, Rivers	1998 Customer Demand (m^3/day) Total	***2010 Customer Demand (m^3/day) *Municipal System	***2010 Customer Demand (m^3/day) **Vereda System, Wells, Rivers	***2010 Customer Demand (m^3/day) Total
C.Carupa	--					0.0			0.0			0.0
Ubate	Milk	153,333	l/day	3,500	l/ton	536.7						
	Cheese	2,723	kg/day	15,000	l/ton	40.8						
	Yogurth	14,878	l/day	24,000	l/ton	357.1						
	Sub-total					934.6	803.8	130.8	934.6	836.0	136.0	972.0
Tausa	Cheese	44	kg/day	15,000	l/ton	0.7						
	Yogurth	15	l/day	24,000	l/ton	0.4						
	Sub-total					1.1	0.9	0.2	1.1	0.9	0.2	1.1
Sutatausa	--					0.0			0.0			0.0
Cucunuba	--					0.0			0.0			0.0
Suesca	--					0.0			0.0			0.0
Villapinzon	--					0.0			0.0			0.0
Lenguazaque	--					0.0			0.0			0.0
Guacheta	Cheese	44	kg/day	15,000	l/ton	0.7						
	Yogurth	15	l/day	24,000	l/ton	0.4						
	Sub-total					1.1	0.9	0.2	1.1	0.9	0.2	1.1
S. M. de Sema	Milk	37,750	l/day	3,500	l/ton	132.1	113.6	18.5	132.1	118.1	19.2	137.3
Raquira	--					0.0			0.0			0.0
Fuquene	Milk	73,333	l/day	3,500	l/ton	256.7						
	Cheese	675	kg/day	15,000	l/ton	10.1						
	Yogurth	7,208	l/day	24,000	l/ton	173.0						
	Sub-total					439.8	378.2	61.6	439.8	393.3	64.1	457.4
Susa	--					0.0			0.0			0.0
Simijaca	Milk	191,083	l/day	3,500	l/ton	668.8						
	Cheese	1,394	kg/day	15,000	l/ton	20.9						
	Yogurth	14,431	l/day	24,000	l/ton	346.3						
	Sub-total					1036.0	891.0	145.0	1,036.0	926.6	150.8	1,077.4
Caldas	--					0.0			0.0			0.0
Chiquinquira	Cheese	440	kg/day	15,000	l/ton	6.6						
	Yogurth	150	l/day	24,000	l/ton	3.6						
	Sub-total					10.2	8.8	1.4	10.2	9.2	1.5	10.7
Saboya	--					0.0			0.0			0.0
Total						2,554.9	2,197.2	357.7	2,554.9	2,285.0	372.0	2,657.0

Note: *Municipal water supply systems serve 86 % of the water consumption.
**Vereda water supply systems, wells, rivers and streams serve 14 % of the water consumption.
***Milk industry sector will increase from 1998 until 2010 by 4 %.

Table C.3.1 Results of Water Balance Analysis under Present Conditions

(Unit: '000 m^3)

Block Name	Gross Area (ha)	Annual Average Water Resources			Annual Average Water Demand				Deficit	Surplus	Annual Probable Deficit*		
		Runoff	Dam/Lake	Total	Irrigation	Livestock	Municipal	Total			1st (1/20)	2nd (1/10)	4th (1/5)
1. Suta	832	11,552	0	11,552	5,067	21	0	5,088	2,049	8,513	3,470	2,700	2,442
		14	0	14	6	0	0	6	2	10	4	3	3
2. Cap-1**	634	39,713	42	39,755	4,290	16	2,398	6,704	0	33,051	0	0	0
		63	0	63	7	0	4	11	0	52	0	0	0
3. Cucunuba	1,892	4,463	7,332	11,795	9,218	47	0	9,265	0	2,530	0	0	0
		2	4	6	5	0	0	5	0	1	0	0	0
4. Lenguazaque	1,751	40,979	0	40,979	10,664	43	0	10,707	1,219	31,490	3,320	3,024	2,464
		23	0	23	6	0	0	6	1	18	2	2	1
5. Cap-2	316	40,457	72	40,529	2,138	39	0	2,177	0	38,351	0	0	0
		128	0	128	7	0	0	7	0	121	0	0	0
6. Mariño	700	1,344	0	1,344	4,263	17	0	4,280	3,652	716	3,953	3,942	3,826
		2	0	2	6	0	0	6	5	1	6	6	5
7. Mariño-Ubate	387	95,937	0	95,937	2,357	10	0	2,366	0	93,570	0	0	0
		248	0	248	6	0	0	6	0	242	0	0	0
8. Fuquene	2,537	17,815	9,479	27,294	15,451	63	0	15,514	0	11,780	0	0	0
		7	4	11	6	0	0	6	0	5	0	0	0
9. Honda	509	20,163	431	20,594	3,100	13	0	3,113	0	17,482	0	0	0
		40	1	40	6	0	0	6	0	34	0	0	0
10. Susa	563	12,023	0	12,023	2,678	14	0	2,692	641	9,972	1,621	1,435	972
		21	0	21	5	0	0	5	1	18	3	3	2
11. Suarez***	8,309	160,345	21,804	182,149	30,320	128	6,312	36,760	0	145,390	0	0	0
		19	3	22	4	0	1	4	0	17	0	0	0
13. Old-Suarez	228	278	0	278	982	6	0	988	877	168	938	934	928
		1	0	1	4	0	0	4	4	1	4	4	4
14. Madron	1,359	11,907	0	11,907	5,854	34	0	5,888	2,893	8,912	4,718	4,635	4,520
		9	0	9	4	0	0	4	2	7	3	3	3
15. Merchan	320	9,273	0	9,273	1,379	8	0	1,387	259	8,145	870	826	693
		29	0	29	4	0	0	4	1	25	3	3	2
Total	20,337	--	39,160	--	97,761	459	8,710	106,929	11,590	--	--	--	--

Note) * 1st, 2nd and 4th annual deficit values in 20 years (in descending order) correspond to 20, 10 and 5 years probable values, respectively.
** Municipal: Ubate, *** Municipal: Chiquinquira. 1. Figures in lower row mean per ha values.

Table C.3.2 Hato Dam Water Supply under Present Conditions

	Necessary Release Water from Hato Dam ('000 m^3/month)*																				Return Period ('000 m^3)**			CAR Release
Mon.	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90	'91	'92	'93	'94	'95	'96	'97	1/20	1/10	1/5	('000 m^3/month)
Jan.	0	109	0	0	0	564	238	24	0	173	0	65	0	0	42	0	0	0	0	0	564	238	109	1,300-1,600
Feb.	0	30	0	0	0	182	0	0	0	17	0	19	0	0	0	0	0	0	0	0	182	30	17	1,200-1,500
Mar.	0	0	0	0	0	109	6	0	0	0	0	0	0	0	0	0	0	0	0	0	109	6	0	1,300-1,600
Apr.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	closed
May	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	49	0	49	0	0	closed
Jun.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1,300-1,600
Jul.	0	0	0	0	0	116	0	0	0	0	0	0	0	0	0	0	0	0	0	0	116	0	0	1,300-1,600
Aug.	0	0	0	0	0	201	12	0	0	0	0	5	0	0	0	0	0	0	0	0	201	12	0	1,300-1,600
Sep.	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	2	0	0	closed
Dec.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	closed
Nov.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	closed
Dec.	0	0	0	0	46	0	0	0	0	0	0	181	0	0	0	0	0	0	0	82	181	82	0	1,300-1,600

Note) * Including irrigation, livestock and Ubate municipal water use. These figures are derived from water balance analysis.

** 1st, 2nd and 4th values in 20 years (in descending order) correspond to 20,10 and 5 years probable values.

Table C.3.3 Results of Optimization Simulation of Fuquene Lake (Present Conditions: Case-1)

Case		Rainy Season Operation Water Level (El. m)																				
		2539.5			2539.3			2539.1			2538.9			2538.7			2538.5			2538.3		
Dry Season Operation Water Level (El. m)	2539.5	MAX	1/2	39.85	MAX	1/2	39.78	MAX	1/2	39.71	MAX	1/2	39.67	MAX	1/2	39.65	MAX	1/2	39.64			
			1/5	40.10		1/5	40.04		1/5	39.99		1/5	39.97		1/5	39.95		1/5	39.95			
			1/10	40.27		1/10	40.21		1/10	40.18		1/10	40.17		1/10	40.15		1/10	40.15			
			1/20	40.43		1/20	40.38		1/20	40.37		1/20	40.37		1/20	40.35		1/20	40.34			
		MIN	1/2	39.06	MIN	1/2	38.98	MIN	1/2	38.85	MIN	1/2	38.75	MIN	1/2	38.68	MIN	1/2	38.64			
			1/5	38.89		1/5	38.81		1/5	38.64		1/5	38.54		1/5	38.45		1/5	38.40			
			1/10	38.82		1/10	38.73		1/10	38.56		1/10	38.45		1/10	38.36		1/10	38.29			
			1/20	38.76		1/20	38.68		1/20	38.49		1/20	38.38		1/20	38.29		1/20	38.22			
		MODE	39.4-39.5	30.9	MODE	39.3-39.4	26.0	MODE	39.4-39.5	18.6	MODE	39.4-39.5	16.5	MODE	39.4-39.5	15.9	MODE	39.4-39.5	16.1			
		CAV.		1.0	CAV.		1.1	CAV.		4.2	CAV.		5.4	CAV.		7.6	CAV.		9.1			
	2539.3				MAX	1/2	39.72	MAX	1/2	39.65	MAX	1/2	39.62	MAX	1/2	39.61	MAX	1/2	39.60	MAX	1/2	39.60
						1/5	40.00		1/5	39.95		1/5	39.92		1/5	39.92		1/5	39.91		1/5	39.91
						1/10	40.19		1/10	40.14		1/10	40.13		1/10	40.12		1/10	40.11		1/10	40.11
						1/20	40.37		1/20	40.33		1/20	40.32		1/20	40.31		1/20	40.30		1/20	40.30
					MIN	1/2	38.85	MIN	1/2	38.77	MIN	1/2	38.68	MIN	1/2	38.62	MIN	1/2	38.58	MIN	1/2	38.58
						1/5	38.69		1/5	38.60		1/5	38.50		1/5	38.42		1/5	38.36		1/5	38.36
						1/10	38.62		1/10	38.52		1/10	38.42		1/10	38.33		1/10	38.26		1/10	38.26
						1/20	38.57		1/20	38.47		1/20	38.36		1/20	38.27		1/20	38.20		1/20	38.19
					MODE	39.2-39.3	27.4	MODE	39.2-39.3	25.1	MODE	39.2-39.3	21.7	MODE	39.2-39.3	19.8	MODE	39.2-39.3	18.6	MODE	39.2-39.3	19.4
					CAV.		2.1	CAV.		4.7	CAV.		6.6	CAV.		9.1	CAV.		10.7	CAV.		10.7
	2539.1							MAX	1/2	39.61	MAX	1/2	39.57	MAX	1/2	39.55	MAX	1/2	39.54	MAX	1/2	39.53
									1/5	39.91		1/5	39.88		1/5	39.87		1/5	39.86		1/5	39.86
									1/10	40.12		1/10	40.08		1/10	40.08		1/10	40.08		1/10	40.08
									1/20	40.31		1/20	40.28		1/20	40.28		1/20	40.29		1/20	40.29
								MIN	1/2	38.63	MIN	1/2	38.58	MIN	1/2	38.52	MIN	1/2	38.49	MIN	1/2	38.48
									1/5	38.46		1/5	38.41		1/5	38.35		1/5	38.30		1/5	38.29
									1/10	38.39		1/10	38.34		1/10	38.28		1/10	38.22		1/10	38.21
									1/20	38.33		1/20	38.29		1/20	38.22		1/20	38.17		1/20	38.15
								MODE	39.0-39.1	24.6	MODE	39.0-39.1	25.9	MODE	39.0-39.1	24.6	MODE	39.0-39.1	22.9	MODE	39.0-39.1	23.1
								CAV.		10.6	CAV.		11.6	CAV.		13.3	CAV.		14.7	CAV.		15.1
	2538.9										MAX	1/2	39.53	MAX	1/2	39.50	MAX	1/2	39.50	MAX	1/2	39.49
												1/5	39.84		1/5	39.83		1/5	39.82		1/5	39.82
												1/10	40.05		1/10	40.04		1/10	40.03		1/10	40.04
												1/20	40.25		1/20	40.24		1/20	40.24		1/20	40.25
											MIN	1/2	38.46	MIN	1/2	38.43	MIN	1/2	38.41	MIN	1/2	38.40
												1/5	38.30		1/5	38.27		1/5	38.23		1/5	38.22
												1/10	38.23		1/10	38.20		1/10	38.16		1/10	38.14
												1/20	38.18		1/20	38.15		1/20	38.10		1/20	38.08
											MODE	38.8-38.9	18.8	MODE	38.8-38.9	19.4	MODE	38.8-38.9	19.3	MODE	38.8-38.9	19.4
											CAV.		20.7	CAV.		22.0	CAV.		21.7	CAV.		22.0

Note) MAX: Probable Annual Maximum Water Level. MIN: Probable Annual Minimum Water Level. MODE: Mode of Water Level Distribution (%).
CAV.: Rate of Cavitation Period at Chiquinquira Pumping Station (%).
(shaded): MAX (1/2) is less than 39.5. (shaded, bold frame): Optimum Operation Rule.

Table C.3.4 Results of Optimization Simulation of Fuquene Lake (Present Conditions: Case-2)

Case		Rainy Season Operation Water Level (El. m)											
Dry Season Operation Water Level (El. m)		2539.5		2539.3		2539.1		2538.9		2538.7		2538.5	
2539.5	MAX	1/2	39.80	1/2	39.71	1/2	39.65	1/2	39.59				
		1/5	40.02	1/5	39.93	1/5	39.89	1/5	39.85				
		1/10	40.16	1/10	40.08	1/10	40.04	1/10	40.03				
		1/20	40.30	1/20	40.22	1/20	40.19	1/20	40.20				
	MIN	1/2	39.04	1/2	38.98	1/2	38.82	1/2	38.66				
		1/5	38.87	1/5	38.80	1/5	38.62	1/5	38.44				
		1/10	38.80	1/10	38.73	1/10	38.54	1/10	38.35				
		1/20	38.75	1/20	38.67	1/20	38.47	1/20	38.28				
	MODE	39.4-39.5	32.4	39.3-39.4	31.0	39.1-39.2	20.7	39.3-39.4	13.4				
	CAV.		1.0		1.1		4.8		7.7				
2539.3	MAX			1/2	39.65	1/2	39.58	1/2	39.52	1/2	39.49		
				1/5	39.90	1/5	39.83	1/5	39.79	1/5	39.78		
				1/10	40.07	1/10	40.00	1/10	39.98	1/10	39.97		
				1/20	40.23	1/20	40.16	1/20	40.15	1/20	40.16		
	MIN			1/2	38.82	1/2	38.74	1/2	38.62	1/2	38.53		
				1/5	38.66	1/5	38.56	1/5	38.43	1/5	38.33		
				1/10	38.58	1/10	38.49	1/10	38.35	1/10	38.24		
				1/20	38.53	1/20	38.43	1/20	38.28	1/20	38.18		
	MODE			39.2-39.3	29.8	39.1-39.2	26.8	39.1-39.2	19.3	39.1-39.2	18.6		
	CAV.				2.9		5.8		8.3		11.9		
2539.1	MAX					1/2	39.51	1/2	39.46	1/2	39.43	1/2	39.42
						1/5	39.80	1/5	39.75	1/5	39.73	1/5	39.73
						1/10	39.99	1/10	39.94	1/10	39.93	1/10	39.93
						1/20	40.17	1/20	40.12	1/20	40.12	1/20	40.13
	MIN					1/2	38.59	1/2	38.52	1/2	38.44	1/2	38.40
						1/5	38.43	1/5	38.36	1/5	38.27	1/5	38.22
						1/10	38.36	1/10	38.28	1/10	38.20	1/10	38.14
						1/20	38.31	1/20	38.23	1/20	38.15	1/20	38.08
	MODE					39.0-39.1	28.3	39.0-39.1	26.0	39.0-39.1	24.2	39.0-39.1	22.2
	CAV.						12.4		13.6		16.6		17.3
2538.9	MAX							1/2	39.42	1/2	39.39	1/2	39.38
								1/5	39.73	1/5	39.70	1/5	39.69
								1/10	39.93	1/10	39.90	1/10	39.89
								1/20	40.13	1/20	40.09	1/20	40.08
	MIN							1/2	38.39	1/2	38.36	1/2	38.32
								1/5	38.23	1/5	38.19	1/5	38.15
								1/10	38.16	1/10	38.11	1/10	38.08
								1/20	38.11	1/20	38.06	1/20	38.02
	MODE							38.8-38.9	20.4	38.8-38.9	20.7	38.8-38.9	21.6
	CAV.								24.8		25.8		24.5

Note) MAX: Probable Annual Maximum Water Level. MIN: Probable Annual Minimum Water Level. MODE: Mode of Water Level Distribution (%).
CAV.: Rate of Cavitation Period at Chiquinquira Pumping Station (%).

(shaded): MAX (1/2) is less than 39.5. (bold frame): Optimum Operation Rule.

Table C.3.5 Results of Optimization Simulation of Fuquene Lake (Present Conditions: Case-3)

Case	Rainy Season Operation Water Level (El. m)																	
Dry Season Operation Water Level (El. m)	2539.5			2539.3			2539.1			2538.9			2538.7			2538.5		
2539.5	MAX	1/2	39.78	MAX	1/2	39.69	MAX	1/2	39.61	MAX	1/2	39.56						
		1/5	39.98		1/5	39.90		1/5	39.84		1/5	39.81						
		1/10	40.12		1/10	40.03		1/10	39.98		1/10	39.97						
		1/20	40.25		1/20	40.16		1/20	40.12		1/20	40.13						
	MIN	1/2	39.04	MIN	1/2	38.98	MIN	1/2	38.81	MIN	1/2	38.62						
		1/5	38.88		1/5	38.81		1/5	38.60		1/5	38.40						
		1/10	38.81		1/10	38.73		1/10	38.52		1/10	38.31						
		1/20	38.76		1/20	38.68		1/20	38.45		1/20	38.24						
	MODE	39.4-39.5	31.1	MODE	39.3-39.4	27.7	MODE	39.1-39.2	21.1	MODE	38.9-39.0	12.5						
	CAV.		1.0	CAV.		1.1	CAV.		5.0	CAV.		8.9						
2539.3				MAX	1/2	39.63	MAX	1/2	39.56	MAX	1/2	39.49	MAX	1/2	39.45			
					1/5	39.87		1/5	39.79		1/5	39.75		1/5	39.73			
					1/10	40.02		1/10	39.95		1/10	39.92		1/10	39.91			
					1/20	40.17		1/20	40.10		1/20	40.08		1/20	40.09			
				MIN	1/2	38.82	MIN	1/2	38.74	MIN	1/2	38.59	MIN	1/2	38.47			
					1/5	38.66		1/5	38.56		1/5	38.40		1/5	38.25			
					1/10	38.60		1/10	38.49		1/10	38.31		1/10	38.16			
					1/20	38.55		1/20	38.44		1/20	38.25		1/20	38.09			
				MODE	39.2-39.3	31.1	MODE	39.1-39.2	27.3	MODE	39.1-39.2	16.5	MODE	39.2-39.3	15.6			
				CAV.		2.4	CAV.		5.6	CAV.		9.6	CAV.		15.9			
2539.1							MAX	1/2	39.48	MAX	1/2	39.41	MAX	1/2	39.39	MAX	1/2	39.36
								1/5	39.75		1/5	39.69		1/5	39.67		1/5	39.65
								1/10	39.93		1/10	39.88		1/10	39.86		1/10	39.85
								1/20	40.10		1/20	40.05		1/20	40.03		1/20	40.04
							MIN	1/2	38.56	MIN	1/2	38.50	MIN	1/2	38.41	MIN	1/2	38.31
								1/5	38.40		1/5	38.34		1/5	38.23		1/5	38.10
								1/10	38.33		1/10	38.27		1/10	38.15		1/10	38.01
								1/20	38.28		1/20	38.22		1/20	38.09		1/20	37.94
							MODE	39.0-39.1	27.7	MODE	39.0-39.1	23.0	MODE	39.0-39.1	21.8	MODE	39.0-39.1	19.7
							CAV.		13.5	CAV.		15.4	CAV.		20.5	CAV.		22.6
2538.9										MAX	1/2	39.37	MAX	1/2	39.33	MAX	1/2	39.29
											1/5	39.66		1/5	39.62		1/5	39.60
											1/10	39.85		1/10	39.82		1/10	39.81
											1/20	40.04		1/20	40.00		1/20	40.00
										MIN	1/2	38.36	MIN	1/2	38.32	MIN	1/2	38.24
											1/5	38.21		1/5	38.16		1/5	38.06
											1/10	38.14		1/10	38.10		1/10	37.99
											1/20	38.09		1/20	38.05		1/20	37.93
										MODE	38.8-38.9	23.7	MODE	38.7-38.8	19.5	MODE	38.8-38.9	16.4
										CAV.		25.8	CAV.		31.1	CAV.		31.3

Note) MAX: Probable Annual Maximum Water Level. MIN: Probable Annual Minimum Water Level. MODE: Mode of Water Level Distribution (%).
CAV.: Rate of Cavitation Period at Chiquinquira Pumping Station (%).
: MAX (1/2) is less than 39.5. : Optimum Operation Rule.

Table C.3.6 Results of Optimization Simulation of Fuquene Lake (Present Conditions: Case-4)

Case: Dry Season Operation Water Level (El. m)			Rainy Season Operation Water Level (El. m): 2539.5	2539.3	2539.1	2538.9	2538.7	2538.5
2539.5	MAX	1/2	39.76	39.66	39.59	39.52		
		1/5	39.95	39.84	39.78	39.74		
		1/10	40.08	39.97	39.90	39.89		
		1/20	40.21	40.08	40.03	40.03		
	MIN	1/2	39.05	38.92	38.78	38.56		
		1/5	38.88	38.73	38.58	38.35		
		1/10	38.80	38.65	38.49	38.26		
		1/20	38.75	38.59	38.43	38.20		
	MODE		39.4-39.5 30.5	39.3-39.4 29.5	39.1-39.2 23.6	38.9-39.0 14.3		
	CAV.		1.0	1.7	5.5	11.4		
2539.3	MAX	1/2		39.59	39.51	39.45	39.40	
		1/5		39.81	39.72	39.67	39.65	
		1/10		39.95	39.86	39.82	39.81	
		1/20		40.09	40.00	39.96	39.97	
	MIN	1/2		38.81	38.73	38.56	38.43	
		1/5		38.65	38.54	38.35	38.22	
		1/10		38.58	38.47	38.27	38.13	
		1/20		38.53	38.41	38.21	38.06	
	MODE			39.2-39.3 30.9	39.1-39.2 32.1	38.9-39.0 16.6	38.7-38.8 14.8	
	CAV.			3.2	6.0	11.9	18.6	
2539.1	MAX	1/2			39.44	39.36	39.34	39.29
		1/5			39.69	39.62	39.59	39.57
		1/10			39.86	39.78	39.76	39.76
		1/20			40.02	39.94	39.92	39.94
	MIN	1/2			38.54	38.48	38.39	38.26
		1/5			38.37	38.32	38.21	38.03
		1/10			38.29	38.24	38.13	37.93
		1/20			38.24	38.19	38.07	37.86
	MODE				39.0-39.1 30.4	39.0-39.1 24.1	39.0-39.1 17.9	39.0-39.1 16.0
	CAV.				14.7	16.4	22.9	27.1
2538.9	MAX	1/2				39.31	39.26	39.23
		1/5				39.59	39.54	39.52
		1/10				39.77	39.72	39.70
		1/20				39.95	39.90	39.88
	MIN	1/2				38.33	38.28	38.20
		1/5				38.17	38.11	38.01
		1/10				38.11	38.04	37.93
		1/20				38.06	37.98	37.87
	MODE					38.8-38.9 22.2	38.7-38.8 23.3	38.8-38.9 17.6
	CAV.					30.2	33.0	34.0

Note) MAX: Probable Annual Maximum Water Level. MIN: Probable Annual Minimum Water Level. MODE: Mode of Water Level Distribution (%).
CAV.: Rate of Cavitation Period at Chiquinquira Pumping Station (%).

[light shading]: MAX (1/2) is less than 39.5. [dark shading, bold frame]: Optimum Operation Rule.