CHAPTER 5 MASTER PLAN OF WATER SUPPLY FOR BOGOTA CITY AREA BY USE OF GROUNDWATER

5.1. Basic Policy of the Master Plan

5.1.1. Water Supply for Case of Emergency

Basic policy for Mater Plan of water supply by use of groundwater is as follows:

<Basic policy for water water supply by use of groundwater>

Water resources development of Chingaza area should be promoted for long-term sustainable water supply for Bogota metropolitan area. On the other hand, water conveyance from Chingaza area is vulnerable to natural disaster. To solve this problem, master plan for emergency water supply by use of groundwater around Bogota city area is formulated.

Background of above strategy is as follows:

＜ Long-term water resources development plan＞

- Surface water resources development is necessary to meet future water demand of Bogotá metropolitan area. Surface water resources have been already developed to the full capacity, and there is no excess potential for further development.
- Therefore, surface water development in Chigaza and Sumapaz area should be promoted to meet the water demand until 2050.

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Water resources development in Chingaza Area

- Water is conveyed though mountain tunnel from Chingaza Dam to Bogota. The current water conveyance through the tunnel is only 11m^3/s, though its full conveyance capacity is 25m^3/s.
- Remaining conveyance capacity of the tunnel, which is not used now, should be used by new water resources development in Chingaza area.
- It is more effective to develop water resources of Chingaza area than the other area. High priority should be given to Chigaza area in new water resources development.

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Vulnerability of Chingaza system

- Amount of water supply by Chingaza system occupies 70% of entire water supply for Bogota metropolitan area.
- Water supply for Bogotá become more vulnerable as Chingaza system becomes more important
- Water supply was stopped for 9 month by collapse of the Chigaza tunnel in 1997
- There is possibility of collapse of Chigaza tunnel again due to outbreak of large earthquake in the future. Damage by the collapse of the tunnel will be more serious than before.

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Master plan for emergency water supply by use of groundwater

- Alternative water sources should be prepared for emergency water supply, which is more important in case of long-term interruption of water conveyance from Chigaza area.
- Groundwater should be used as alternative water sources for emergency water supply with advantage as listed below:
  - ①Emergency wells will be drilled in suburb of Bogotá where there is large water demand
  - ②Emergency wells will be located scattered around Bogotá to mitigate risk
  - ③Emergency well can be operated by a generator beside a well even when power supply is interrupted.

5.1.2. Ordinary Water Supply by Groundwater

As described in the previous section, water supply facilities by groundwater are for case of emergency. These facilities need regular operation for maintenance. It is proposed that these facilities should be used not only for emergency water supply but also for ordinary water supply as explained below:

Water resources development for usual water supply

For groundwater development, new investment is necessary for construction of wells. On the other hand, Acueducto has surpluses water sources of more than 4.2 m^3/s that is not used currently. It means that Acueducto can develop more than 4.2 m^3/s of without any additional investment. Therefore, groundwater is not necessary for ordinary water supply because it needs new investment.

Effective use of water supply facilities by groundwater

However, groundwater development has great importance if considering its necessity in water supply in case of emergency. Thus, if once water supply facilities by use of groundwater are constructed, it should be used not only for emergency but also for ordinary water supply, if condition meets below:

<Condition that groundwater can be used for ordinary water supply>

If operation cost of water supply by use of groundwater is cheaper than that of existing water supply by use of surface water, groundwater should be used not only for emergency but also usual water supply

Operation cost of water supply by use of groundwater is considered to be cheaper than that of Tibitóc and Southern water supply system. If so, there is possibility that groundwater can be used not only for emergency but also for usual water supply as alternative of Tibitóc and Southern System.

Review of Acueducto Master Plan

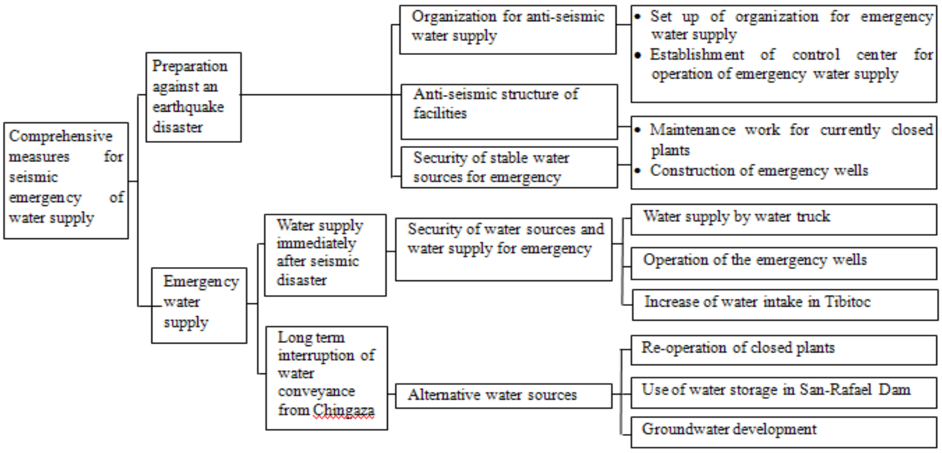
Acueducto is going to update the M/P in 2008 based on new water demand projection. How to use groundwater for ordinary water supply should be re-examined in the updating of M/P.

5.2. Water Supply Plan in Case of Emergency

5.2.1. Alternative for Water Supply in Case of Emergency

(1) Comprhensive Measures for Seismic Emergency of Water Supply

The comprehensive measures for emergency of water supply are proposed as shown in Figure-2.5-1. The measures are divided into 2 categories, i) the preparation against earthquake disaster, and ii) emergency water supply. Moreover, emergency water supply is sub-divided into "water supply immediately after disaster", and "water supply in case of long term interruption of water conveyance". For the latter case, it is necessary to secure as many alternative water sources as possible



Source: JICA Study Team

Figure-2.5- 1 Comprehensive Measure for Seismic Emergency of Water Supply

(2) Assessment of Damage to Water Supply System by Earthquake

Two type damages by earthquake is assessed for water supply system in Bogotá

- Damage to the water pipe network of Bogotá Metropolitan area
- Damage to the water conveyance tunnel and pipeline from water sources

The following urgent water supply is required respectively.

Damage to the water pipe network in Bogotá ⇨ Breakage of the water pipe network in Bogotá City can be restored for a short period of time. Before restoration of the network, urgent water supply is necessary (Acueducto plans 15 ℓ/person/day as emergency water supply).

Damage to the water conveyance tunnel and pipes from water sources ⇨ Breakage of water conveyance tunnel needs a long period of time for restoration. Especially Chingaza tunnel requires a long period of time for restoration. In the meantime, Acueducto should use entire alternative water sources to maintain water supply as usual level.

(3) Alternative of Emergency Water Supply

Alternative of emergency water supply is shown in Table-2.5-1.

Table-2.5- 1 Emergency Water Supply

Damage	Restoration	Emergency water supply	Alternative water sources
1) Damage to the water pipe network in Bogotá Metropolitan Area	• It will be restored in a short period of time. • Restoration period depends on extent of damage (several days-one month).	• Urgent water supply by water-supply wagons. • Amount of water supply is 15 litter/person/day, minimum for survival (Plan of Acueducto).	Water sources should be below: • Remaining water of distribution reservoirs/tanks. • Groundwater from emergency wells. Amount of remaining water of the reservoirs/tanks is unknown. Emergency groundwater is around 1.4 m^3/s.
2) Damage to water conveyance tunnel/pipeline from water sources	• Water conveyance pipeline of Tibitóc and Southern System will be restored for short period of time. • Restoration of tunnel collapse of Chingaza System will take a long period of time. The past "Chingaza Crisis" took nine months for restoration.	• Water stored in San-Rafael Reservoir can be used for 3 months. • Water conveyance from Tibitóc and Southern System will be restored gradually, and water supply rate will increases. • When interruption of Chingaza tunnel prolonged, entire alternative water sources must be used to full capacity. Then water supply can be maintained as same as usual level (14.5 m^3/s).	• Water stored in San-Rafael Reservoir, of which volume is equivalent of total water production of 3 month by Chingaza System. • Southern System (0.5 m^3/s). • Full operation of Tibitóc Plant (10.5 m^3/s). • Re-operation of closed water purification plants (1.3 m^3/s) • Groundwater from emergency wells (1.4 m^3/s). The total amount of emergency water supply by above-mentioned alternatives is about 13.3 m^3/s, and is almost equal to the usual water supply.

Source: JICA Study Team

The scenario of the emergency water supply after the occurrence of a big earthquake is proposed as shown below.

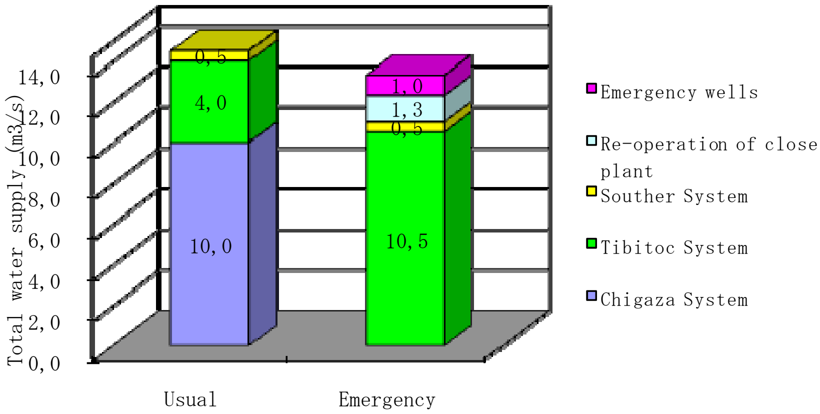
<u>Immediately after occurrence of seismic disaster</u>

Water will be supplied by water-supply trucks, immediately after occurrence of a seismic disaster, (JICA Study team proposal), because of damage to water pipe network in the urban area. In that case, the remaining water in distribution reservoirs/tanks of Acueducto and groundwater from emergency wells will be water sources for emergency water supply.

Amount of water to be supplied should be 15 litter/person/day, which is minimum for human survival (target of Acueducto), immediately after occurrence of seismic disaster. If amount of groundwater to be pumped from emergency wells is 1.4 m^3/s, it can be distributed 5,800.000 people in case of emergency. Repair work will begin immediately after occurrence of seismic disaster. As water conveyance pipes and main distribution pipes are restored gradually, water supply rate will also increase gradually.

<u>Long term interruption of water conveyance</u>

If the tunnel from Chingaza collapses, water conveyance interruption may continue for a long period (Crisis of Chingaza took place in 1997, and interruption of water conveyance continued for 9 months). In that case, it is necessary to use entire alternative water sources to maintain water supply as same as usual water supply. Usual water supply rate is 14.5 m^3/s as shown in Figure-2.5-2, 70% of which is by Chingaza System. Even though Chingaza System is interrupted, 13.3 m^3/s of water can be supplied by alternative water sources as shown in Figure-2.5-2. The characteristic of the alternative water sources that can be used in case of interruption of Chingaza system is summarized in Table-2.5-2.



Source: JICA Study Team

Figure-2.5- 2 Water Sources in Usual and Emergency Water Supply

Table-2.5- 2 Alternative Water Sources for Interruption of Water Conveyances from Chingaza

Water resources for emergency	Advantage	Disadvantaged	Solution
(1) Use of storage water of San-Rafael Reservoir	If San-Rafael Reservoir is full of water, it can provide the same amount of water that Wiesner plant can treat for 3 month.	• Water in San-Rafael Reservoir is pumped up to Wiesner plant for 3 months every year during tunnel maintenance. • The amount of water to be used for emergency depends on amount of remaining water in the reservoir at the time seismic disaster.	Water storage of the reservoir should be recovered immediately after 3 month pumping.
(2) Increase of water intake at Tibitóc Plant	Maximum production capacity of the Tibitóc plant is 10.5 m^3/s by increase of water intake.	• The amount of water to be taken under concession for emergency and its period are not clearly agreed between CAR and Acueducto. • Amount of water to be taken at Tibitóc Plant depends on natural river discharge (natural conditions).	Water concession for emergency should be agreed with CAR in advance. • CAR and Acueducto are under lawsuit about the water concession of Bogotá River, and decision has not yet been made. • There is no regulation on emergency water concession of Tibitóc Plant.
(3) Southern System	Southern System can be restored shortly after seismic disaster. • El Dorado Plant (0.5 m^3/s) • Yomasa Plant (0.01 m^3/s) Total water production of above 2 plants is 0.51 m^3/s.	-	-
(4) Re-operation of closed water purification plant	Re-operation of closed water purification plant: • Vitelma plant (0.9 m^3/s) • Laguna Water Treatment Plant (0.3 m^3/s) • Sun Diego plant (0.1 m^3/s)	The closed plants are not used for a long period of time, and maintenance of the plants is not performed. Subsequently, immediate re-operation after an earthquake is difficult.	Maintenance of closed plants must be performed periodically.

Water resources for emergency	Advantage	Disadvantaged	Solution
	Total water production of above 3 Plants is 1.3 m^3/s.		
(5) Emergency wells	• By distributing many wells along the Eastern and Southern hill, a risk of damage to water sources can be dispersed. • The electric power supply will stop in case of emergency. But pumps of emergency wells can be operated by generators. • There is low possibility of wells to be collapsed by an earthquake. • The amount of water to be supplied by emergency wells is estimated more than 1.0 m^3/s.	• A new investment for construction of emergency wells is required. • Regular maintenance of emergency wells is required. • Amount of water to be supplied by emergency wells depends on groundwater development potential.	• Maintenance of emergency wells must be performed periodically. • If possible, emergency wells should be used also for usual water supply for maintenance.
Total amount of water to be supplied for emergency	• Even during interruption of water conveyance from Chingaza, water supply can be continued same as usual for 3 months using water stored in San-Rafael Reservoir. • After this, water supply of 12.4 m^3/s can be maintained by above mentioned (2)-(4). By Adding water production of Emergency wells, the total supply will be mote than 13.4 m^3/s. It is almost same as usual water supply (=14.5 m^3/s).		

Source: JICA Study Team

5.2.2. Evaluation of Alternative Plant

Alternative plan for emergency water supply is evaluated as shown below Table-2.5-3:

Table-2.5- 3 Evaluation of Emergency Water Supply Plan

Alternative	Stability of water sources in emergency		Cost (New investment)	Water Production
	Immediately after disaster (up to 1 week)	Prolonged emergency period (up to 9 month)		
a) Use of storage water of San-Rafael Dam	Unstable (damage to the facilities is expected)	Stable for 3 months	Not necessary	Big (10 m^3/s ×3 month)
b) Increase of water intake at Tibitóc Plant	Unstable (damage to the facilities is expected)	Stable	Not necessary	Big (10.5 m^3/s ×3 month)
c) Southern System	Unstable (damage to the facilities is expected)	Stable	Not necessary	Small (0.51 m^3/s)
d) Re-operation of closed water purification plants	Unstable (damage to the facilities is expected)	Stable	Necessary (for maintenance)	Small (1.3 m^3/s)
e) Emergency wells	Stable (direct water supply is available at well site)	Stable	Necessary	Small (1.5 m^3/s)

Source: JICA Study Team

As shown in Table-2.5-3, two alternatives, "(a) Use of storage water of San-Rafael Dam" and "(b) Increase of water intake at Tibitóc Plant", are more effective than others in terms of cost and scale of water production. On the other hand, alternative of "(e) Emergency wells" is more stable than others because Emergency wells can be scattered covering whole Bogotá City, which can be more useful in water supply immediately after serious disaster.

Water supply by use of groundwater may be most effective during short period of time just after disaster. However, as water supply facilities are recovered with time, the other alternatives will become more effective than the Emergency wells.

In case of prolonged interruption of water conveyance from Chingaza System (collapse of tunnel from Chingaza), every alternatives are necessary to supplement deficit of water conveyance from Chingaza. Therefore, it is proposed that every alternatives listed in Table-2.5-3 should be used for emergency water supply.

5.3. Groundwater Demand

The objective to develop groundwater is to secure and supply water in emergency caused by natural disasters such as big earthquake. For such a reason, the use of groundwater should be considered as an alternative water source for emergency water supply and thus integrated in the contingency plans of Acueducto.

The groundwater demand in emergencies is estimated separately in two scenarios as below:

- Scenario 1: Damage to distribution networks of Bogotá City.
- Scenario 2: Damage to water conveyance from Chingaza.

Demand of Scenario 1

It is estimated based on the minimum water volume 15 litters/day/person in emergencies that Acueducto expects, corresponding to 15% of the usual water consumption per inhabitant in Bogotá D.C. (90-110 litters/day/person).

Demand of Scenario 2

It is estimated by taking into account the full operation and supply from other plants such as Tibitóc, Vitelma, Yomasa and El Dorado.

Table-2.5-4. shows the groundwater demand for two damage cases in 2007 and 2020.

Table-2.5- 4 Groundwater Demand in Emergency

Scenario	Period until Restoration	Base for estimate			Groundwater Demand
<Scenario 1> Damage to Distribution Networks	60 days	Per person/day (a)		Population of Bogotá City (b)	= (a) x (b)
		Year 2007	15 litter [1]	6.8 million [2]	1.18 m^3/s
		Year 2020		9.7 million [3]	1.68 m^3/s
<Scenario 2> Damage to water conveyance tunnel from Chingaza	9 months	Total demand (c)		Full supply from other plants (d)	= (c) – (d)
		Year 2007	14.5 m^3/s	Tibitóc (10.5m^3/s), Southern (0.5m^3/s) and others (1.3m^3/s)	2.2 m^3/s
		Year 2020	18.4 m^3/s [4]		6.1 m^3/s

Note:1) Expected volume of Acueducto, 2) Estimate from 2005 census population, 3) "Proyecciones de la población, 2003" of Humberto Molina, 4) Master Plan of Acueducto 2005.

Source: JICA Study Team.

WHO (World Health Organization) announces the minimum water quantity needed for domestic use in emergency in the "technical notes for emergencies", which is 20 liters/day/person for short term survival including drinking and cooking. The following Box is an example for emergency water supply in Japan for reference

Emergency Water Supply

(Source: The Study on Disaster Prevention in the Bogotá Metropolitan Area, JICA, March 2002)

1. Stepwise water supply in line with the elapse time of disaster.

-To supply life-keeping volume of water by manual conveyance within 3 days after disaster.
-To start temporary water supply within 2 weeks after disaster.
-To maintain and reinforce water supply system for usual operation and wider supply.

2. Minimum water supply volumes.

- Up to 3rd day: 3 liters/day/person.
- From 4th to 10th day: 20 to 30 liters/day/person.
- From 11th to 20th day: 30 to 40 liters/day/person.

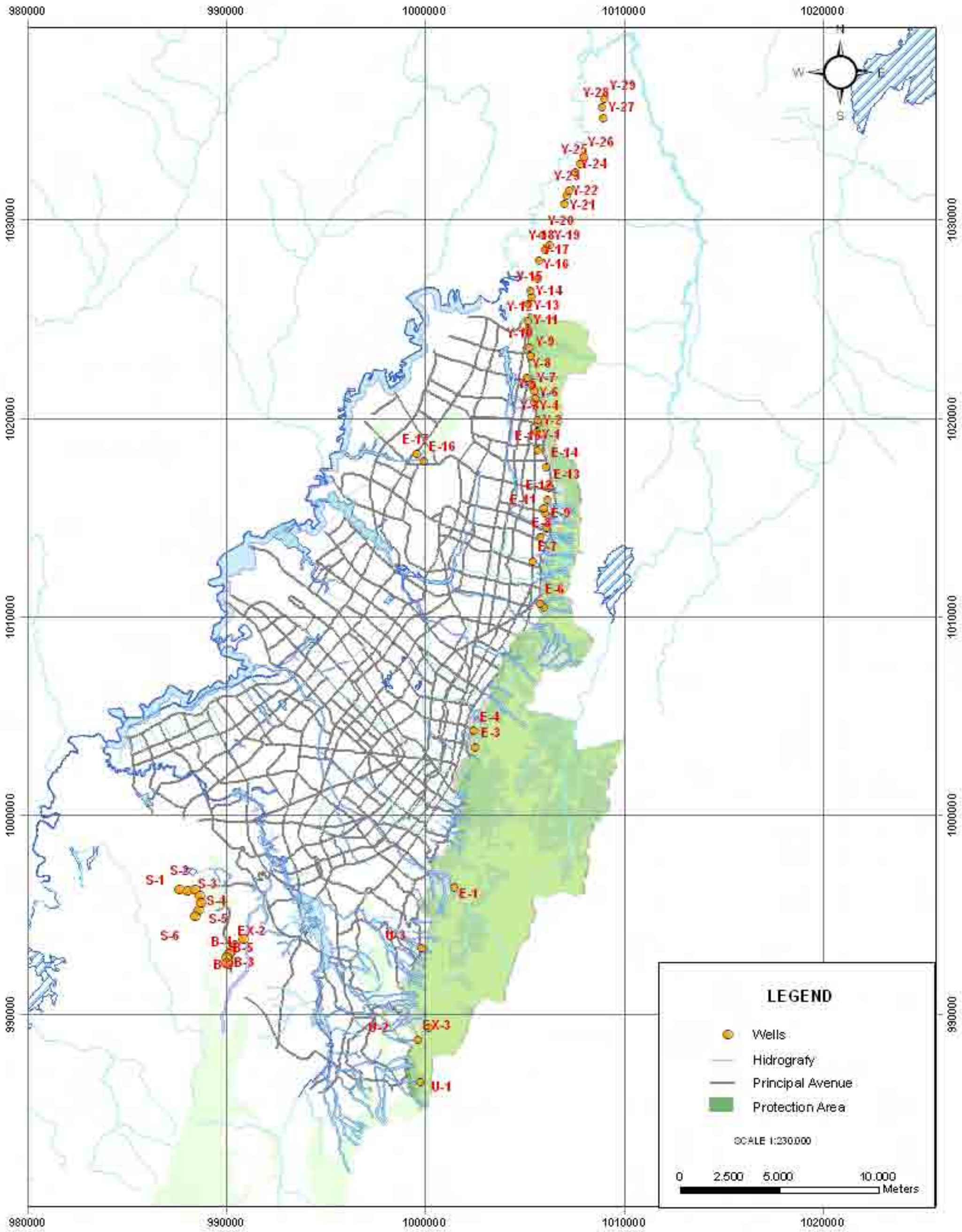
5.4. Simulation of Groundwater

5.4.1. Production Wells

(1) Well Location

Well location was planned considering emergency water supply. Location of proposed wells is shown in Figure-2.5-3 and listed in Table-2.5-5. Total number of the proposed wells is 62, from which 4 already exist.

The locations of the wells is proposed based on comprehensive analysis on result of topographical, geological, hydrogeological and geophysical survey including the result of the previous exploratory drillings.



Source: JICA Study Team

Figure-2.5- 3 Well Locations

Table-2.5- 5 Proposed Wells

Type	Project	Area	No.	Latitude	Longitude	Elevation (m.a.s.l.)	Surface geology
Proposed wells for emergency water supply	Eastern hill	Bogotá	E-1	4°33'46.8"N	74°03'55.2"W	2,810	K2d, hanging wall of Bogotá fault
			E-2	4°36'08.9"N	74°03'39.5"W	2,680	K2E1g, footwall of Bogotá fault
			E-3	4°37'37.4"N	74°03'18.7"W	2,825	K2d, near the geologic boundary of K2p
			E-4	4°38'04.4"N	74°03'20.7"W	2,768	K2E1g, footwall of Bogotá fault
			E-5	4°41'25.1"N	74°01'28.7"W	2,686	K2t, footwall of E-W fault
			E-6	4°41'34.1"N	74°01'32.6"W	2,643	K2t, on E-W fault
			E-7	4°42'43.2"N	74°01'44.3"W	2,583	Q2c(K2t)
			E-8	4°43'22.7"N	74°01'32.9"W	2,583	Q2c(K2t)
			E-9	4°43'38.4"N	74°01'22.5"W	2,597	K2t
			E-10	4°44'01.6"N	74°01'24.4"W	2,587	K2t
			E-11	4°44'09.6"N	74°01'26.4"W	2,577	Q2c(K2t)
			E-12	4°44'24.6"N	74°01'20.9"W	2,583	Q2c(K2t)
			E-13	4°44'42.8"N	74°01'19.2"W	2,592	Q2c(K2t)
			E-14	4°45' 17.4"N	74°01'22.5"W	2,605	Q2c(K2t)
			E-15	4°45'45.5"N	74°01'36.8"W	2,578	Q2c(K2t)
			E-16	4°45' 27.0"N	W74°04'42.2"	2,581	Q2c(K2t)
			E-17	4°45' 40.0"N	W74°04'53.4"	2,575	Q2c(K2t)
			Y-1	4°46'14.1"N	74°01'38.4"W	2,570	Q2c(K2t)
			Y-2	4°46'28.3"N	74°01'36.9"W	2,571	Q2c(K2t)
Proposed wells for emergency water supply	Yerba Buena		E-1	4°46'34.6"N	74°01'35.8"W	2,571	Q2c(K2t)
			Y-4	4°47'04.4"N	74°01'42.3"W	2,575	Q2c(K2p)
			Y-5	4°47'10.5"N	74°01'40.4"W	2,582	Q2c(K2p)
			Y-6	4°47'21.3"N	74°01'42.9"W	2,571	Q2c(K2p)
			Y-7	4°47'32.2"N	74°01'45.9"W	2,573	Q2c(K2p)
			Y-8	4°47'44.9"N	74°01'53.8"W	2,581	Q2c(K2t)
			Y-9	4°48'20.5"N	74°01'48.5"W	2,568	K2t
			Y-10	4°48'34.4"N	74°01'50.3"W	2,570	Q2c, Q2ch
			Y-11	4°49'02.2"N	74°01'51.6"W	2,569	Q2c, Q2ch
			Y-12	4°49'17.7"N	74°01'53.4"W	2,586	K2t, west limb of anticline
		Chía City	Y-13	4°49'45.4"N	74°01'51.7"W	2,566	K2t, west limb of anticline
			Y-14	4°49'57.4"N	74°01'48.4"W	2,564	K2t, west limb of anticline
			Y-15	4°50'07.1"N	74°01'47.7"W	2,558	K2t, west limb of anticline, along the lineament
			Y-16	4°50'27.2"N	74°01'36.2"W	2,564	K2t, west limb of anticline
			Y-17	4°50'55.6"N	74°01'35.4"W	2,556	K2t, west limb of anticline, along the lineament
			Y-18	4°51'15.1"N	74°01'25.6"W	2,571	K2t, west limb of anticline, along the lineament
			Y-19	4°51'21.4"N	74°01'17.6"W	2,617	K2t, west limb of anticline
			Y-20	4°51'38.8"N	74°01'28.8"W	2,577	K2E1g
			Y-21	4°52'29.5"N	74°00'53.8"W	2,570	K2t, west limb of anticline, along the lineament

Table-2.5-5 Proposed Wells (2)

Type	Project	Area	No.	Latitude	Longitude	Elevation (m.a.s.l.)	Surface geology
Proposed wells for emergency water supply	Yerba Buena	Sopó	Y-22	4°52'43.5"N	74°00'48.4"W	2,566	K2t, west limb of anticline, along the lineament
			Y-23	4°52'52.3"N	74°00'45.6"W	2,563	K2t, west limb of anticline, along the lineament
			Y-24	4°53'21.3"N	74°00'34.8"W	2,557	Q1sa(K2t)
			Y-25	4°53'35.2"N	74°00'26.9"W	2,559	Q1sa(K2t)
			Y-26	4°53'46.8"N	74°00'22.6"W	2,559	Q1sa(K2t)
			Y-27	4°54'49.5"N	73°59'50.3"W	2,558	Q1sa(K2d), west limb of anticline
			Y-28	4°55'08.5"N	73°59'51.1"W	2,554	Q1sa(K2d), west limb of anticline
			Y-29	4°55'21.2"N	73°59'47.8"W	2,561	K2d, west limb of anticline
	Usme	Bogotá	U-1	4°29'46.7"N	74°04'48.1"W	3,113	E1b, footwall of Bogotá fault
			U-2	4°29'55.6"N	74°04'45.9"W	3,141	E1b, beside Bogotá fault
			U-3	4°30'46.9"N	74°05'00.6"W	3,147	Q1si(E1b), footwall of Bogotá fault
			U-4	4°30'52.6"N	74°05'01.8"W	3,139	Q1si(E1b), footwall of Bogotá fault
	Soacha	Soacha	S-1	4°33'43.3"N	74°11'20.8"W	2,746	K2d,west limb of anticline
			S-2	4°33'42.2"N	74°11'08.2"W	2,760	K2d,west limb of anticline
			S-3	4°33'43.3"N	74°10'56.4"W	2,748	K2d, axis of anticline
			S-4	4°33'33.6"N	74°10'47.6"W	2,762	K2d, east limb of anticline
			S-5	4°33'08.9"N	74°10'49.9"W	2,809	K2d, hanging wall of fault
			S-6	4°33'00.4"N	74°10'56.3"W	2,837	K2d, hanging wall of fault
	Ciudad Bolivar	Bogotá	B-1	4°32'21.9"N	74°09'37.7"W	2,835	K2p, east limb of anticline
			B-2	4°32'02.7"N	74°09'56.1"W	2,907	K2p, axis of anticline
			B-3	4°31'58.2"N	74°10'01.4"W	2,918	K2p, axis of anticline
Exploratory wells	S[1]	S[2]	EX-1	4°33'21.7"N	74°10'46.4"W	2,786	K2d, hanging wall of fault
	B[1]	Bo[2]	EX-2	4°32'14.4"N	74°09'51.7"W	2,867	K2p, axis of anticline
	U[1]		EX-3	4°29'38.1"N	74°04'51.5"W	3,073	E1b, footwall of Bogotá fault
Additional wells	Usme	Bogotá	U-101	4°28'28.8"N	74°04'48.6"W	3,210	K2d, hanging wall of Bogotá fault
			U-102	4°29'57.7"N	74°04'35.6"W	3,243	K2d, hanging wall of Bogotá fault
			U-103	4°32'07.9"N	74°04'47.2"W	3,022	K2d, beside Bogotá fault
	Eastern hill	Bogotá	E-104	4°37'03.7"N	74°03'32.3"W	2,732	K2E1g, footwall of Bogotá fault
			E-105	4°37'05.7"N	74°03'28.2"W	2,747	K2E1g, Bogotá fault
			E-101	4°36'01.3"N	74°03'3.3"W	2,743	K2d, on the fault(E-W)
			E-102	4°37'24.1"N	74°03'22.8"W	2,709	K2d, hanging wall of Bogotá fault
			E-103	4°38'56.6"N	74°02'51.6"W	2,723	K2d, hanging wall of Bogotá fault

Legend of Geology:

- Quaternary
- Bogota Formation (Eocene)
- Guaduas Formation (Paleocene)
- Labor-Tierna Formation (Cretaceous)
- Plaeners Formation (Cretaceous)
- Dura Formation (Cretaceous)

Note: 1) U: Usme, B: Ciudad Bolívar, S: Soacha, Bo: Bogotá.

Source: JICA Study Team

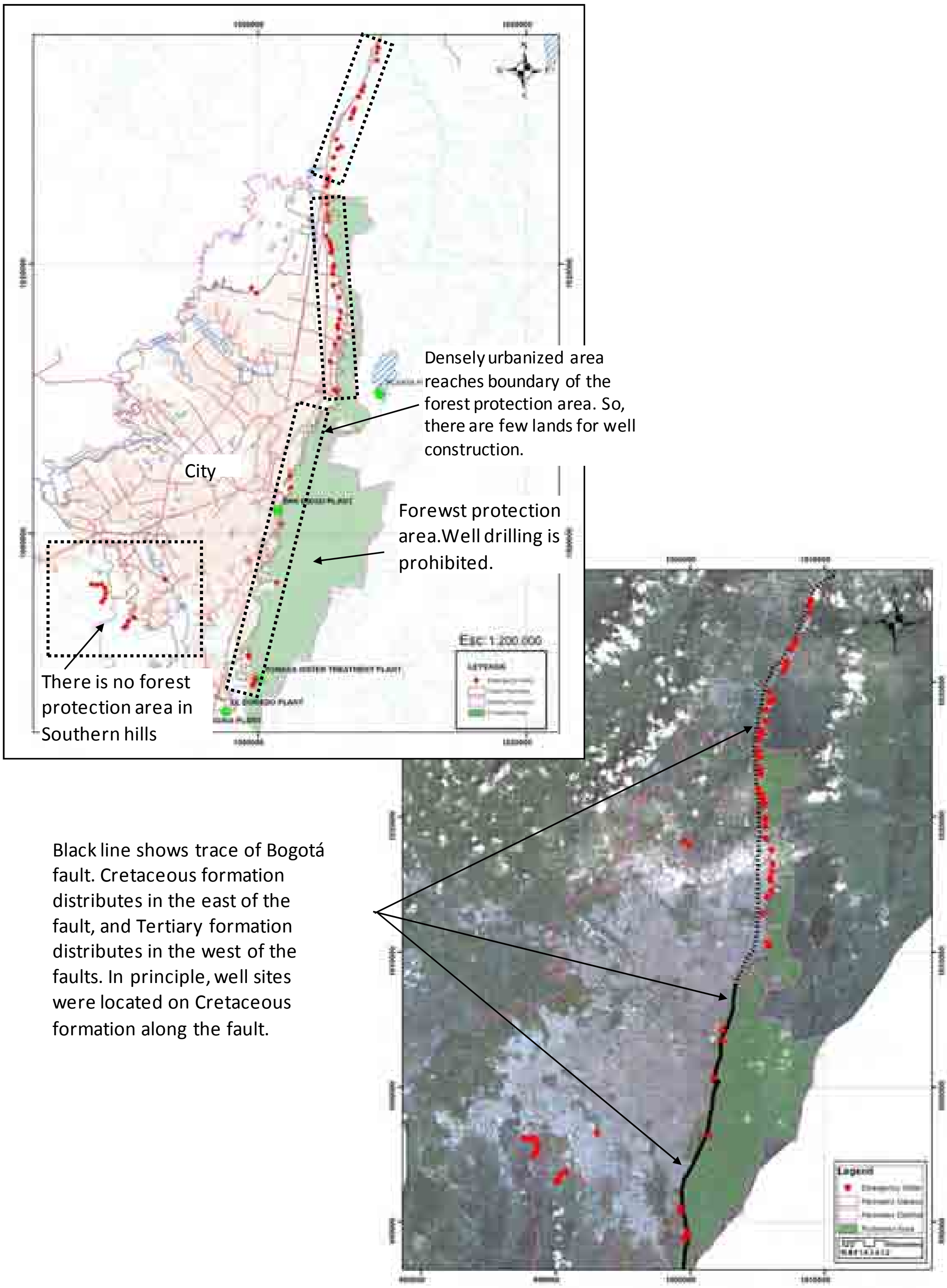
Table-2.5- 6 Basic Condition and Restriction in Selection of Well Sites (1)

Condition/Restriction	Detail
Hydrogeology	• Groundwater development should be done targeting Guadalupe Group of the Cretaceous in the Eastern and Southern Hills. • The wells should be located near anticline axis or a big fault, and furthermore, within sand-rich strata in the Eastern and Southern Hills. • The wells should be located within the large river-basin with high groundwater recharge. • The wells should be located away from unstable area with possibility of land slide/collapse and debris flow etc. • Wells should be located scattered in wide area to prevent serious lowering of groundwater level by well interference. Distance between the wells should be more than 250 m.
Risk reduction	The wells should be distributed scattered in wide area of the Eastern and Southern Hills in order to reduce risk of damage concentration of wells by large earthquake.
Environment	The forest protection area is established in the Eastern Hills, where groundwater development is restricted. Therefore, the wells must be located out of the forest protection area.
Land procurement	The well should be located where site procurement is possible.
Facilities design	• The wells will be located near the existing tank, which will make easy connection between the wells and the existing tanks. • Site for the wells will be located near the existing road for easily access of drilling rigs.

Source: JICA Study Team

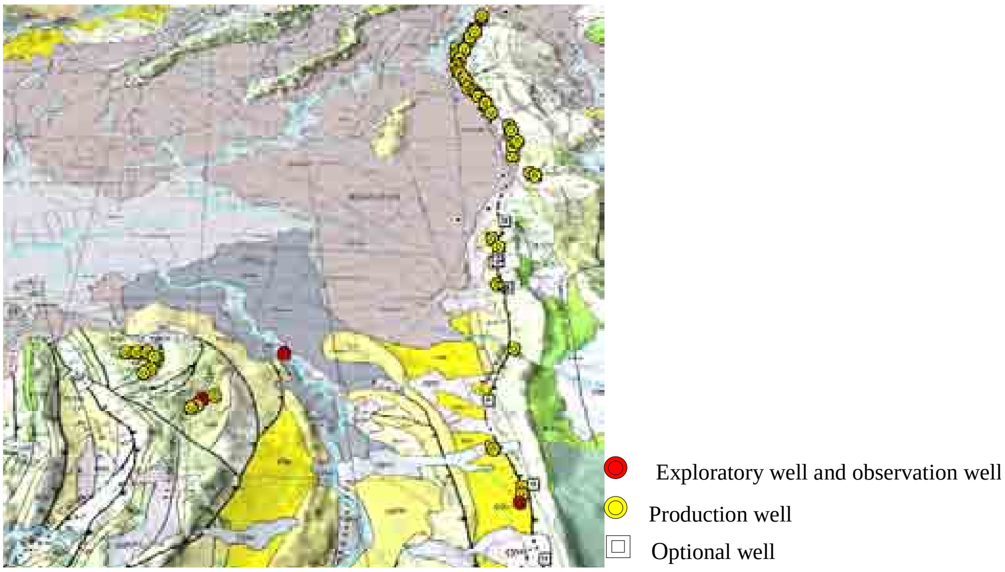
Selected well points are shown in Figure-2.5-4. In Figure-2.5-4, forest protection area and densely urbanized area, where there are little lands for well construction, are shown. Every act city for development is prohibited within the forest protection area.

In addition, it is difficult to find land for well construction where densely urbanized area reaches the boundary with the forest protection area. Well sites are selected out of the forest protection area and densely urbanized area (see Figure-2.5-4). Relation between well site and geology is shown in Figure-2.5-5.



Source: JICA Study Team

Figure-2.5- 4 Forest Protection Area and Densely Urbanized Area



Source: JICA Study Team

Figure-2.5- 5 Locations of Proposed Wells

(2) Wells in the Forest Protection Area

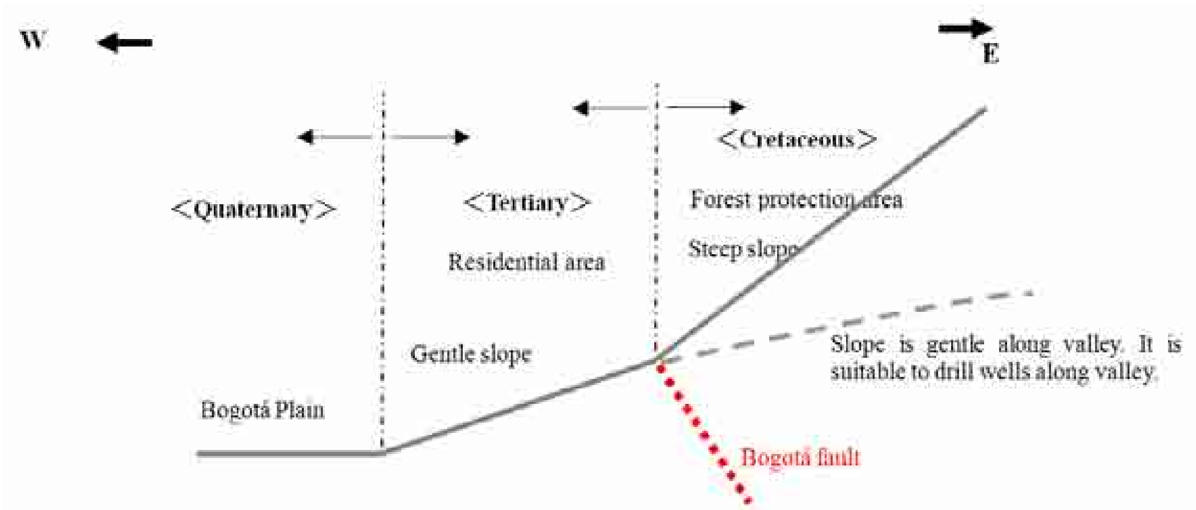
Any activity for economic development is currently prohibited within the forest protection area of the Eastern Hills. On the other hand, there are several places suitable for drilling wells inside the forest protection area. Advantage of the forest protection area for drilling is as follows:

- Drilling wells inside the protection area is favorable in hydrogeological view point.
- The forest protection area is near the Bogotá city center, and water cab be quickly delivered from the forest protection are to the city center in emergency.
- There are many properties of Acueducto inside the forest protection area. Land acquisition for construction of facilities for water supply is much easy inside forest protection area.

Hydrogeological characteristics if the forest protection area is as follows:

Geological Characteristics

Bogotá fault forms geological boundary between the Cretaceous and the Tertiary. Moreover, it forms boundary of topographic future (see Figure-2.5-6). In the west of Bogotá fault, the Tertiary is distributed, of which slope is gentle, due to lower resistance of Tertiary rocks against erosion. On the other hand, in the east of Bogotá fault, the Cretaceous is distributed, of which slope is steep, due to higher resistance of Cretaceous rocks against erosion. As a result, area of the Tertiary is relatively flat, where residential area is developed. On the other hand, area of the Cretaceous is rugged, where only forest is spreading without development. So this area is regulated as the forest protection area.



Source: JICA Study Team

Figure-2.5- 6 Criteria of Drilling site in Eastern Hills

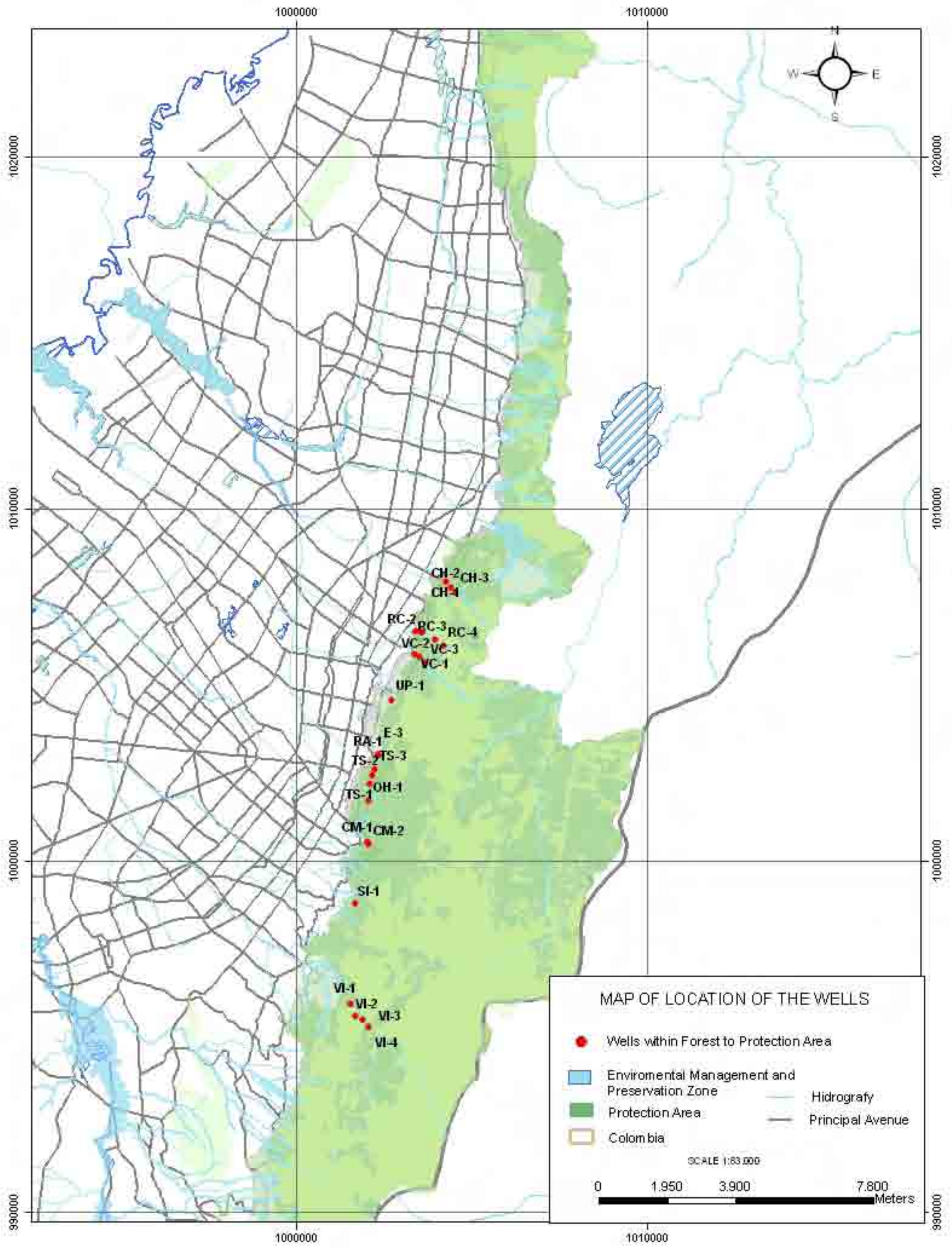
Promising well sites inside the forest protection area is shown in Table-2.5-7 and Figure-2.5-7. Drilling wells inside protection area is not currently allowed by law.

Table-2.5- 7 Wells within Forest Protection Area

Site		No.	Coordinate		Elevation	Mark	Note
			Latitude	Longitude			
San Cristbal	Vitelma	VI- 1	N 4°33' 33.5"	W 74°03' 48.0"	2,881	K2d	Acueducto site
		VI-2	N 4°33' 23.3"	W 74°03' 44.2"	2,911	K2d	Acueducto site
		VI-3	N 4°33' 19.1"	W 74°03' 37.3"	2,918	K2d	Acueducto site
		VI-4	N 4°33' 12.8"	W 74°03' 31.2"	2,921	K2d	Acueducto site
Santa Fe	Sant Isabel	SI-1	N 4°35' 07.1"	W 74°03' 44.3"	2,871	K2d	Acueducto site
	Casa Morino	CM-1	N 4°36' 04.5"	W 74°03' 33.0"	2,715	K2d	Acueducto site
		CM-2	N 4°36' 01.6"	W 74°03' 31.5"	2,728	K2d	Acueducto site
	Tank Silencio	TS-1	N 4°36' 57.8"	W 74°03' 31.6"	2,790	K2d	Acueducto site
		TS-2	N 4°37' 06.2"	W 74°03' 28.4"	2,771	K2d	Acueducto site
		TS-3	N 4°37' 10.8"	W 74°03' 25.8"	2,774	K2d	Acueducto site
	Olaya Herrera	OH-1	N 4°36' 42.0"	W 74°03' 31.4"	2,800	K2d	－
	Rio Arzobispo	RA-1	N 4°37' 24.3"	W 74°03' 22.9"	2,721	K2d	－
Chapinero	Unv. Poli-Technology	UP-1	4° 38'16.0"N	74° 03'10.0"W	2,725	K2d	－
	La Vieja Creek	VC-1	N 4°38' 57.6"	W 74°02' 48.9"	2,733	K2d	Acueducto site
		VC-2	N 4°38' 55.7"	W 74°02' 44.4"	2,757	K2d	Acueducto site
		VC-3	N 4°38' 50.1"	W 74°02' 38.9"	2,777	K2d	Acueducto site
	Rosales Creek	RC-1	N 4°39' 18.6"	W 74°02' 48.0"	2,722	K2d	－
		RC-2	N 4°39' 17.8"	W 74°02' 41.9"	2,774	K2d	－
		RC-3	N 4°39' 10.6"	W 74°02' 30.3"	2,827	K2d	－
		RC-4	N 4°39' 05.2"	W 74°02' 22.8"	2,857	K2d	－
	Chico	CH-1	N 4°40' 05.0"	W 74°02' 20.5"	2,709	K2t	Acueducto site
		CH-2	N 4°39' 59.7"	W 74°02' 15.6"	2,748	K2t	Acueducto site
		CH-3	N 4°39' 55.3"	W 74°02' 11.3"	2,757	K2t	－
Usaquen	Escuela de Caballeria (Military)	EC-1	N 4°40' 49.8"	W 74°02' 14.4"	2,600	K2t	Military site
		EC-2	N 4°40' 53.3"	W 74°02' 06.5"	2,613	K2t	Military site
		EC-3	N 4°40' 55.9"	W 74°02' 01.6"	2,618	K2t	Military site

Leyend	Q2c, Q2ch	Quaternaru	K2t	Labor & Tierna (Cretaceosu)
	E1b	Bogota (Tertiary)	K2p	Plaeners (Cretacesou)
	K2E1g	Guaduas (Tertiary)	Ksd	Dura (Cretacesou)

Source: JICA Study Team

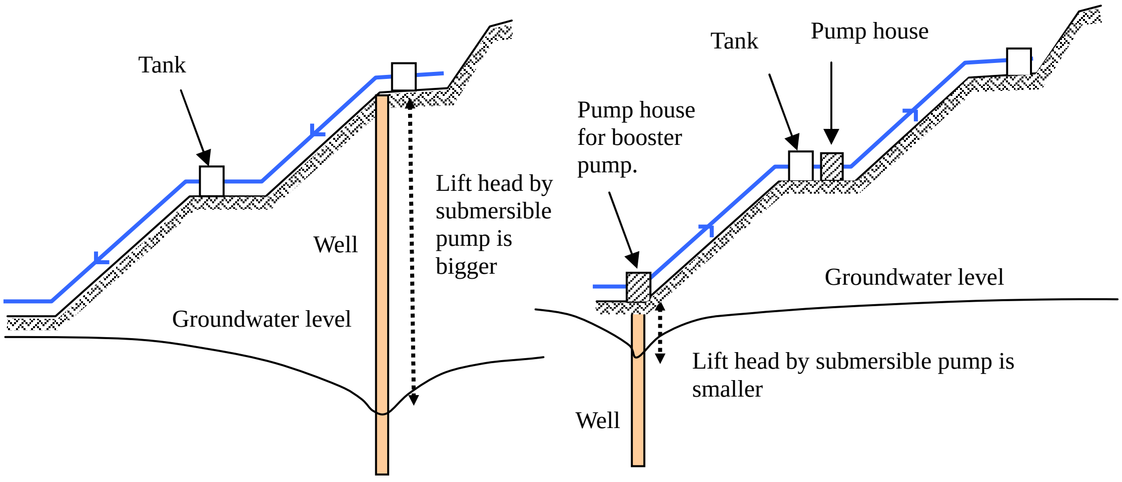


Source: JICA Study Team

Figure-2.5- 7 Location of Wells inside Forest Protection Area

(3) Wells location of hillside

Principally, wells will be located along the hillside. Cost for well construction and operation depends on location of wells in hillside as shown in Figure-2.5.8.



Alternative-1 Wells located in upper part of hills　　Alternative-2 Wells located in lower part of hills

Source: JICA Study Team

Figure-2.5- 8 Alternative of Well Location

As shown in Table-2.5-8, wells should be located in the lower part of the hills. Groundwater will be pumped by submersible pump from a well to a tank on the ground. Then, groundwater in the tank will be pumped up again to upper part of hills by booster pump, which is more efficiency in operation cost than pumping groundwater directly from a well to upper part of hills.

Table-2.5- 8 Comparison of Alternatives of Well Locations on the Slope of the Hills

Alternative	Well location	Hydrogeological condition		Cost of well	Operation Cost		Forest protection	Evaluation
		Groundwater level	Length of well		Type of pumping	Pumping cost		
Alternative-1	Middle to upper part of hill	Deeper	Longer	More expensive	Well submersible pump	More expensive	Within protection area	Not good
Alternative-2	Foot of hills	Shallower	Shorter	Less expensive	Well submersible pump + booster pump	Less expensive	Out of protection area	Good

Source: JICA Study Team

(4) Number of Wells

The total number of wells was decided based on principle below:

- To minimize lowering of groundwater level, yield from each well should be reduced by increasing number of wells.
- Yield from one well should be 1,500-3,000 m^3/s, taking into account of capacity of Cretaceous Aquifer, as well as standard diameter of wells and available capacity of submersible pump. The relationship between number of wells and total yield from the wells is shown in Table-2.5-9. Yellow part of the Table-2.5-9 means desirable yield of the wells.
- On the other hand, increased number of wells means increased cost for well construction and facilities.

Table-2.5- 9 The Relationship Between Number of Wells and Total Yield from the Wells

Alternative	Total yield from wells (m^3/s)	Number of wells								
		40	50	60	70	80	90	100	110	120
Alternative-1	1.0	2,160	1,728	1,440	1,234	1,080	960	864	785	720
Alternative-2	2.0	4,320	3,456	2,880	2,469	2,160	1,920	1,728	1,571	1,440
Alternative-3	3.0	6,480	5,184	4,320	3,703	3,240	2,880	2,592	2,356	2,160
Alternative-4	4.0	8,640	6,912	5,760	4,937	4,320	3,840	3,456	3,142	2,880
Alternative-5	5.0	10,800	8,640	7,200	6,171	5,400	4,800	4,320	3,927	3,600
Alternative-6	6.0	12,960	10,368	8,640	7,406	6,480	5,760	5,184	4,713	4,320

Desirable yield from well: 1,500-3,000 m^3/day

Source: JICA Study Team

In this Study, 62 wells were proposed. According to the relationship in Table-2.5-9, desirable total yield from 62 wells is around 1 m^3/s to 2 m^3/s. Restriction in availability of site for wells construction is main reason of limitation in total number of wells. However, optimum amount of groundwater to be developed depends on groundwater development potential not wells number.

5.4.2. Optimum Yield

(1) Water Demand by Groundwater

Groundwater development proposed in this Study is for emergent water supply. Amount of groundwater to be developed should be decided by emergency water demand. Planned yield from emergency wells is proposed following emergency Scenario shown in Table-2.5-10.

Table-2.5- 10 Necessary Yield from Emergency Wells

Emergency Scenario		Period of emergency water supply	Water demand by groundwater	
			Year	Water supply
Scenario-1	Damage of distribution pipes in Bogotá City	Short time (10 days)	2007	1.18 m^3/s
			2020	1.68 m^3/s
Scenario-2	Damage to water conveyance tunnel of Chingaza	Long time (9 months)	2007	2.2 m^3/s
			2020	6.1 m^3/s

Source:JICA Study Team

As shown in Table-2.5-10, necessary yield from emergency wells is between 1.18 m^3/s and 6.1 m^3/s, depending on emergency scenario and year.

(2) Optimum Yield

The optimum yield from wells is restricted by groundwater development potential. To decide the optimum yield, lowering of groundwater level by pimping from planned wells should be carefully examined. For decision of the optimum yield, six alternative yields from the wells were examined as shown in Table-2.5-11. Lowering of groundwater level by each alternative yield was analyzed by groundwater simulation.

Table-2.5- 11 Alternative Yield from Wells

Alternative	Total yield (m^3/s)	Yield from one well (Total number of wells is 62)	Note
Alternative-1	1.0	1,400 m^3/day	Corresponding to Scenario-1 in 2007
Alternative-2	2.0	2,800 m^3/day	
Alternative-3	3.0	4,300 m^3/day	
Alternative-4	4.0	5,600 m^3/day	
Alternative-5	5.0	7,000 m^3/day	
Alternative-6	6.0	8,400 m^3/day	Corresponding to Scenario-2 in 2020

Source:JICA Study Team

(3) Pumping Plan by Groundwater Simulation

The influence of pumping of the 62 planned wells (from the Cretaceous Aquifer) over the hydraulic head distribution of the surrounding aquifers was investigated using the calibrated model. Based on analyzed influence, the optimum yield was selected from Alternative-1 to Alternative-6.

1) Details of Pumping

All the planned wells were installed into the 4th layer of the simulation model, which is the Cretaceous Aquifer. These wells are planned for emergency uses such as water supply after a big earthquake. According to the plan, the expected operation time of the wells ranges from one (1) to nine (9) months. The pumping rate for each planned well of the simulation model was then given based on the following assumptions.

- The total pumping rate is equally distributed among the 62 planned wells.
- All the wells operate 24 hours.
- The total pumping rate for simulation is changed from 1.0 m^3/s to 6 m^3/s, according to Alternative-1 to Alternative-6 in Table-5.12.
- The simulation period is set from 0 to 365 days (=12 month).

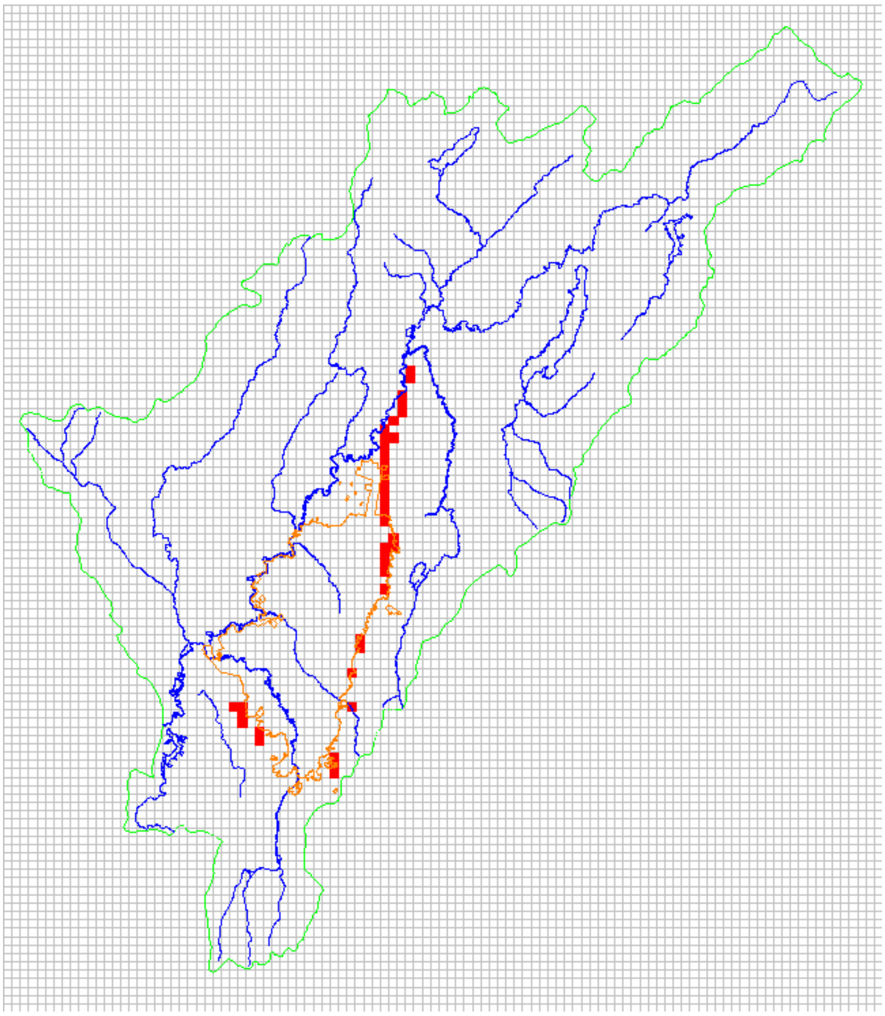
Details of pumping for the simulation determined based on the above conditions are given in Table-2.5-12. Six alternatives with different pumping rates were considered.

Table-2.5- 12 Pumping Schedule of the Wells for Simulation

Alternative	Total pump rate	Pump rate per well	Pump period
Alternative-1	1.0 m^3/s	1,400 m^3/day	0-365 days
Alternative-2	2.0 m^3/s	2,800 m^3/day	0-365 days
Alternative-3	3.0 m^3/s	4,300 m^3/day	0-365 days
Alternative-4	4.0 m^3/s	5,600 m^3/day	0-365 days
Alternative-5	5.0 m^3/s	7,000 m^3/day	0-365 days
Alternative-6	6.0 m^3/s	8,400 m^3/day	0-365 days

Source: JICA Study Team.

The location of the newly planned wells is shown in Figure-2.5-9.



Source: JICA Study Team.
Note: Red cells represent those with pumping wells, up to 3 wells in a cell.

Figure-2.5- 9 Distribution of Planned Wells in the Model

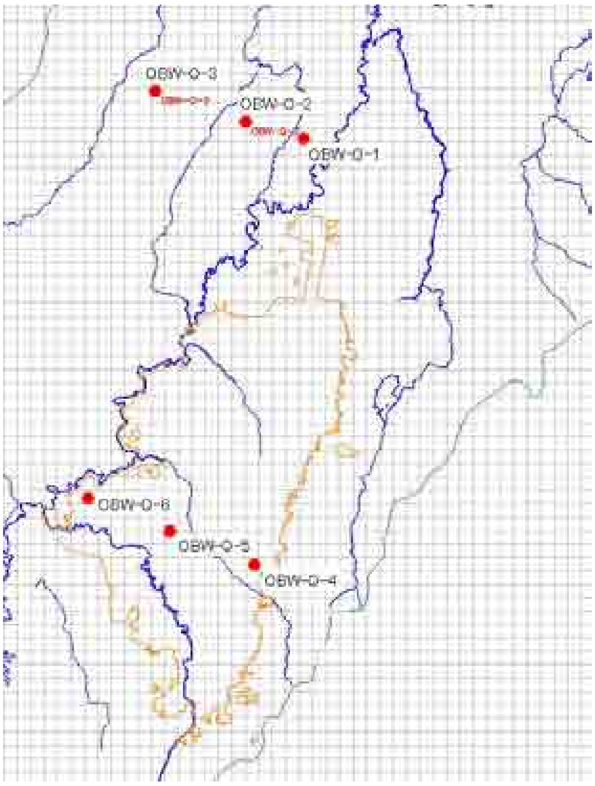
(4) Initial Heads for Simulation

For transient simulation, the initial hydraulic heads for each layer were imported from the calibrated steady state model (see Figure-5.28 "Head Distribution after Calibration of Steady State Model"). In the steady state model, the influence of the existing pumping wells (total number of more than 7,000) is already reflected in the head distribution in the calibrated model. Thus, using this head distribution data in the transient simulation enables evaluation of sole effect of pumping with newly planned wells.

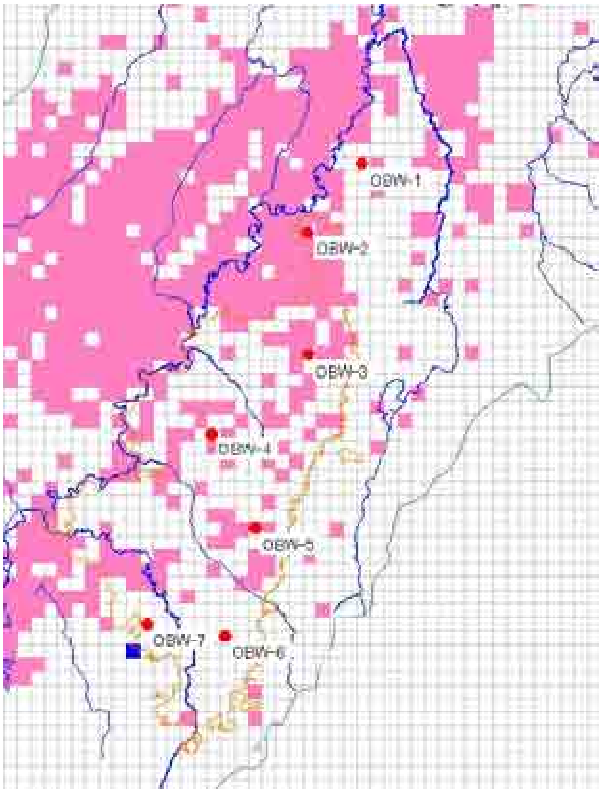
(5) Head Observation Wells

The drawdown of water table and hydraulic heads due to pumping of newly planned wells were observed in the Cretaceous aquifer and in the Quaternary sediment layer above it. The latter is anticipated to suffer a land subsidence problem due to the pumping. The observation wells are assumed to screen over the entire vertical thickness of the model layers concerned. Thus, the observation values are calculated as the average for the entire thickness of the model layers concerned.

The observation wells installed in the Cretaceous aquifer were positioned at least 1,000 m away from pumping wells including the existing ones. Seven of them were installed along the eastern edge of the urban area of Bogotá, along which most of the new wells are planned. The observation wells for the Quaternary sediment layers were positioned in two lines: One in the north of the Bogotá plain away from the urban area in E-W direction, the other in the center of the Bogotá plain where the urban area of Bogotá lies in also E-W direction. Both lines carry three observation points. The location of the observation wells are shown in Figure-2.5-10.



Observation wells for Quaternary sediment layer



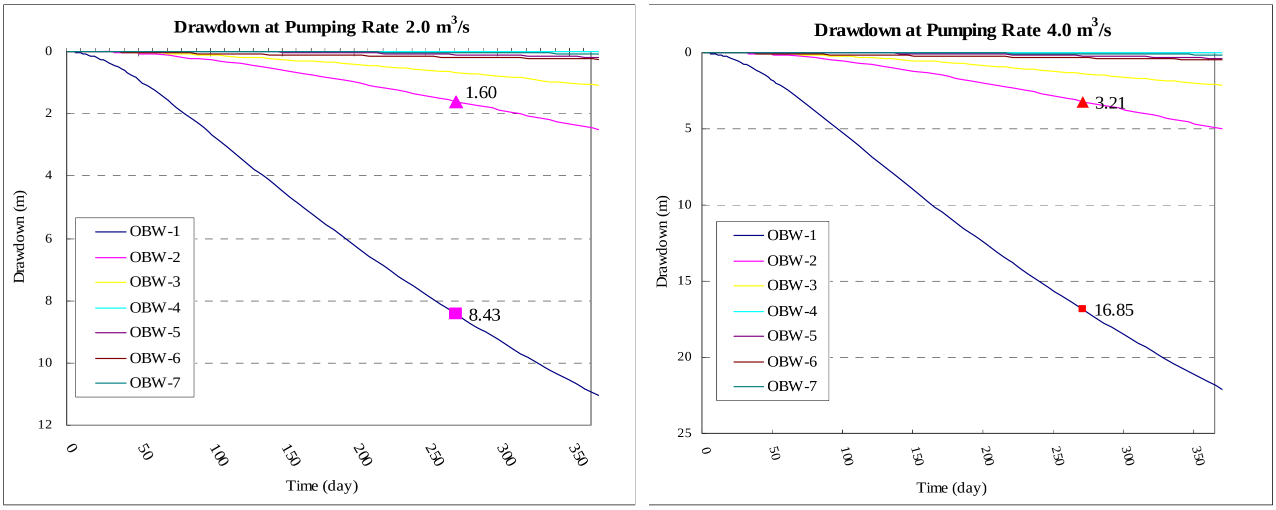
Observation wells for Cretaceous aquifer

Source: JICA Study Team.

Figure-2.5- 10 Location of Observation Wells

(a) Drawdown Cretaceous Aquifer

As a result of the transient simulation, the hydraulic head with time at each observation wells were calculated and two examples are shown in Figure-2.5-11.

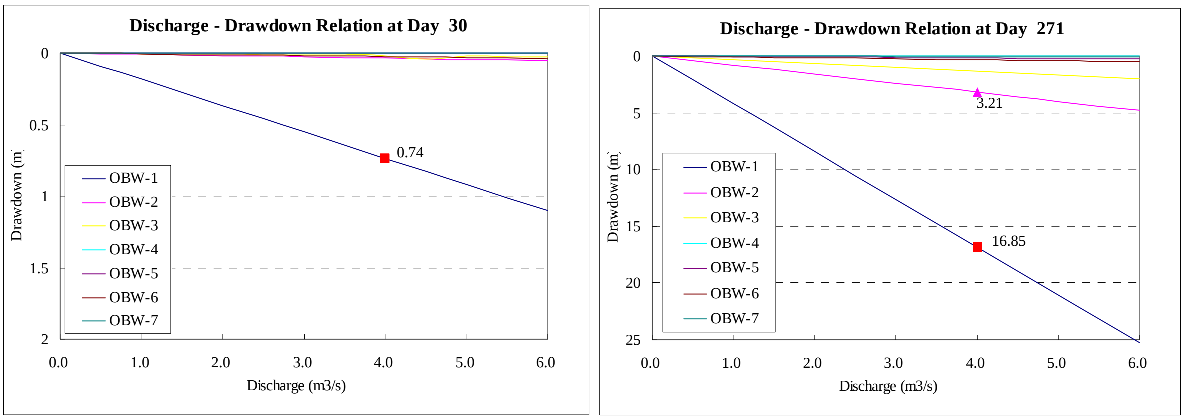


Scenario 2 (total pumping rate 2.0 m^3/sec) Scenario 4 (total pumping rate 4.0 m^3/sec)

Note: The markers indicate drawdown at time 271 days (9 months).
Source: JICA Study Team.

Figure-2.5- 11 Drawdown-Time Relation in Cretaceous Aquifer

The drawdown at OBW-1 that is located at the foot of a mountain slope is exceptionally large, but the other wells show a drawdown of no more than a few meters after 9 months of continuous pumping. Especially at OBW-4 that is located in the urban center, being away from the pumping wells, shows only negligible drawdown. In addition to this, the relation between drawdown and pumping rate was investigated at the minimum and maximum pumping time of one (1) month and nine (9) months respectively. The results are plotted on graphs in Figure-2.5-12.



Drawdown after 1 month of pumping Drawdown after 9 months of pumping

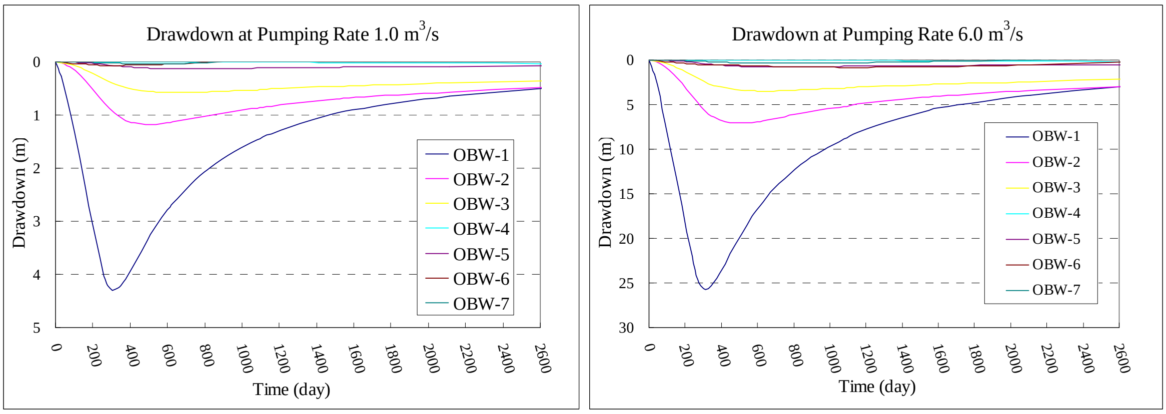
Note: The markers indicate drawdown for Scenario-4, pumping rate of 4 m^3/s.
Source: JICA Study Team.

Figure-2.5- 12 Relation between Drawdown and Pumping Rate in Cretaceous Aquifer

As can be seen in Figure-2.5-12, the drawdown linearly increases with pumping rate. The maximum drawdown at the maximum simulated pumping rate of 6.0 m^3/s after 9 months of pumping is approximately 25 m at OBW-1.

Another simulation was conducted to see the recovery process of hydraulic heads after pumping is stopped after 9 months (271 days) of operation. Scenario 1 and 6 were studied and the results are shown in Figure-2.5-13.

As can be clearly observed from Figure-5.13, the recovery of hydraulic heads after the termination of pumping takes much longer than its drawdown. Also, at even day 2,600 (approximately 6.4 years after pumping is stopped), the head is not completely recovered and up to 3 m of residual drawdown is still observed. This is probably because the pressure exerted on the groundwater by pumping is much larger than the infiltration pressure of rain water recharging the groundwater.



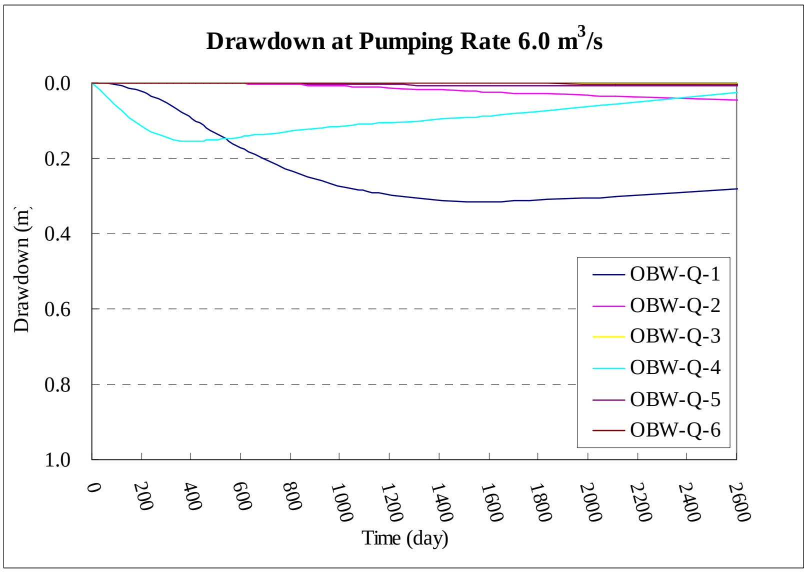
Head recovery after 1 month of pumping　　Head recovery after 9 months of pumping

Source: JICA Study Team.

Figure-2.5- 13 Head Recovery with Time after Termination of Pumping

(b) Drawdown in Quaternary Sediment Layers

For the Quaternary sediment layers, the maximum drawdown at day 271, in the case of scenario 6 that has the largest pumping rate, was found to be very small. Even when the simulation time was extended up to 2,600 days (approximately 7 years), the result showed little difference as illustrated in Figure-2.5-14. Therefore, the possibility of land subsidence is considered very small and negligible in this area.



Source: JICA Study Team.

Figure-2.5- 14 Drawdown in Quaternary Sediment Layers

(6) Result of Simulation

The following conclusions, concerning the groundwater behavior by pumping of newly planned 62 wells, are suggested from the results of the groundwater simulation.

- In an area, where the hydrogeological conditions are not favorable, the maximum drawdown after nine (9) months of operation with the largest pumping rate (6.0 m^3/s) is 25 m. The average drawdown is estimated to be around 5 m under the same condition. The drawdown of this degree is considered not to hinder operation of pumping wells.
- Larger drawdown is anticipated near the foot of mountains or on the mountain slopes.
- Pumping of newly planned wells has little effect on the water table of the Quaternary sediment layers.
- Up to a few meters of residual drawdown remains in the Cretaceous aquifer long after the pumping is stopped.

(7) Optimum Yield

Optimum yield is defined as follows:

<Optimum yield>

The yield that will cause minimum impact to natural environment

Impact by pumping from 62 planned wells is predicted as shown below:

(a) Lowering of the groundwater level of the other existing wells

(b) Occurrence of land subsidence of Quaternary formation by lowering of groundwater level

Influence by pumping is predicted as shown in Table-2.5-13.

As shown in Table-2.5-13, lowering of groundwater level in Quaternary aquifer by pumping of Alternative-1 (1.0m^3/s) to Alternative-6 (6.0m^3/s) is small and negligible. Conclusion on optimum yield is made as explained below:

<Impact to existing wells>
Groundwater water lowering of the existing well by pumping from 62 planned wells can be small, and groundwater use of the existing wells will not be interrupted. The existing wells are used for agricultural and industrial use. In case of emergency, public water use for domestic water supply will dominates the other water use. Therefore groundwater pumping from the emergency wells have higher priority than pumping from the private wells.

＜Impact on land subsidence＞
Land subsidence will be caused by consolidation of soft clay of the alluvial formation of the Quaternary. However, distribution of soft alluvial clay and its mechanical parameters is still not clear. Therefore, it is not easy to estimate exact behavior of land subsidence of the alluvial clay by pumping of Cretaceous wells. To mitigate impact by the pumping, yield of 1.5 m^3/s, average of Alternative-1 and Alternative-2, is proposed as an optimum yield in this Study. Possibility to adopt bigger yield (Alternative-3 to 6) will be examined in the further study based on more detailed information on land subsidence of Quaternary.

<u>Note for interpretation of result of the simulation</u>

There are several points to note when interpreting the results the simulation.

Table-2.5- 13 Predicted Influence by Pumping of Planned Wells

Influence by pumping of planned wells		Aquifer to be influenced
1	Lowering of the groundwater level of the other existing wells	<Quaternary> Most of existing wells withdraw groundwater from Quaternary Aquifer.
2	Occurrence of land subsidence by lowering of groundwater level	<Quaternary> Land subsidence will occur in the soft clay of Quaternary Formation.

Analyzed Result		
Alternatives of yield	Alternatives of yield	Alternatives of yield
Alternative-1	1.0	0.06
Alternative-2	2.0	0.07
Alternative-3	3.0	0.09
Alternative-4	4.0	0.11
Alternative-5	5.0	0.12
Alternative-6	6.0	0.14

Source: JICA Study Team.

<u>Grid size of the model</u>

The groundwater flow model discussed in this study is something that should be categorized as a regional model if the size of the grid is considered. Thus, all the calculated values from the model simulation are given as the average over an entire grid cell. Likewise, all the model parameters have to be put into a model grid cell as the averaged value. In other words, small topographical variations of up to tens of meters and heterogeneity within an aquifer of the same scale are not considered in the model. Therefore, actual drawdown of much larger degree than the calculated value by this simulation can be observed at places such as near pumping wells, depending on the site conditions.

<u>Boundary condition of the Model</u>

Some cautions have to be taken with regard to the boundary conditions in the model.

One is that the groundwater table was set in the model nearly parallel to ground surface in mountain areas. In reality, in such areas of topography and geology in the Study Area, a thick layer of unsaturated zone with some perched water bodies is anticipated to develop. However, the simulation code used for this model cannot properly handle this condition. Therefore, to get stable solution in the simulation, groundwater level was set near the ground surface of mountain slopes.

Another one is about the fixed head conditions for rivers and dams. This boundary condition assumes that the water levels of these surface water bodies never change though the entire simulation period. However, if the pumping rates of the wells are extremely huge and the pumping duration extends up to tens of years, and when the pumping wells are located beside these water bodies, they (= water level of rivers and dams) will inevitably be affected by pumping (water levels will go down) and consequently, there will be a contradiction.

5.4.3. Water Treatment Facilities

(1) Plan for water Treatment Facility

Optimum plan for water treatment facilities will be formulated basically based upon the following conditions:

1. The quality of the groundwater in the stratum of the Cretaceous is considered better than that in the stratum of the Quaternary. The water quality items to be noted in the groundwater are iron (Fe) and manganese (Mn). Therefore, adoption of Water Treatment System (Alternative A-2 in Table-2.5-14) to remove Fe and Mn should be examined.

2. In case the substances that are difficult to be removed by Alternative A-1 (such as high turbidity, soluble silicic acid and so on) are contained in the raw water, the conventional system (Alternative A-3 in Table-2.5-14) composed of mixing, coagulation, sedimentation, and filtration will be adopted.

3. In case the concentration of Fe and Mn can be decreased by mixing the groundwater with other treated water, the system (Alternative A-1 in Table-2.5-14) combination of chlorination and mixing with the other treated water is adopted. The mixing ratio between treated

groundwater and the other treated water is approximately 1 to 9.

Based upon the above-mentioned conditions, four (4) alternatives are proposed depending on the purpose of water use and water quality of groundwater as shown inTable-2.5-14.

Table-2.5- 14 Alternatives for Water Treatment System for Groundwater

Conditions of raw water quality / Conditions of water supply			In case Fe and Mn exceeds standard value			In case Fe and Mn are less than standard value
			Alternative A-1	Alternative A-2	Alternative A-3	Alternative B-1
Scenario of Disasters	①Damages of water distribution network in Bogotá city	Period of emergency water supply will be about 10 days	Chlorination	Chlorination + Small system [1]	Conventional system [2]	Chlorination
	②Damages of water conveyance tunnel from Chingaza	Period of emergency water supply will about 9 months	Chlorination + Water mixing with the other treated water	Chlorination + Small system	Conventional system	Chlorination
Construction cost/Operation cost			Low	Medium	High	Low

Notes: 1. Small system: The system composed of sand filtration (Pressure filtration type).
2. Conventional system: The system composed of sedimentation and sand filtration.

Source: JICA Study Team

The optimum water treatment system will be determined after further examination from technical, geological and economical points of view. Procedure for examination is as follow:

- Raw water quality will be surveyed in detail and water treatment systems to satisfy the required water quality will be selected.
- Proposed systems will be studied whether they meet the requirements for topographical restriction.
- Performance against the total cost including construction/operation cost will be examined to decide the optimum treatment system.

The details for each water treatment system are described below.

(2) Water Treatment System

1) Alternatives A-1 and B-1

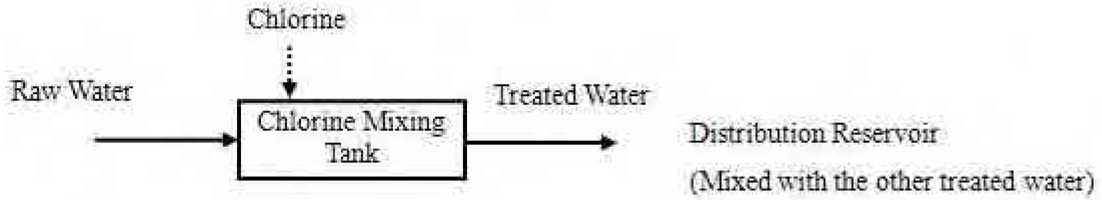
Design raw water quality and design treated water quality for these alternatives are shown in Table-2.5-15.

Table-2.5- 15 Design Raw Water Quality and Design Treated Water Quality (Alternatives A-1 and B-1)

Water Quality Item	Unit	Design Raw Water Quality	Design Treated Water Quality	Standard
pH	-	5.8-8.6	5.8-8.6	Water Quality Standards in Japan
Turbidity	NTU	Less than 20	Less than 5	Water Quality Standards in Colombia
Fe	mg/L	Less than 1	Less than 0.3	Water Quality Standards in Colombia
Mn	mg/L	Less than 1	Less than 0.1	Water Quality Standards in Colombia

Source: JICA Study Team

Alternatives A-1 and B-1 are shown in Figure-2.5-15. In these systems, only chlorine injection is applied for disinfection of raw water. In this plan, treated water is assumed to be mixed with the other treated at the ratio of about 1 to 9



Source: JICA Study Team

Figure-2.5- 15 Water Treatment System of Alternative A-1 and B-1

2) Alternative A-2

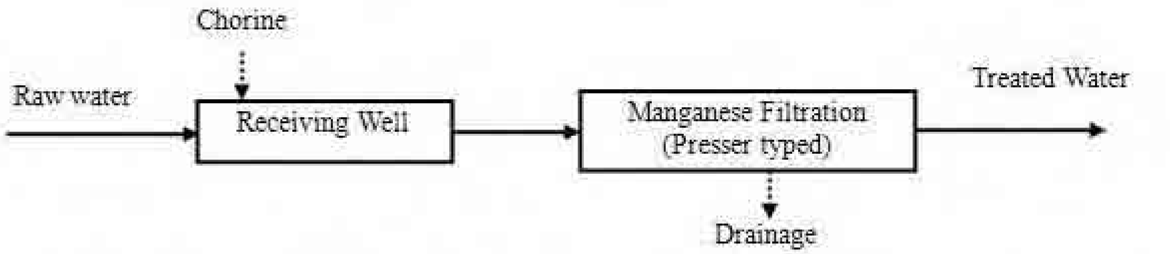
Design raw water quality and design treated water quality of Alternative A-2 are shown in Table-2.5-16.

Table-2.5- 16 Design Raw Water Quality and Design Treated Water Quality (Alternative A-2)

Water quality Item	Unit	Design Raw Water Quality	Design Treated Water Quality	Standard
pH	-	5.8-8.6	5.8-8.6	Water Quality Standards in Japan
Turbidity	NTU	Less than 10	Less than 5	Water Quality Standards in Colombia
Fe	mg/L	Less than 1	Less than 0.3	Water Quality Standards in Colombia
Mn	mg/L	Less than 1	Less than 0.1	Water Quality Standards in Colombia

Source: JICA Study Team

Alternative A-2 is shown in Figure-2.5-16. In Alternative A-2, at first chlorine to make soluble iron and soluble manganese oxidized is added in receiving well. And soluble iron is oxidized and finally changed into insoluble shape as ferric hydroxide. At second soluble manganese is contact-oxidized into insoluble manganese in sand filter, which is composed of manganese sand (*i.e.* sand of which surface is covered with MnO_2H_2O). These insoluble iron and manganese are removed by filter media.



Source: JICA Study Team

Figure-2.5- 16 Water Treatment System for Alternative A-2

3) Alternative A-3

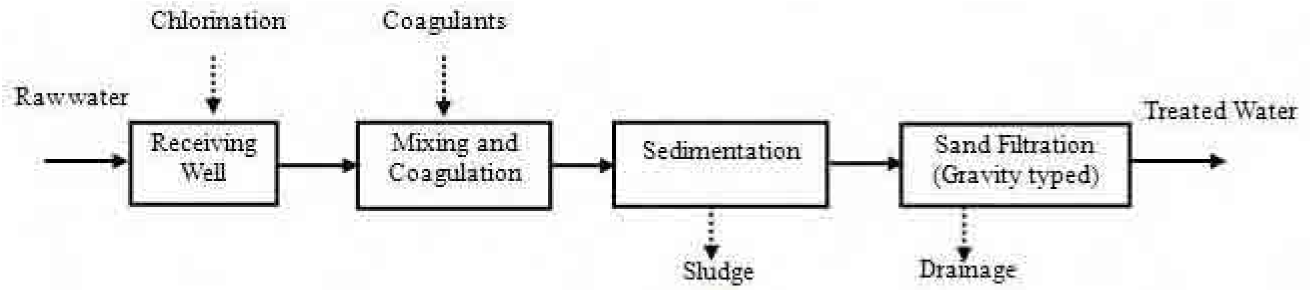
Design raw water quality and design treated water quality for Alternative A-3 are shown in Table-2.5-17.

Table-2.5- 17 Design Raw Water Quality and Design Treated Water Quality(Alternative A-3)

Water quality Item	Unit	Design Raw Water Quality	Design Treated Water Quality	Standard
pH	-	5.8-8.6	5.8-8.6	Water Quality Standards in Japan
Turbidity	NTU	Less than 20	Less than 5	Water Quality Standards in Colombia
Fe	mg/L	Less than 1	Less than 0.3	Water Quality Standards in Colombia
Mn	mg/L	Less than 1	Less than 0.1	Water Quality Standards in Colombia

Source: JICA Study Team

Alternative A-3 is shown in Figure-2.5-17. In Alternative A-3, at first chlorine to make soluble iron and soluble manganese oxidized is added in receiving well. Soluble iron is oxidized and finally changed into insoluble shape as ferric hydroxide. In mixing and coagulation basin, coagulant is added. Subsequently, the substances such as high turbidity or soluble silicic acid, which accelerate clogging of filter media, are flocculated and removed in sedimentation basin. Soluble manganese supernatant in the sedimentation basis is contact-oxidized into insoluble manganese in sand filter, which is composed of manganese sand. Turbidity and insoluble manganese, which are not removed in sedimentation basin, are removed by filter media in sand filtration basin



Source: JICA Study Team

Figure-2.5- 17 Water Treatment System for Alternative A-3

(3) Sludge Treatment Facilities

Criteria for judgment of adopting sludge treatment systems corresponding to each alternative water treatment method are shown inTable-2.5-18.

Table-2.5- 18 Criteria for Judgment of Adopting Sludge Treatment System

Water quality item (Units)	Design drainage quality alternative			Design effluent standard	Standard
	A-1 and B-1	A-2	A-3		
pH	-	5.8-8.6	5.8-8.6	5.8-8.6	Water Quality Standards in Japan
Turbidity (NTU)	-	Less than 100	More than 1,000	Less than 200	Water Quality Standards in Japan
Fe (mg/L)	-	Less than 10 [2]	More than 50	Less than 10 (Soluble ferrous)	Water Quality Standards in Japan
Mn (mg/L)	-	Less than 10	More than 50	Less than 10 (Soluble manganese)	Water Quality Standards in Japan
Necessity of sludge treatment	No (No drainage)	No	Yes [1]		

Notes: 1. Refer to Figure-5.15 for the sludge treatment system.
2. In case concentration of iron in drainage is more than 10 mg/l, installation of thickener should be examined.

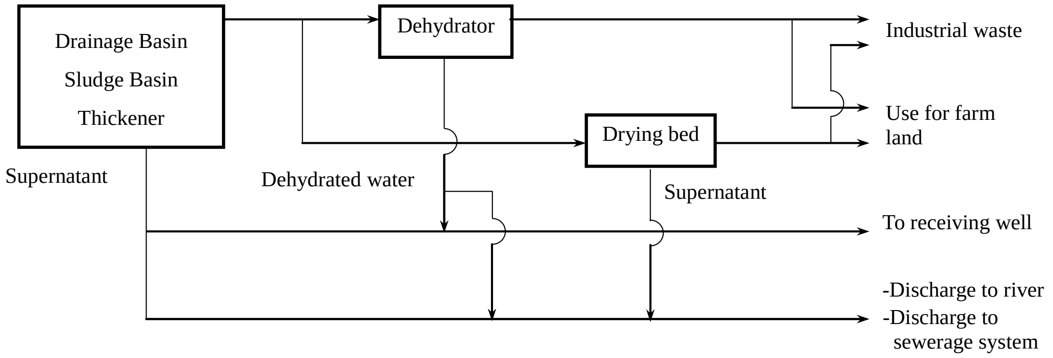
Source: JICA Study Team

To discharge untreated water may cause deterioration of landscape in public waters when drainage contains a considerable amount of iron and manganese. So installation of sludge treatment facilities is considered preferable. However, the concentration of each substance in drainage from the systems of Alternative A-1 and Alternative B-1 is predicted to fall within the effluent standard of Colombia. Consequently, in this master plan, sludge treatment systems are not applied taking into account the cost effectiveness against the construction cost.

Therefore, sludge treatment system will be applied only when Alternative A-3 is adopted. The sludge treatment system for Alternative A-3 is shown in Figure-2.5-18. Attention should be paid in design of the system as shown below:

- Basically, it is desirable that concentrated sludge should be treated in a drying bed, in terms of the easiness in operation and maintenance, when sufficient land is available. On the contrary, it is desirable that dehydrator should be adopted when sufficient land is not available.
- In case that the land for water treatment system has a sufficient space, it may be possible that sludge treatment system can also be installed at the same site. However, it is desirable that sludge from several water treatment facilities should be collected and disposed of at one site to minimize construction cost.

Finally, optimum water and sludge treatment system should be determined from view points of technical, geological and economical aspects.



Source: JICA Study Team

Figure-2.5- 18 Sludge Treatment System for Alternative A-3

(4) Layout Plan for Water Treatment Plant

Layout plan of water treatment plant for emergency water supply by use of groundwater will be formulated in such a way that water from several deep wells are collected and transferred to water treatment plant, which will be constructed at the selected site, with a capacity of 2,000 m^3/day to 10,000 m^3/day. The treated water will be conveyed to each service reservoir.

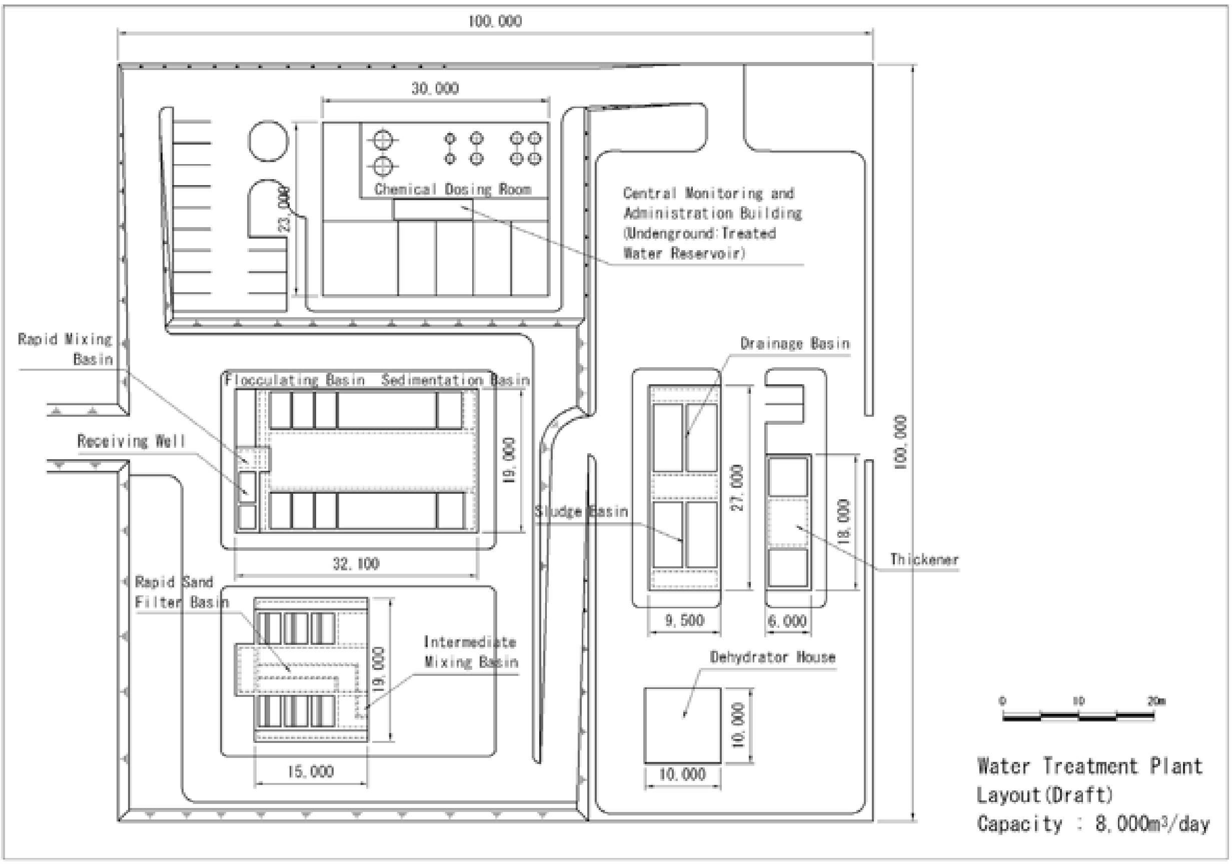
For reference, installation spaces for Alternative A-3 are shown in Table-2.5-19.

Table-2.5- 19 Installation Spaces for Water Treatment and Sludge Treatment (Alternative A-3)

No.	Capacity (m^3/day)	Installation Space (m x m)		
		Water treatment [1]		Sludge treatment [2]
		Water treatment facilities	Administration building	Sludge treatment facilities and administration building
1	2,000	25×20	30×30	6×6
2	4,000	50×35	30×30	8×8
3	6,000	75×55	30×30	9×9
4	8,000	100×70	30×30	10×10
5	10,000	125×90	30×30	11×11

Notes: 1. Water Treatment System is composed of basins of mixing, coagulation, sedimentation, sand filtration, drainage, sludge and thickener
2. Sludge treatment system stands for dewatering by dehydrator; Source: JICA Study Team

Typical layout plan of water treatment plant (Alternative A-3,) for emergency water supply by use of groundwater is shown in Figure-2.5-19.



Source: JICA Study Team

Figure-2.5- 19 Typical Layout of Water Treatment Plant for Groundwater (for Alternative A-3)

(5) Selection of Purification and Sludge Treatment System

In this Master Plan, purification and sludge treatment system shown in Table-2.5-20 is finally proposed, taking into account of quality of raw water, type of treatment necessary and cost-effectiveness.

Table-2.5- 20 Proposed Purification and Sludge Treatment System to be applied in this Study

Proposed system		Content
Item	Type of Treatment	
Purification	Alternative-2	Chlorination＋Small system [1)]
Sludge treatment	Not necessary	Sludge treatment is not necessary in principle. However, the minimum treatment necessary must be implemented to prevent impact to natural environment.

Note: 1. Small system: The system composed of sand filtration (Pressure filtration type).
Source: JICA Study Team

5.4.4. Plan for Water Transmission and Distribution Facilities

Regarding the construction of the water transmission and distribution facilities to utilize the groundwater in the emergency water supply, optimum plan will be formulated basically based upon the following conditions.

(1) Water Conveyance Facilities

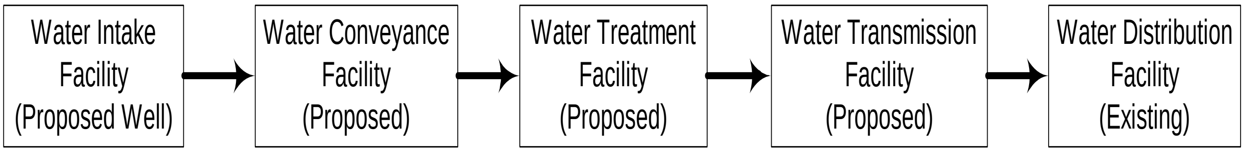
The groundwater produced by the well group (see “7.4.1 Layout Plan for Proposed Well”) is conveyed to the water treatment facility (see “7.4.3 Plan for Water Treatment Facility”), which is planned based upon the condition of the topography, land use and so on. The number of wells, which is connected together to the same water treatment facility, is assumed to be between one (1) and five (5). It means that amount of planned conveyance water from each treatment facility is between 2,000 and 10,000 m^3/day.

(2) Water Transission Facility

The treated water in the water treatment facility is transferred to the water distribution facility. The type of connection with the existing distribution facility is planned based upon the condition of the topography, existing water distribution facilities, efficiency of the water distribution and so on.

(3) Composition of Facilities for Water Transmission and Distribution for Groundwater Use

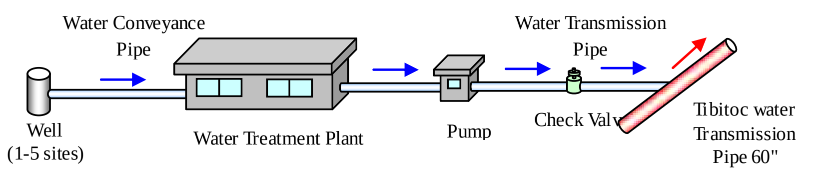
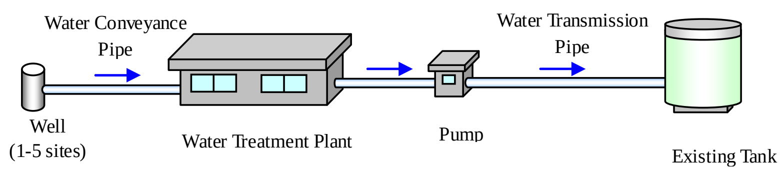
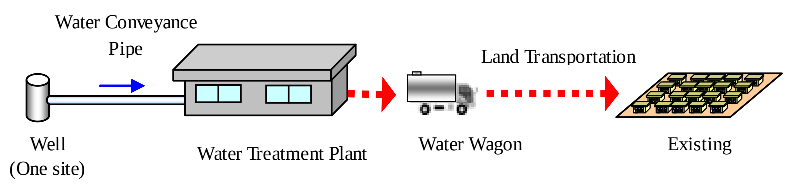
The fundamental composition of facilities for water transmission and distribution, from the water intake facilities to the water distribution facilities, for use of the groundwater in the emergency water supply, is proposed as shown in Figure-2.5-20.



Source: JICA Study Team

Figure-2.5- 20 Composition of Facilities for Water Transmission and Distribution for Use of Groundwater in Emergency Water Supply

As the composition of facilities for water transmission and distribution, three (3) types of facilities are planned as shown in Figure-2.5-21. Water supply by use of groundwater is proposed for emergency case. However, the system by the groundwater is available even for usual water supply. Usual water supply by groundwater is also proposed in Figure-2.5-21.

Form	Purpose for Transmission/ Distribution	Facilities composition for water transmission and distribution for use of groundwater
Type-1	Regular/ Emergency	
Type-2	Regular/ Emergency	
Type-3	Emergency	

Source: JICA Study Team

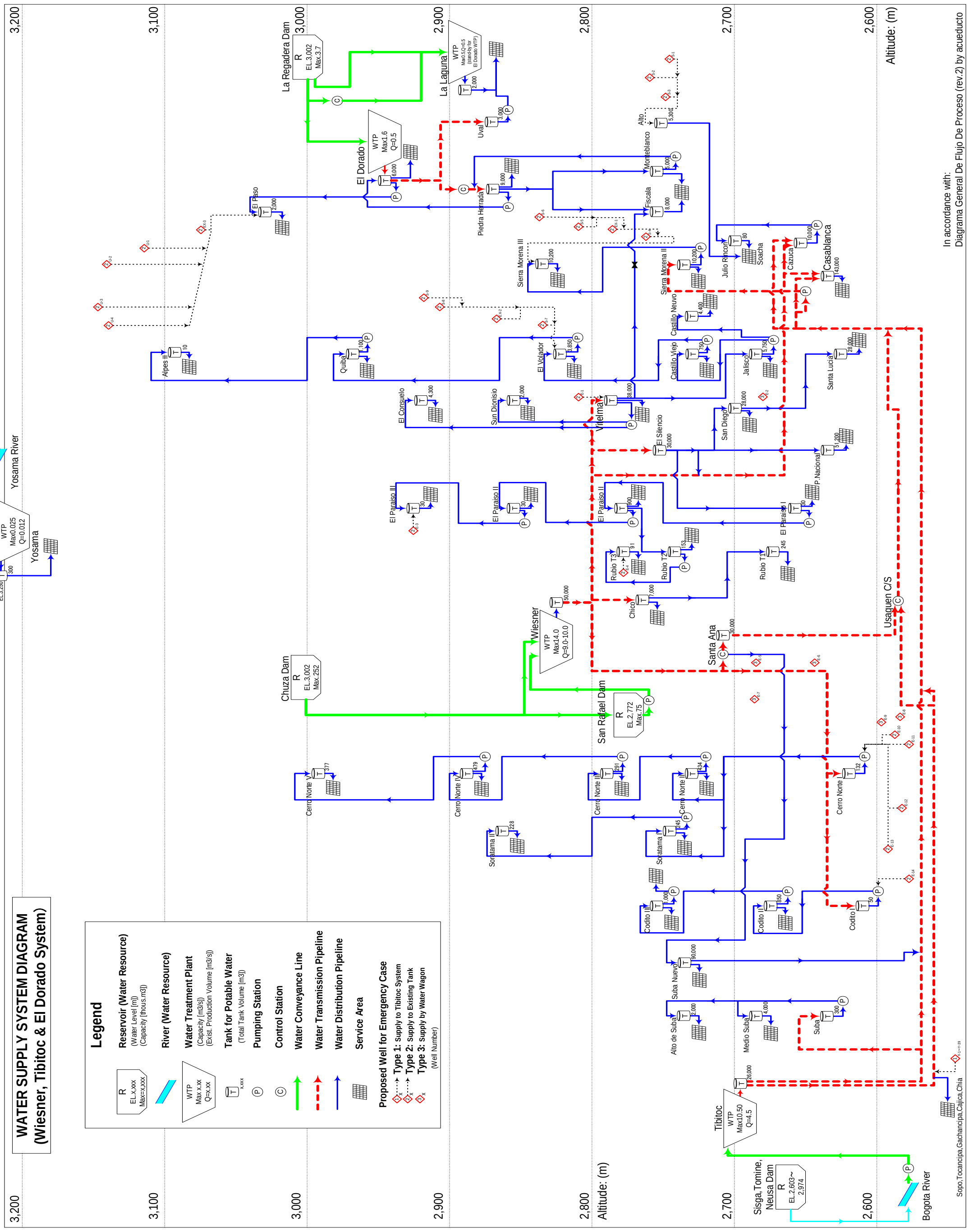
Figure-2.5- 21 Composition of Water Transmission and Distribution Facilities by Use of Groundwater

The system flow (planned target year of 2020) of the whole Bogotá City for emergency water supply by use of the groundwater is shown in Figure-2.5-21.

5.5. Management of Well Operation

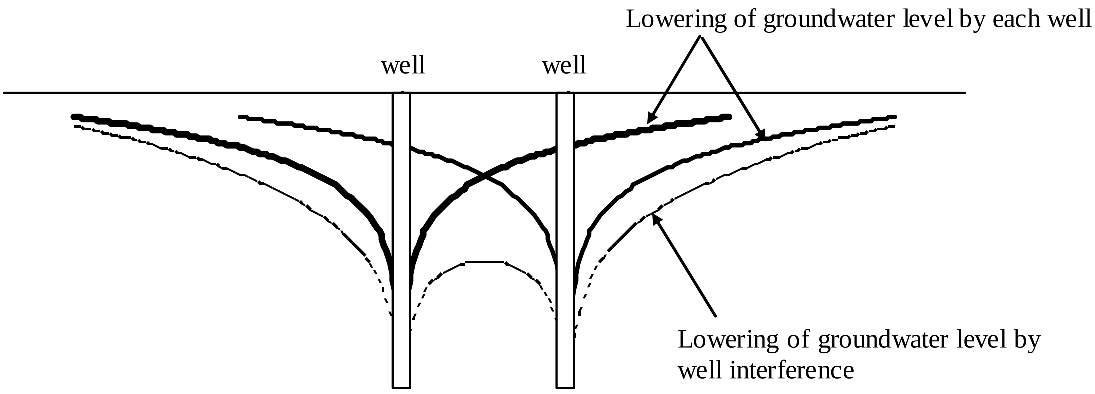
(1) Well Interference and Yield

Total yield from wells is proposed as 62 × 2,000 m^3/day = 1.44 m^3/s. However, it is necessary to increase yield from wells, when more water is requested than planned yield, in case where water shortage is more serious. In this case, there is a possibility that large lowering of groundwater level can happen by well interference. Pumping from one well will cause lowering of the groundwater level of neighboring wells, as shown in Figure-2.5-22.



Source: JICA Study Team

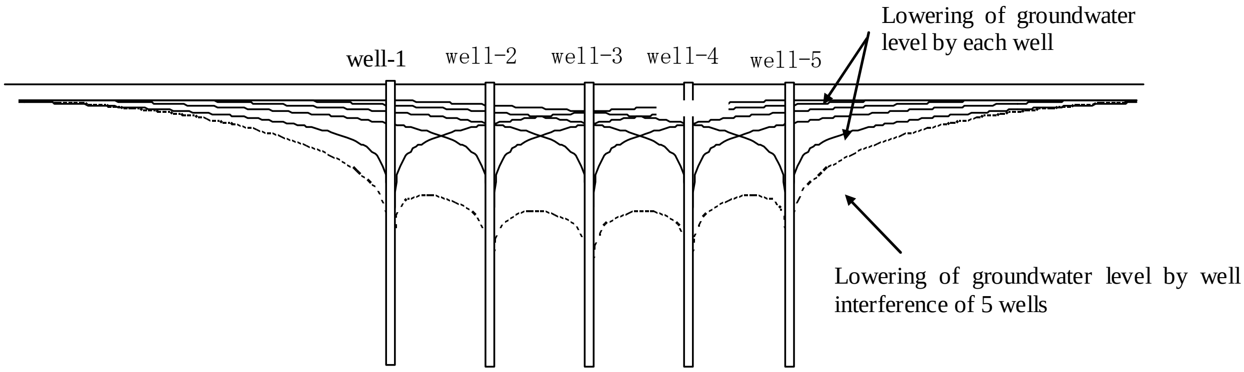
Figure-2.5- 22 System Flow of Whole Bogotá City for Emergency Water Supply by Use of Groundwater (2020)



Source: JICA Study Team

Figure-2.5- 23 Well Interference

If wells are located in a line, lowering of groundwater level is biggest in the center (well-3) by well interference, as shown in Figure-2.5-24.



Source: JICA Study Team

Figure-2.5- 24 Well interference by 5 wells

Therefore, when great amount of groundwater is pumped up from well field, it is necessary to control yield from each well of the wells field to avoid harmful lowering of groundwater level by well interference.

Emergency wells proposed in the Study are located along the Eastern hills in a line. It is planned to pump up 2,000 m^3/day of groundwater from each wells in average in case of emergency. When more groundwater is needed, pumping rate from each well should be increased with different rate

(2) Optimum allocation of yield by well

To increase yield of wells, it is necessary to allocate optimum yield to each wells. It was examined by linear programming. Objective and constraint of the linear programming is as follows.

- Objective: To get the maximum total yield from 62 wells.
- Constraint: To make the same lowering of groundwater level of each well.

(a) Lowering of groundwater level of 62 wells by punping with well interference was calculated by well formula beloww

$$s_i = \frac{Q_i}{(2\pi T_i)x\,Ln\left(\frac{R_{ij}}{r_{ij}}\right)}$$

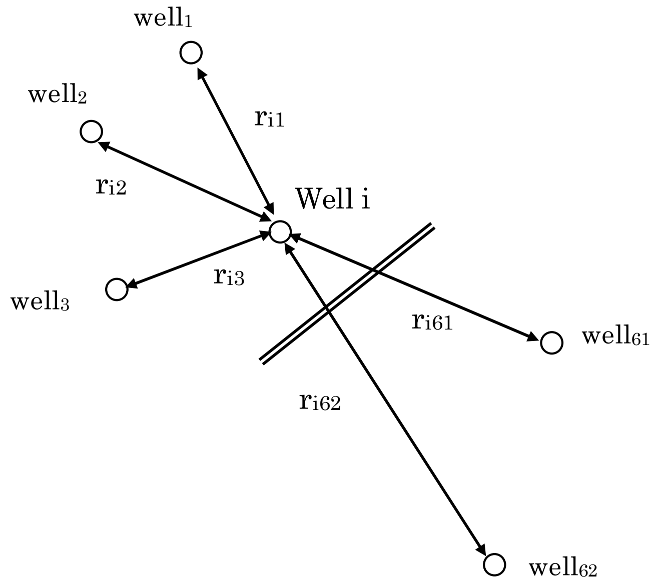
s_i : lowering of groundwater level of well No. i

R_i : Radius of influence of well No. i

Q_i : Yield from well No. i

r_{ij} : Distance between well No. i and well No. j

T_i : Transmissivity of well No. I



Source: JICA Study Team

Figure-2.5- 25 Well Location

(b) Yield of each well for the same lowering of groundwater level was calculated. This was calculated by linear programming method.

(Objective) Total yield from 62 wells will become maximum

Total yield = $Q_1 + Q_2 + Q_3 + \cdot\cdot\cdot\cdot + Q_{60} + Q_{61} + Q_{62} \rightarrow$ Maximum

(Constraint) Lowering of groundwater level is same at every well

$s_1 = s_2 = s_3 = \cdot\cdot\cdot\cdot = s_{60} = s_{61} = s_{62}$

(3) Result of calculation

According to the calculation result, yield of each well with ratio (%) shown in Table-2.5-21 can make the same lowering of groundwater level of every well. In Table-2.5-21, yield of each well is given by % with maximum yield of 62 well being 100%.

Theoretically it is desirable to make the same lowering of groundwater for environmental aspect. However, it is not practical in actual well operation. Therefore, ratio of yield shown in Table-2.5-21 should be considered as guideline of operation to increase pumping rate of wells when more water is requested in case of emergency.

Table-2.5- 21 Optimum Ratio of Yield from Wells

Area	Well No.	Ratio of yield	Area	Well No.	Ratio of yield	Area	Well No.	Ratio of yield	Well No.	Ratio of yield
Soacha	S-1	55%	Eastern Hill	E-1	100%	Yerba Buena	Y-1	32%	Y-16	37%
	S-2	44%		E-2	98%		Y-2	28%	Y-17	37%
	S-3	43%		E-3	86%		Y-3	28%	Y-18	34%
	S-4	40%		E-4	88%		Y-4	27%	Y-19	35%
	S-5	39%		E-5	71%		Y-5	26%	Y-20	42%
	S-6	45%		E-6	68%		Y-6	26%	Y-21	42%
	EX-1	38%		E-7	61%		Y-7	28%	Y-22	37%
Ciudad Bolívar	B-1	57%		E-8	47%		Y-8	32%	Y-23	39%
	B-2	48%		E-9	43%		Y-9	35%	Y-24	43%
	B-3	53%		E-10	34%		Y-10	35%	Y-25	43%
	EX-2	48%		E-11	33%		Y-11	35%	Y-26	49%
Usme	EX-3	68%		E-12	35%		Y-12	36%	Y-27	63%
	U-1	60%		E-13	38%		Y-13	35%	Y-28	62%
	U-2	64%		E-14	40%		Y-14	32%	Y-29	70%
	U-3	65%		E-15	37%		Y-15	34%		
	U-4	67%		E-16	76%					
				E-17	80%					

Note: Optimum % of yield of each well when maximum yield of 62 well is given 100%
Source: JICA Study Team

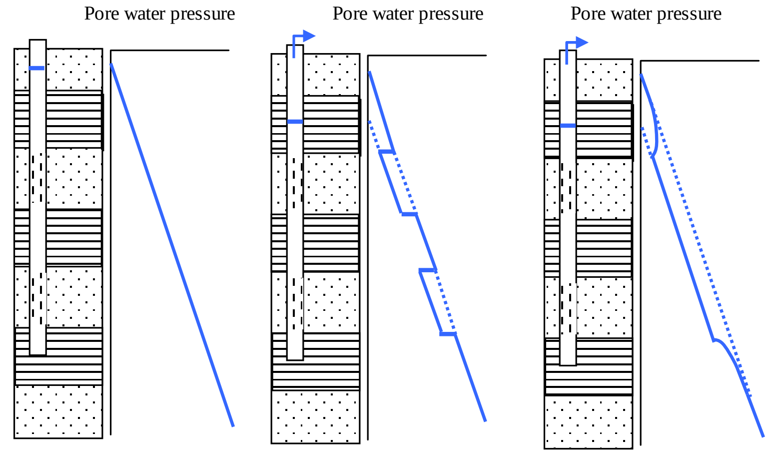
5.6. Analysis of land subsidence

Land subsidence by proposed project was analyzed as explained below.

(1) Mechanism of land subsidence

Mechanism of land subsidence by pumping of groundwater is as follows.

1. Water Pressure of confined aquifer will be reduced by pumping groundwater from the aquifer (see Figure-2.5-26(b)).
2. Confined aquifer will be compressed by reduce in water pressure within the aquifer.
3. Pore water pressure of clay layer (impermeable layer), which is over-lying and under lying the confined aquifer, will be reduced by reduce in water pressure of the confined aquifer (see Figure-2.5-26 (c)).
4. By difference in water pressure, groundwater within clay layer will flow toward the confined aquifer. As a result, the clay layer will be consolidated.



(a)Before pumping (b)Immediate after pumping (c) Final condition（after consolidation）

Source: Land subsidence and measures for it, Department of Environment of Japan, 1989.

Figure-2.5- 26 Well Interference

(2) Analysis of Land Sunsidence

Analysis of land subsidence should be implemented taken into account of items below:

Amount of land subsidence

Amount of land subsidence can be calculated formula below.

Amount of land subsidence＝mv×H×P

mv: Coefficient of Volume Compressibility (m^2/t)

H: Thickness of layer (m)

P: Reduce in water pressure of layer (t/m^2)

Table-2.5- 22 Typical Value of Coefficient of Volume Compressibility

Geology	m_v (m^2/t)	Geology	m_v (m^2/t)
Soft clay (alluvial clay)	1.9×10^{-3} - 2.4×10^{-4}	Dense sand	1.9×10^{-5} - 1.3×10^{-5}
Medium clay (diluvial clay)	2.4×10^{-4} - 1.2×10^{-4}	Dense sand and gravel	9.4×10^{-6} - 4.6×10^{-6}
Hard clay (diluvial clay)	1.2×10^{-4} - 8.5×10^{-5}	Rock with cracks	1.9×10^{-6} - 3.0×10^{-7}
Loose sand	9.4×10^{-5} - 4.6×10^{-5}	Hard rock	3.0×10^{-7}

Source: Domenico, Mifflin.

As shown in Table-2.5-22, coefficient of compressibility will become smaller as material of layer becomes harder, like clay → sand → rock. Lowering of groundwater level will cause. Generally, it is said

- Lowering of groundwater level of the confined aquifer (sand, sandstone) will cause compression of confined layer itself and clay layer overlaying and underlying the confined aquifer.
- Generally, compression of the confined aquifer itself is small and negligible.
- If layers overlying and underlying the confined aquifer is hard rock, its compression is small and negligible.
- However, if layers overlying and underlying the confined aquifer is soft clay, its compression is large by consolidation.

Speed of land subsidence

Consolidation of a layer will proceed in proportional to reduce in excess water pressure within the layer, which was caused by reduce in water pressure of a neighboring confined aquifer. Progress of consolidation can be predicted by formula of Terzaghi. As shown in the formula, speed of consolidation is proportional to coefficient of permeability of clay layer. Consequently, it will take long time until consolidation of clay layer finishes because of its low permeability.

$$\frac{\delta u}{\delta t} = \frac{k}{m_v \gamma_w} \times \frac{\delta^2 u}{\delta^2 z}$$

u: Excess water pressure of layer.
k: Coefficient of permeability.

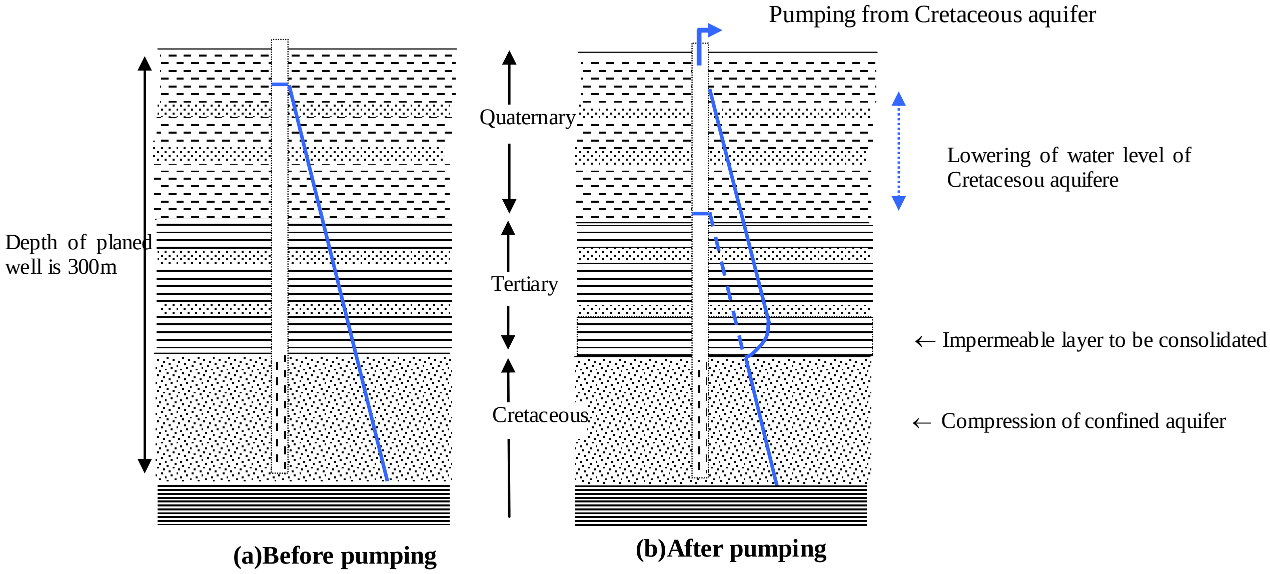
m_v : Coefficient of volume compressibility.

γ_w : Unit weight of water.

(3) Land Subsidence Model of Study Area

Mechanism of land subsidence of the Study Area by proposed project is predicted as shown in Figure-2.5-27.

A shown in Figure-2.5-27, only limited part of Tertiary layer, which has contact with Cretaceous aquifer, will be influenced by pumping from the Cretaceous aquifer. The other layer will not be influenced by pumping of the Cretaceous aquifer.

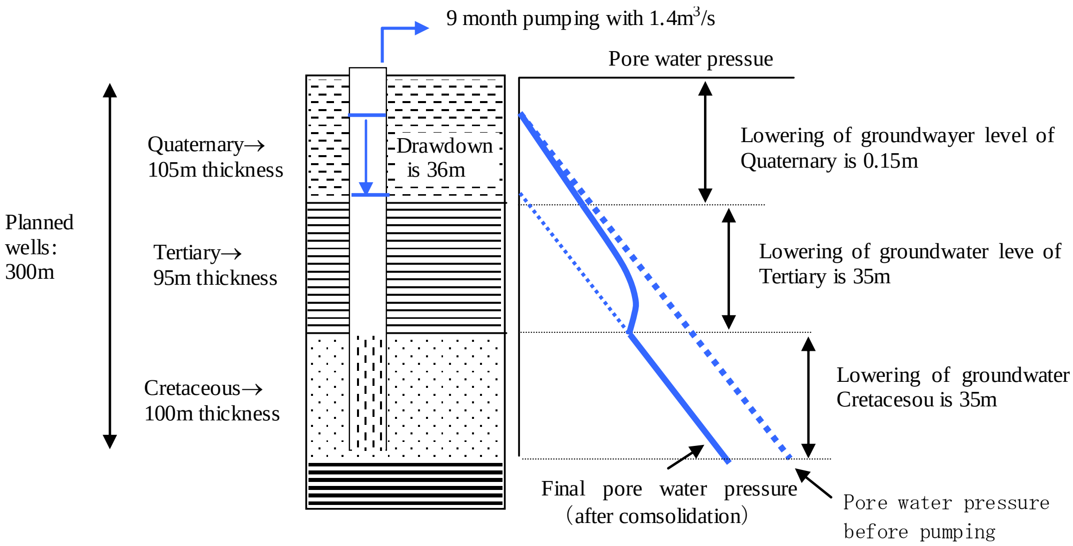


Source: JICA Study Team

Figure-2.5- 27 Mechanism of Land Subsidence

Model for consolidation

Model for analysis of consolidation by proposed project is shown in Figure-2.5-28. Values of reduce in pore water pressure shown in Figure-2.5-28 was result of groundwater simulation (see section 5.4.2).



Source: JICA Study Team

Figure-2.5- 28 Consolidation Model

Consolidation model for Quaternary (Alluvial clay)

There is the existing consolidation model for alluvial clay in the northern part of Bogotá city (see Figure-2.5-29). This model was used for this analysis. It was assumed that groundwater drained from clay layers by consolidation will go down and finally flow away from the bottom layer (layer No. 16 inFigure-2.5-29).

Symbol	Soil layer No.	Soil layer Soil name	Depth of layer (m)	Thickness of layer (m)	Unit weight (t/m^2)	Compression index (Cc)	Cv (cm^2/d)	Converted thickness (m)
	1	Fill	1.0	1.0	1.56	-	-	-
	2	Silt	2.5	1.5	1.38	1.72	2.59	1.2
	3	Clay	6.7	4.2	1.48	0.99	20.74	1.2
	4	Clay	20.1	13.4	1.34	1.48	0.86	19.0
	5	Clay	26.4	6.3	1.32	1.55	1.73	6.3
	6	Clay	30.5	4.1	1.46	1.37	117.07	0.5
	7	Clay	36.2	5.7	1.41	1.6	1.73	5.7
	8	Clay	39.7	3.5	1.33	3.77	1.73	3.5
	9	Clay	42.3	2.6	1.53	2.21	1.73	2.6
	10	Clay	50.5	8.2	1.46	1.16	1.73	8.2
	11	Clay	62.3	11.8	1.5	0.95	24.19	3.2
	12	Tuff	66.5	4.2	1.07	2.26	4.75	2.5
	13	Clay+sand	71.0	4.5	1.67	0.77	42.34	0.9
	14	Clay+sand	85.0	14.0	1.73	0.7	1.30	16.2
	15	Clay+sand	89.8	4.8	1.84	0.62	1.30	5.5
	16	Sandy clay	105.0	15.2	1.7	0.97	9.50	6.5
Total				105.0				83.0

Source: National University.

Figure-2.5- 29 Consolidation Model of alluvial Layers

<u>Compression model for the Tertiary and the Cretaceous</u>

The Tertiary and the Cretaceous layers consist of rock materials, different from the Quaternary layers that consist of unconsolidated soft sediments. Therefore, not consolidation but elastic compression will occur in the Tertiary and the Cretaceous layers by lowering of groundwater level. In this case, their compressions will occur immediately after pumping and will finish soon. There is no observed data on coefficient of compression of the Tertiary and Cretaceous layers of the Study Area. Therefore, instead of observed value, general values for the Tertiary and Cretaceous layer was used for this analysis as shown below.

Coefficient of volume compressibility

Tertiary 1×10^{-6} (t/m^2)

Cretaceous 1×10^{-7} (t/m^2)

----

(4) Analysis of Land Subsidence by Proposed Project

Land subsidence was calculated for the model shown in Figure-2.5-29, and result is shown in Table-2.5-23. It must be noticed that land subsidence shown in Table-2.5-23 will be attained after a long period of pumping. On the other hand, 62 emergency wells proposed in this Study will be operated in case of emergency only, which will be less than 9 month operation. In this case, land subsidence will be smaller than those shown in Table-2.5-23.

Table-2.5- 23 Land Subsidence after Long Period of Pumping

Geology	Thickness(m)	Reduce in pore water pressure (m)	m_v (t/m^2)	Land subsidence (m)
Quaternary	105	0.15	0.133 1)	0.02 1)
Tertiary	95	35	0.000001	0.003325
Cretaceous	100	35	0.0000003	0.00105
Total				0.024375

Note:Land subsidence of Quaternary layers was calculated 0.02m from Cc in Figure-2.27. Mv =0.133 was calculated back from the calculated land subsidence (0.0133) and reduce in pore water pressure (0.15).
Source: JICA Study Team

Land subsidence after 9 month pumping can be analyzed from relation below:

- Amount of consolidation after 9 month pumping =Final consolidation × degree of Consolidation.

Degree of consolidation was calculated by procedure below.

Coefficient of consolidation and thickness of layers

Speed of consolidation is dominated by coefficient of consolidation (Cv). The Quaternary layers consist of multiples layers with different Cv as shown in Figure-2.5-29. For easy analysis, the Quaternary layers were unified into single layer with unified Cv by method bellow.

$$\text{Converted thickness of each layer} = \sqrt{\text{thickness each of layer} \times \text{Cv of each layer} \div \text{unified Cv}}$$

Unified Cv = 1.73 cm^2/day (Cv of layer No. 5, No. 7 – No. 10 in Figure-2.5-29 was applied)

Thickness of unified layer = Total thickness of converted layers

On the other hand, coefficient of consolidation of Tertiary and Cretaceous layer can not be defined because they are expected elastic compression.

Degree of consolidation

Degree of consolidation (Uz) is function of time factor (Tv). Tv is defined as shown below.

Time factor Tv = $Cv/H^2 \times t$

Cv: Coefficient of Consolidation (cm^2/day)

H: Thickness of layer (cm)

T: Time after consolidation begins (day)

For the model shown in Figure-5.27, Tv =1.733/(83002)×270=6.79×10^{-6}

Amount of land subsidence

Amount of land subsidence of the model layer in Figure-2.5-29 was finally calculated as shown in Table-2.5-24.

Table-2.5- 24 Amount of Land Subsidence

Geology	Darin condition for consolidation	Time factor (Tv)	Amount of land subsidence after 9 month pumping		
			Final land subsidence (m)	Degree of consolidation (%)	Land subsidence after 9 month pumping (m)
			(a)	(b)	(a)×(b)
Quaternary	One side	9.6×10^{-5}	0.02	5	0.001
Tertiary	-	-	0.003325	100	0.003325
Cretaceous	-	-	0.00105	100	0.00105
Total					0.0091

Source: JICA Study Team

As shown in Table-2.5-2, amount of land subsidence after 9 month pumping is small and negligible. This is because intermediate Tertiary layers between Quaternary and Cretaceous layers prevent land subsidence of soft Quaternary layers.

5.7. Pilot Project for Groudwater Use

Pilot Project for groundwater use is proposed by Acueducto to know technical problem and solution of the project. Purpose of the project is as follow:

- To know and solve technical problems in construction, operation and management of emergency water supply facilities by use of groundwater.

- To estimate cost of construction, operation and maintenance for emergency water supply facilities by use of groundwater.

In this project, an emergency well will be connected to the existing water pipe to send groundwater into the existing water supply system.

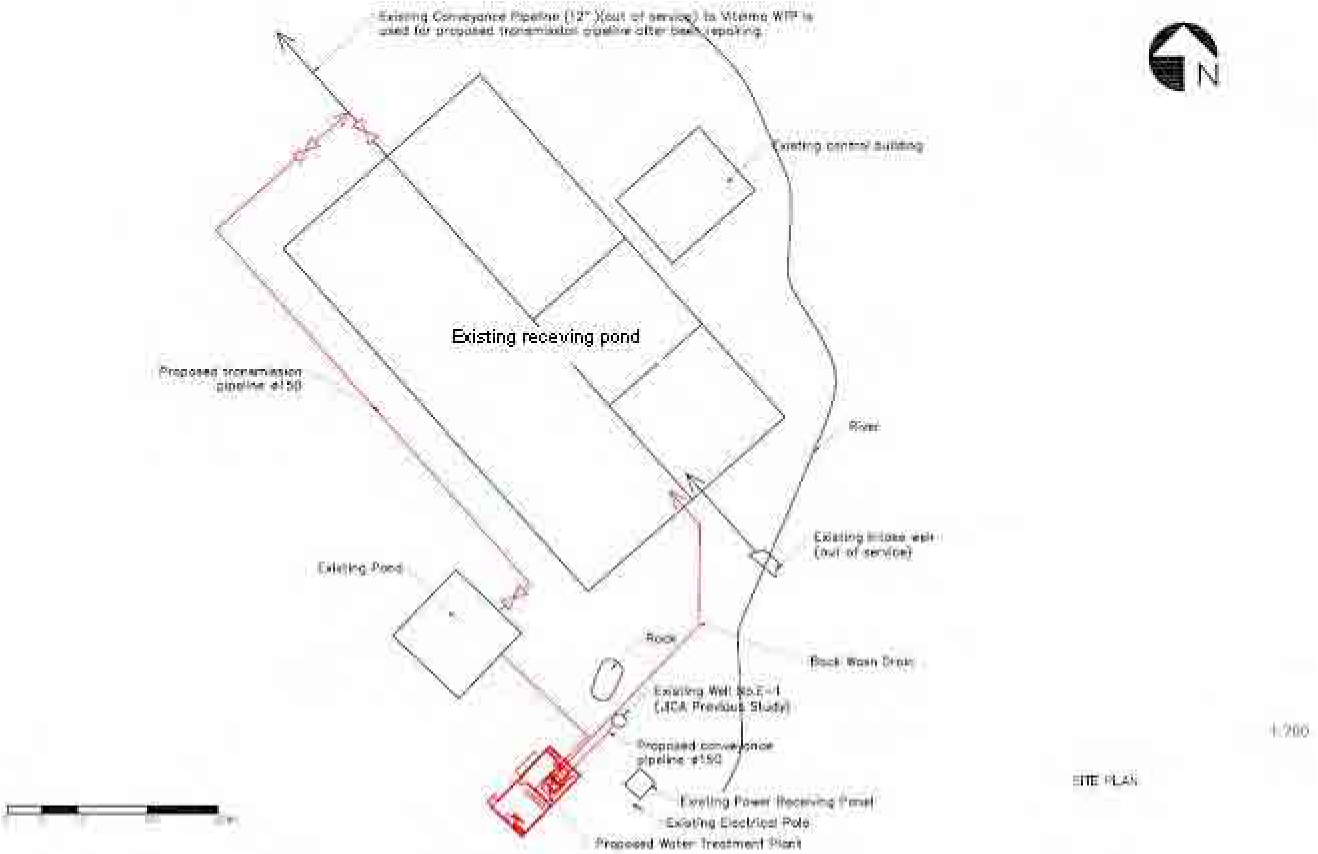
<u>Site for Pilot Project</u>

Pilot Project should be implemented in Vitelma sedimentation ponds of Acueducto because of good condition described below:

- Pilot project for artificial recharge was implemented in Vitelma site in the previous JICA Study. The facilities for it still remain in the site including recharge well and tank, which can be used for this pilot project. Yield of 2,000 m^3/day can be expected from the well in the site.
- There is a water conveyance pipeline from this site to Vitelma purification plant. Groundwater pumped from the wells can be sent to Vitelma plant though the existing pipeline.

<u>Facilities for Pilot project</u>

Facilities for emergency water supply consist of a well, simple water treatment facilities, energy facilities and pipeline. Groundwater pumped from well is from Cretaceous Aquifer, and it has good quality for drinking but contains a little high concentration of Fe and Mn. Treatment facilities to remove Fe and Mn is necessary. Concept of facilities is shown in Figure-2.5-30 to Figure-2.5-32.



Source: JICA Study Team

Figure-2.5- 30 Site for Pilot Project

<u>Alternatives for treatment facilities</u>

Treatment facilities are important in this pilot study. There are two type of facilities proposed in this Study.

Table-2.5- 25 Amount of Land Subsidence

Alternative	System of facilities
Type-A (see Figure-5.29)	Groundwater from well→ precipitation→ single pressure filter→ treated water
Type-B (see Figure-5.30)	Groundwater from well→ aeration→ precipitation→ mixing and settling → multiple pressure filters→ treated water

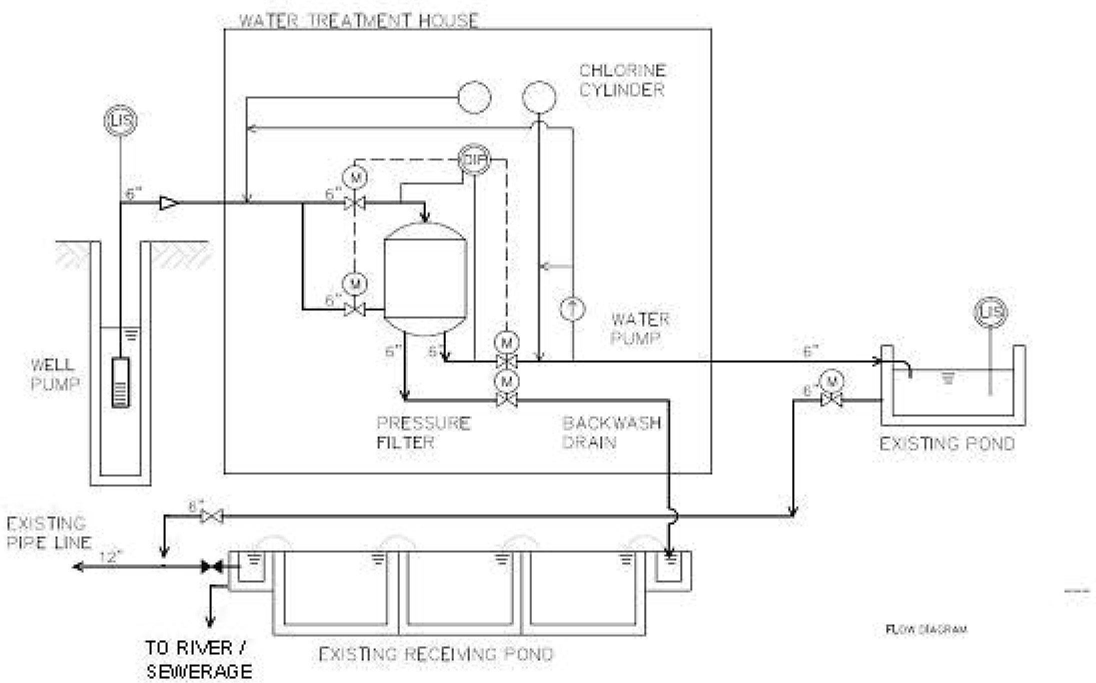
Source: JICA Study Team

Difference in alternatives is summarized in Table-25-26

Table-2.5- 26 Difference in Alternatives

Alternative	Precipitation of Fe and Mn	Settling and filtration of Fe and Mn	Number of presure filter	Method for water injection to pressure filter
Type-A	chlorination	Pressure filter	One filter: Capacity of a filter well be decided based on required treatment amount.	By pressure of submersible pump of well.
Type-B	aeration + chlorination	Settling pond + pressure filters	3 filters: Capacity of 3 filters will be decided based on required treatment amount.	Groundwater will be pumped up to an elevated aeration tank, from which water will be sent to filters by gravity.

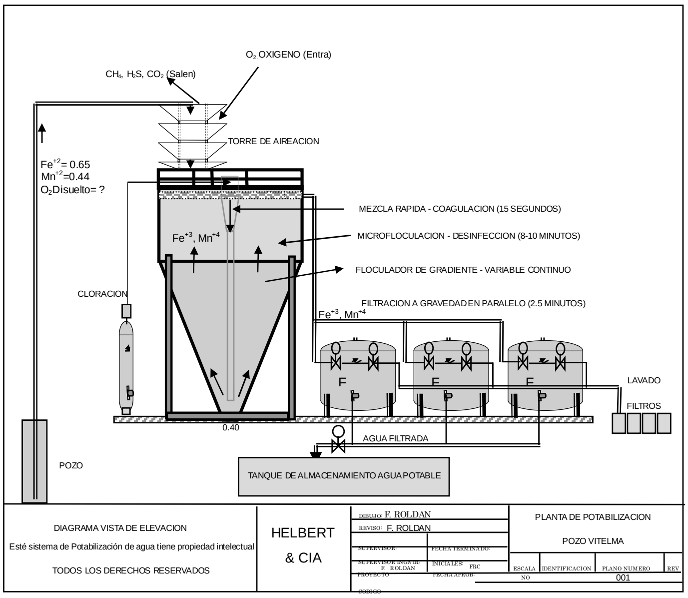
Source: JICA Study Team



Source: JICA Study Team

Figure-2.5- 31 Water treatment System (Alternative type-A)

Backwash water from Figure-2.5-31 is finally discharged from the Existing Receiving Pond to the river or existing sewerage system if its characteristics comply with the regulations. Accumulated sludge in the Existing Receiving Pond must be disposed and treated appropriately.



Source: JICA Study Team

Figure-2.5- 32 Water treatment System (Alternative type-B)

Difference between two alternatives is summarized as follows:

- Precipitation of Fe and Mn is only by chlorine in type-A, but by both aeration and chlorine in type-B.
- Chlorine for precipitation is injected into pipeline in type-A, but chlorine is put into mixing tank in type-B.
- Fe and Me is removed by only pressure filter in type-A, but by settling pond and pressure filter in type-B.
- Water is injected into filter and distributed into the existing water system by pressure of submersible pump within a well in type -A, but by gravity from aeration tower in type-B.
- Type–A has simple treatment system with small facilities and the cheapest construction cost. On the other hand, type-B has more complicated treatment system with larger facilities and higher cost for construction.

Which should be selected depends on i) concentration of Fe^{2+} and Mn^{2+} of the groundwater and ii) cost for construction. Water treatment facilities, proposed in this Study for emergency water supply project, was planned by type–A, after considering i) water quality and ii) cost of construction. However, water treatment facilities should be examined further though planning and design of the pilot study.

<u>Effective Use of pilot project</u>

Further expansion can expected from the result of the pilot project.

- Pilot project has role of Feasibility Study for emergency water supply project by use of groundwater

Master Plan of emergency water supply project by use of groundwater is proposed in this Study. Following this pilot project, similar projects as this pilot project can be newly implemented, which will finally expand to the proposed emergency water supply projects by 62 wells

5.8. Monitoring Plan

Well maintenance is necessary to use production wells for a long period of time at best condition. For this purpose, monitoring of groundwater level and groundwater quality of the wells is indispensable. Moreover, monitoring to inspect influence by pumping to natural environment, such as land subsidence, is also necessary. Above two types monitoring have different purpose as shown below:

(a) Monitoring to control water production from wells.

(b) Monitoring to inspect influence to natural environment caused by pumping.

Monitoring to control water production from wells

Content of monitoring is described in Table-2.5-27.

Table-2.5- 27 Monitoring to Inspect Influence by Pumping to Natural Environment (1)

Target	Item to be monitored		Frequency	Use of monitoring result
	Item	Note		
Groundwater level	Dynamic groundwater level of operating well (Static water level of non-operated well)	Groundwater level will be observed by automatic recorder	Continuous observation	• Yield will be controlled according to fluctuation of groundwater level • Well cleaning will be carried out when specific capacity [1).] • Pump failure will be detected [2)]
Yield	Yield of well	Yield from well will be observed by flow-meter.	Continuous observation	
Water quality	Several representative items stipulated in water quality standard	Both row water and treated will be sampled and analyzed	Once/month	• Suitability for drinking water will be judged • Change of water quality will give information on change of aquifer property and contamination.

Note: 1) Specific capacity = yield (m^3/day)/groundwater draw-down (m).
2) Decrease in production capacity of well can be judged from decrease of specific capacity. On the other hand, decrease of yield without decrease of specific capacity means pump failure. It will be caused by i) corrosion of pump and, ii) abrasion of pump by sand from aquifer.

Source: JICA Study Team

Monitoring to inspect influence to natural environment caused by pumping

Content of the monitoring is summarized in Table-2.5-28.

Table-2.5- 28 Monitoring to inspect influence to natural environment caused by pumping

Target	Item to be monitored		Monitoring frequency	Use of monitoring result
	Item	Method for observation		
Groundwater level of well	Static water level of observation wells	Static water level of Quaternary observation wells will be observed by automatic recorder. The observation wells should be near the Cretaceous production wells.	Continuous observation	Occurrence of impact to groundwater level of Quaternary aquifer by pumping from Cretaceous aquifer can be judged.
Land subsidence	Land elevation	Land elevation of the Quaternary observation well will be observed.	Once/6 month	• Occurrence of land subsidence in Quaternary formation can be judged • Relationship between the land subsidence and pumping from Cretaceous aquifer can be judge.

Source: JICA Study Team

5.9. Institution and Operation/Maintenance

(1) Procedure of Water Supply in Case of Emergency

The procedure of water supply in case of emergency is planned as shown in the Table below. Organization in charge of emergency water supply is to be Corporate Management Office of Master

System under the leadership of the General Manager of Acueducto. Close communication with related organization will be necessary, especially at early stages of the emergency operation.

Table-2.5- 29 Procedure of Water Supply in Case of Emergency

Procedure	Operation	Organization in Charge in Acueducto [1]	Related Organization in Acueducto [1]	Related Organization out of Acueducto [2]
Information collection on disaster Situation	- Information collection on demands for emergency water supply - Information collection on conditions of facilities/equipment for water conveyance treatment, storage, transmission and distribution - Information collection on availability of other public services (electricity, fuel, telecommunications, transport, etc.), and road conditions, etc.	- G.G.. - G.C. of Master System	-	- D.C.P.A.E - DPAE - C.I.D. - C.L.E.
Identification of operation for Emergency Water Supply	- Identification of areas required for emergency water supply - Identification of facilities/equipment to be used for emergency water supply - Organizing emergency water supply (dispatching staff and procurement of required materials, etc) - Identification and planning of rehabilitation works for facilities of conveyance, treatment, storage, and distribution	- G.G.. - G.C. of Master System	- G.C.G..H.A. - G.C. of Planning and Control	- D.C.P.A.E - DPAE - C.I.D. - C.L.E.

Implementation of Emergency Water Supply	- Implementation of rehabilitation works
	- Emergency water supply by surface water
	- Emergency water supply by groundwater
	  - Point Water Supply (water supply by water wagon)
	  - Water supply using rehabilitated water distribution network
	<Refer to Table-5.23>
		- G.G..
		- G.C. of Master System
		- G.C. of Service to the Client
			- S.G.
			- G.J.
			- G.C.G..H.A.
			- G.C. of Finance
				- D.C.P.A.E
				- DPAE
				- C.I.D.
				- C.L.E.

Post-emergency settlement and evaluation	- Financial settlements and compensations - Post-evaluation on emergency operation and learning lessons to improve future emergency water supply and to enhance preparedness for emergency events	- G.G.. - G.C. of Master System	- G.C. of Planning and Control - G.C. of Service to the Client - S.G. - G.J. - G.C.G..H.A. - G.C. of Finance	- D.C.P.A.E - DPAE - C.I.D. - C.L.E.

Note: 1). G.G.; General Manager, G.C.; Corporate Management Office, S.G.; General Secretariat, G.J.; Legal Management Office, G.C.G..H.A.; Corporate Management Office of Human Resource Management and Administration. 2). C.D.P.A.E; District Committee for Prevention and Attention of Emergencies, DPAE; Directorate of Prevention and Attention of Emergencies of the District C.I.D.; District Inter-institutional Commissions, C.L.E.; Local Emergency Committees.

Source: JICA Study Team

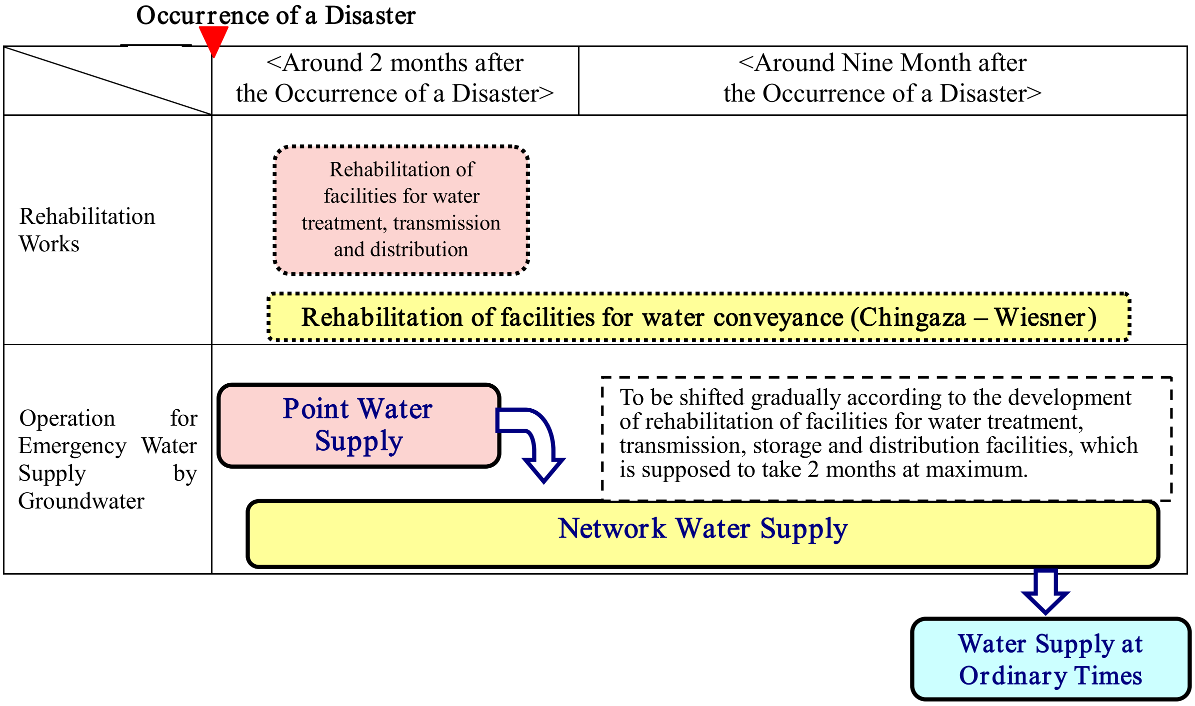
(2) Operation and Maintenance for Water Supply in Case of Emergency by Groundwater

Types of operation for emergency water supply by groundwater are classified as follows:

1) Point water supply: Water supply using water wagons for distribution. Water wagons will go to the locations of wells or treatment facilities (water distribution points) proposed in Section 5.4.

2) Network water supply: Water supply using existing or rehabilitated water supply facilities for water treatment, transmission and distribution with automatic control system. Water wagons also can be available, being provided water from hydrants of the network water supply system.

Timing the two types of emergency water supply is illustrated in the figure below. Operation of the two types of emergency water supply are to be shifted gradually according to the development of rehabilitation of facilities for water treatment, transmission and distribution facilities, which is supposed to take 2 months at maximum.



Source: JICA Study Team.

Figure-2.5- 33 Operation for Emergency Water Supply by Groundwater

Operation works of emergency water supply by groundwater are listed in the table below, Table-2.5-30. With the development the rehabilitation of the transmission and distribution network, point water supply can be made at the places of hydrants in the areas of the rehabilitated network. Operation works of network water supply are same as those for water supply at ordinary times. To shift to network water supply from point water supply, some transitional period will be necessary, when the checks of the control system are conducted.

Table-2.5- 30 Operation Works of Emergency Water Supply by Groundwater

<table>
<tr><th>Emergency Water Supply</th><th>Facility</th><th>Operation Process</th><th>Personnel Requirement</th></tr>
<tr><td rowspan="4">Point Water Supply</td><td>Pumps, Generator</td><td>- Disconnect from remote control system
- Switch on the generator (if electricity is not available)
<u>Facility Inspection (once/day)</u>
1) Check the generator (appearance, vibration, frequency, temperature, change in color /shape, looseness, pressure, rotation, leakage, pipes, measuring instruments).
2) Check the electric current and voltage of the pumps.
3) Check dynamic water level by observation of the meter.
4) Check water quality (turbidity, sand, cleanliness around the well) by observation and by water quality checker.</td><td rowspan="3">- One operator for a well (2 shifts/day)
- Contracts for distribution by water wagon
- One person for a water wagon to check the distribution</td></tr>
<tr><td>Treatment Facility</td><td>- Disconnect from the transmission network.
- Disconnect from remote control system.
<u>Facility Inspection (once/day)</u>
1) Check the storage of chemicals, structures, valves, injection system.
2) Water quality analysis by a water quality checker.</td></tr>
<tr><td>Distribution Facility</td><td>- Supply water to water wagon.
- Check water quality by a water quality checker.</td></tr>
<tr><td>Building, Site</td><td>- Continue daily works for the security and maintenance of the building and the site.</td><td>- Service contract for the security and maintenance</td></tr>
<tr><td>Transitional Operation</td><td>Pump, Transmission Facility</td><td>- Check the remote control system.
- Connect to the remote control system.
- Connect to the transmission network.</td><td>- One operator for a well under supervision of engineers of the headquarters</td></tr>
<tr><td rowspan="4">Network Water Supply</td><td>Pumps</td><td><u>Facility Inspection (once/month)</u>
1) Check operation of the pumps. In case some disorder is found, repair the pump.
2) Check static and dynamic water level by observation of the meter, and collect data of automatic water level for analysis.
3) Analyze water quality with the laboratory and by water quality checker.
4) Check automatic water level recorders.</td><td rowspan="3">- Two teams, a senior technician and a junior technician for a team, will be necessary
- Service contracts for services of regular facility inspection and well monitoring</td></tr>
<tr><td>Treatment Facility</td><td><u>Facility Inspection (once/month)</u>
1) Check the storage of chemicals, structures, valves, injection system.
2) Analyze water quality with the laboratory and by water quality checker.</td></tr>
<tr><td>Conveyance and Transmission Facility</td><td><u>Facility Inspection (once/month)</u>
1) Check the pipeline (appearance, cracks on road surface, other construction works near to the pipe lines).
2) Check operation of the pump. In case some disorder is found, repair of the pumps.</td></tr>
<tr><td>Building, Site</td><td>- Continue daily works for the security and maintenance of the building and the site.</td><td>- Service contract for the security and maintenance</td></tr>
</table>

Source: JICA Study Team.

(3) Staffing for Emergency Water Supply by Groundwater

It is recommendable not to employ permanent personnel for emergency water supply only, but to respond with existing staff of Acueducto. Acueducto has already prepared contracts with companies that have water wagons or similar vehicles, by which they will provide the vehicle and drivers in case of emergencies, with the experience of the emergency case of Chingaza.

Table-2.5- 31 Staffing for Emergency Water Supply by Groundwater

Type of Emergency Water Supply	Staffing
Point Water Supply	Pumping, Treatment and Supply to Water Wagons - For operation of pumping, treatment and supply water to water wagons, two technicians for a well are necessary. - Total number of required persons will depend on number of wells to be used for point water supply (or conditions of available transmission and distribution facilities). Maximum persons will reach to around 120 persons when all of the proposed wells are used for point water supply. - Technicians of Directorates of Water Supply and Water Supply Network of Corporate Management Office of Master System, as well as Management Office of Zones and Directorate of Technical Support of Corporate Management Office of Services to Client have to be dispatched. Distribution - Contract with the companies that have water wagons or similar vehicles. - One person from Acueducto staff for a vehicle is required to check the distribution by the contracted company. - Persons from Management Office of Zones and other Directorates of Corporate Management Office of Services to Client have to be dispatched. Maintenance of Building and Site - Service contract for security and the maintenance is recommendable.
Network Water Supply	Pumping, Conveyance, Treatment and Transmission - Network water supply will be implemented with automatic control system as water supply at ordinary times. - Two senior technicians and two junior ones will be employed by Acueducto to manage operation of network water supply by groundwater. These personnel will also be in charge of water supply by groundwater at ordinary time. - Outsourcing with service contracts is recommendable for regular facility inspection and well motoring. Maintenance of Building and Site - Service contract for security and the maintenance is recommendable.

Source: JICA Study Team

(4) Operation for Water Supply at Ordinary Times by Groundwater

Operation works for water supply at ordinary times are same as those for the network water supply in emergency cases (see Table-2.5-32). In other words, shifting to the network water supply from the point water supply in emergency cases means restarting operation of water supply at ordinary times. Ordinary water supply by groundwater will be automatically controlled by the remote control system managed by the control center of Acueducto.

Table-2.5- 32 Operation Works of Water Supply at Ordinary Times by Groundwater

Facility	Operation Process	Personnel Requirement
Pumps	Facility Inspection (once/month) 1). Check operation of the pumps. In case some disorder is found, repair the pump 2). Check static and dynamic water level by observation of the meter, and collect data of automatic water level for analysis 3). Analyze water quality with the laboratory and by water quality checker 4). Check automatic water level recorders	- Two teams, a senior technician and a junior technician for a team, will be necessary - Service contracts for services of regular facility inspection and well monitoring
Treatment Facility	Facility Inspection (once/month) 1). Check the storage of chemicals, structures, valves, injection system 2). Analyze water quality with the laboratory and by water quality checker	
Conveyance and Transmission Facility	Facility Inspection (once/month) 1). Check the pipeline (appearance, cracks on road surface, other construction works near to the pipe lines) 2). Check operation of the pump. In case some disorder is found, repair of the pumps	
Building, Site	- Continue daily works for the security and maintenance of the building and the site	Service contract for the security and maintenance

Source: JICA Study Team.

(5) Enchancing Preparedness for Emergency Events

Since emergency operation tends to be complicated and confusing in nature under the circumstances of uncertainties, the followings are recommended for quick and proper emergency responses.

1) Communication with relevant organizations related Prevention and Attention of Emergencies of the District

   Since emergency water supply is one of the actions for attention of emergences as a whole and is closely related to the actions of other sectors, communication with the relevant organizations should be kept closely and frequently.

2) Preparation and updating of lists (contacts to personnel of Acueducto for emergency water supply, contractors for water wagons, and contractors for material supply, etc.)

   For smooth and proper start of operation for emergency water supply, information on these should always be updated. Periodical checks, like twice a year, are recommendable.

3) Preparation of Operation Manual and Training

   As written above, substantial number of persons is to be involved in emergency water supply, whose daily jobs are different from those of emergency water supply, especially for point water supply. Easily applicable manuals should be prepared for the personnel operation works of emergency water supply.

4) Exercises and Drills

To start and implement operation of emergency water supply quickly and smoothly at the actual occurrence of disasters, periodical exercises and drills can be recommended with an assumption of a disaster. Exercises and drills are a kind of simulations. From the exercises and drills, problems and the countermeasures can be learned before the actual occurrence.

(6) Organization to Manage Water Supply by Groundwater

Although pumps, valves and treatment facilities can be controlled by remote control system, regular activities for well monitoring can be outsourced. Moreover, establishment of a unit in Corporate Management Office of Mater System to manage groundwater supply is recommended with the following staff and jobs.

Table-2.5- 33 Organization to Manage Water Supply by Groundwater

Staff	Jobs
Chief of the Unit	* To manage groundwater development projects under supervision of Director of Water Supply * To manage water supply by groundwater in coordination with Division of Control Center of Directorate of Water Supply Network * To analyze well monitoring data, to report CAR and SDA, and to take necessary measures according to the results of the analysis.
Two Teams (a Team is composed with a senior technician and junior technician)	* To inspect facilities for by supervising contractors for the service * To take necessary measures when disorders of the facilities are found under supervision of the Chief. * To conduct well monitoring (water level and water quality) by supervising contractors for the service * To submit the monitoring data to the Chief * Other jobs ordered by the Chief
Administrative Assistant	* Administrative support

Source: JICA Study Team.

5.10. Implementation Schedule for Master Plan

Project component and implementation schedule for Master Plan of emergency water supply by use of groundwater is proposed as below:

Project Component

Entire project is consists of three projects as shown in Table-2.5-34.

Table-2.5- 34 Master Plan for Emergency Water Supply by Use of Groundwater

Project			Number of wells	Produced water (m^3/s)	Characteristics of project
a)	Southern area	Soacha	7 wells (S1-S6 EX1)	0.16	• Proposed emergency water supply system consists of well-tank - purification plant. Water from this system will be distributed to the existing tank in emergency. • Water supply will not be sufficient in the future in this area. The emergency water supply system can be used for usual water supply.
		Ciudad Bolívar	4 wells (B1-B3 EX2)	0.10	
		Usme	5 wells (U1-U4 EX3)	0.12	
b)	Yerbabuena area		17 wells (E1-E17)	0.32	• Proposed emergency water supply system consists of well-tank-purification plant. Water from this system will be distributed to the existing tank in emergency.
c)	Eastern area		29 wells (Y1-Y29)	0.67	• Proposed emergency water supply system consists of well-tank-purification plant. Water from this system will be put into distribution main pipe from Tibitóc to Bogotá in emergency.
Total			62 wells	1.37	―

Source: JICA Study Team

(1) Period of Projects Commencement

Purpose of this project is emergency water supply, of which period will be limited from 10 days to 9 months. The project should begin as soon as possible for earlier completion, because nobody knows when disaster will happen.

(2) Plan for Stage Construction of Project

Proposed 3 projects should be implemented by 3 phases, and each phase has 1 year period. Strategy for stage construction of the project is as follows:

- In case of groundwater development by construction of wells, economy of scale is not dominant, different from in case of dam construction. The reason is: amount of groundwater to be developed is proportional to the number of the wells to be constructed. Cost of the project is proportional to the number of the wells. It means that cost of the project is almost proportional to amount of groundwater to be developed.
- In above case, the groundwater should be developed (= wells should be constructed) closely following growing water demand, which can be optimum investment. However, this project is for emergency water supply. Therefore, project should be scheduled aiming at earlier completion.
- Project implementation schedule should be formulated taking into account of i) urgency and scale of the project, ii) capacity of contractors for facilities construction, and iii) capacity of Acueducto for budget procurement.

Pre-condition for formulation of project implementation schedule is shown in Table-2.5-35.

Table-2.5- 35 Pre-Condition for Formulation of Project Schedule

Item	Plan	Note
Number of wells	62 wells	• Planned yield from one well is 2,000 m^3/day. • Total yield=2,000 m^3/day ×62 wells =1.5 m^3/s • Of 62 proposed wells, 5 wells will be drilled within JICA Study. 4 wells are existing wells. So, total of 53 wells be drilled after JICA Study.
Construction period	3 years	Construction period is decided from: • Capacity of Acueducto for budget procurement • Capacity of contractor for construction.
The number of well to be drilled for 1 year	Around 20 wells	• 2 month is necessary for completion of 1 well. • 6 wells will be completed by 1 drilling machine. • 3 drilling machines ×6 wells/1 year=20 wells/year.

Project implementation schedule is proposed in Table2.5-36.

Table-2.5- 36 Project Implementation Schedule

Item		Year														Note
		2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	
Master Plan for the project		■	■													JICA Study
FS Feasibility Study			■													JICA Study 1)
－Project approval －Budget procurement				■												Investment decision by Acueducto
Detail design					■											－Geophysical survey, －Water quality analysis
Construction	Southern area					■										Well construction: 13
	Yerbabuena area						■									Well construction: 17
	Eastern area							■								Well construction: 23
O/M of facilities							■	■	■	■	■	■	■	■	■	

Note: 1) Implementation of JICA Study is not yet fixed.
Source: JICA Study Team.

5.11. Design and Cost Estimate

5.11.1. Design

(1) Design Standard

In Colombia, for the well drilling works, civil work, concrete structure work and the electrical installation work, the following design criteria are applied. These criteria depend on the criteria of USA. Therefore, the design of emergency water supply facilities by use of groundwater of this Study is based on the criteria below:

(a)	Well Drilling Work:	AWWA-100(1997)
(b)	Civil Work:	Installation of Pipe Works: Reglamento tecnico del sector de Augua Potable y Saneamiento Basico RAS-2000
(c)	Concrete Structure Works:	Normas Colombianas de Diseno y Construccion Sismoresistente NSR-98
(d)	Electric Work:	Codigo Electrico nacional Colombiano (CEC) Resolución Numero 18 0466 de (2-Abril 2007)

(2) Capacity of Well

Arrangement of production wells is designed based on size, depth and capacity of standard well as shown in Table-2.5-37.

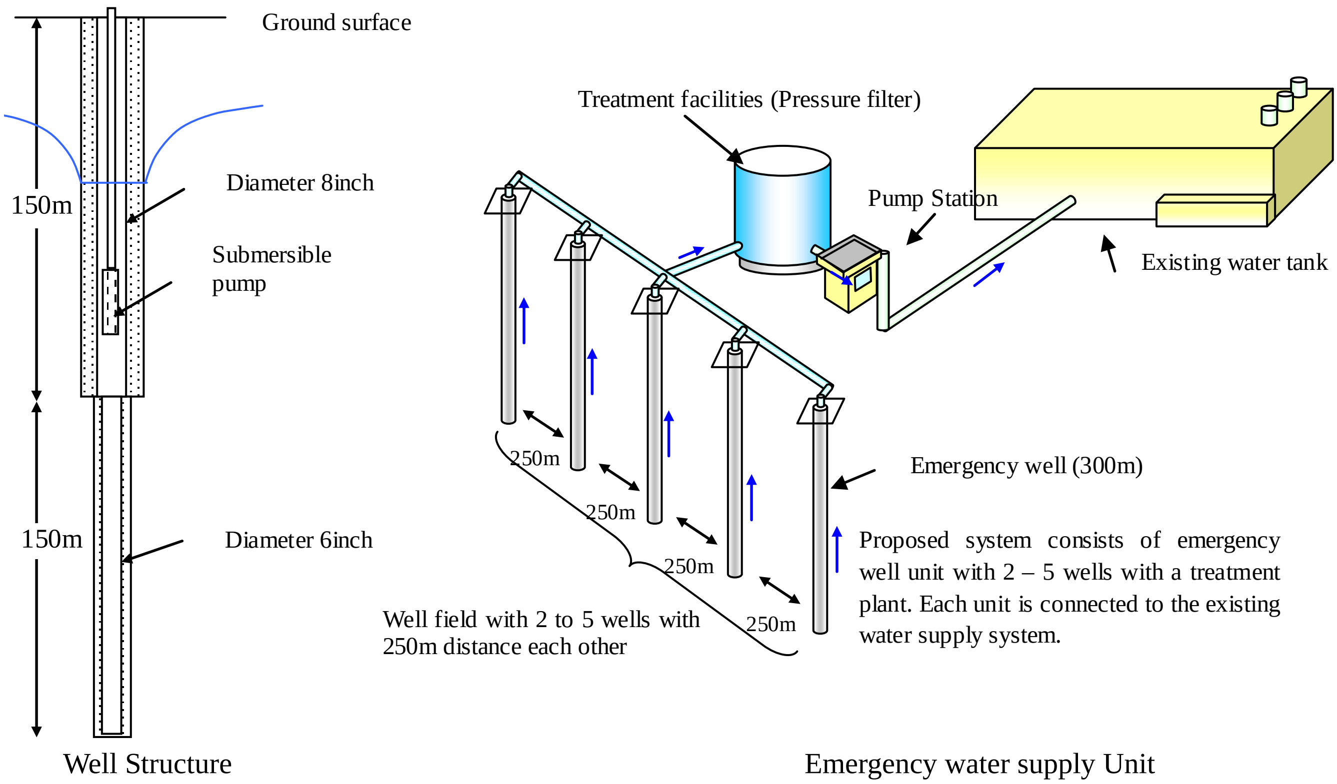
Table-2.5- 37 Standard Capacity of Well

Type of well	Aquifer	Length of well	Diameter of well	Production Capacity
Production well	Cuaternary Cretaceous	300 m	- 0 m to 150 m: 8 inch - 150 m to 300 m: 6 inch	2,000 m^3/day (1.4 m^3/min.)

Source: JICA Study Team

(3) Facility Layout

Proposed project is for emergency water supply. Layout emergency water facilities are shown in Figure-2.5-34.



Source: JICA Study Team

Figure-2.5- 34 Layout emergency water facilities

Emergency water supply unit

As shown in Figure-2.5-35, a well field consists of 2 to 5 wells and is connected to a water treatment filter. This system constitutes one emergency water supply unit. Treated water from the unit will be sent to the existing tanks and pipelines. Composition of each emergency water supply unit and existing facilities to be connected are shown in Table-2.5-38.

Table-2.5- 38 Composition of Emergency Water Supply Unit (1)

Phase & Region		Well No.	Conveyance pipe		Water Treatment		Transmission		Connection Point (existing facilities)	Purpose[1]	Legend[2)]
		New	Size (inch)	Length (m)	Capacity (m^3/day)	Facility	Size (in)	L (m)			
Phase-I Southern hill	Soacha	S-1	6	767	6,000	Chlorine + pressure filter	8	500	Tank Alto (owned by Soacha city)	E/N	A
		S-2	6	425							
		S-3	6	80							
		S-4	6	33	8,000	Chlorine +pressure filter	12 12	1,528 2,369	Tank Sierra Morena III	E/N	B
		S-5	6	959							
		S-6	6	1,294							
		EX-1	6	571							
	Ciudad Bolívar	B-1	6	80	8,000	Chlorine +pressure filter	8	1,381	Tank El Volador	E/N	C
		B-2	6	894							
		B-3	6	1,240							
		EX-2	6	589							
	Usme	U-1	6	488	10,000	Chlorine +pressure filter	12	1688	Tank El Paso	E/N	D
		U-2	6	1,036							
		U-3	6	2,757							
		U-4	6	2,989							
		EX-3	6	96							
Phase-II Yerbabuena		Y-13	6	1,442	8,000	Chlorine +pressure filter	12	591	60 in Tibitóc main line	E/N	E
		Y-14	6	1,052							
		Y-15	6	751							
		Y-16	6	65							
		Y-17	6	65	8,000	Chlorine +pressure filter	10	284	60 in Tibitóc main line	E/N	F
		Y-18	6	1,357							
		Y-19	6	1,571							
		Y-20	6	2,402							
		Y-21	6	1,388	6,000	Chlorine +pressure filter	8	300	60 in Tibitóc main line	E/N	G
		Y-22	6	347							
		Y-23	6	141							
		Y-24	6	381	6,000	Chlorine +pressure filter	8	306	60 in Tibitóc main line	E/N	H
		Y-25	6	187							
		Y-26	6	70							
		Y-27	6	200	6,000	Chlorine +pressure filter	8	254	60 in Tibitóc main line	E/N	I
		Y-28	6	478							
		Y-29	6	920							

Note 1) E: Point water supply, N: Network water supply
2) Legend is for Figure -2.5-35

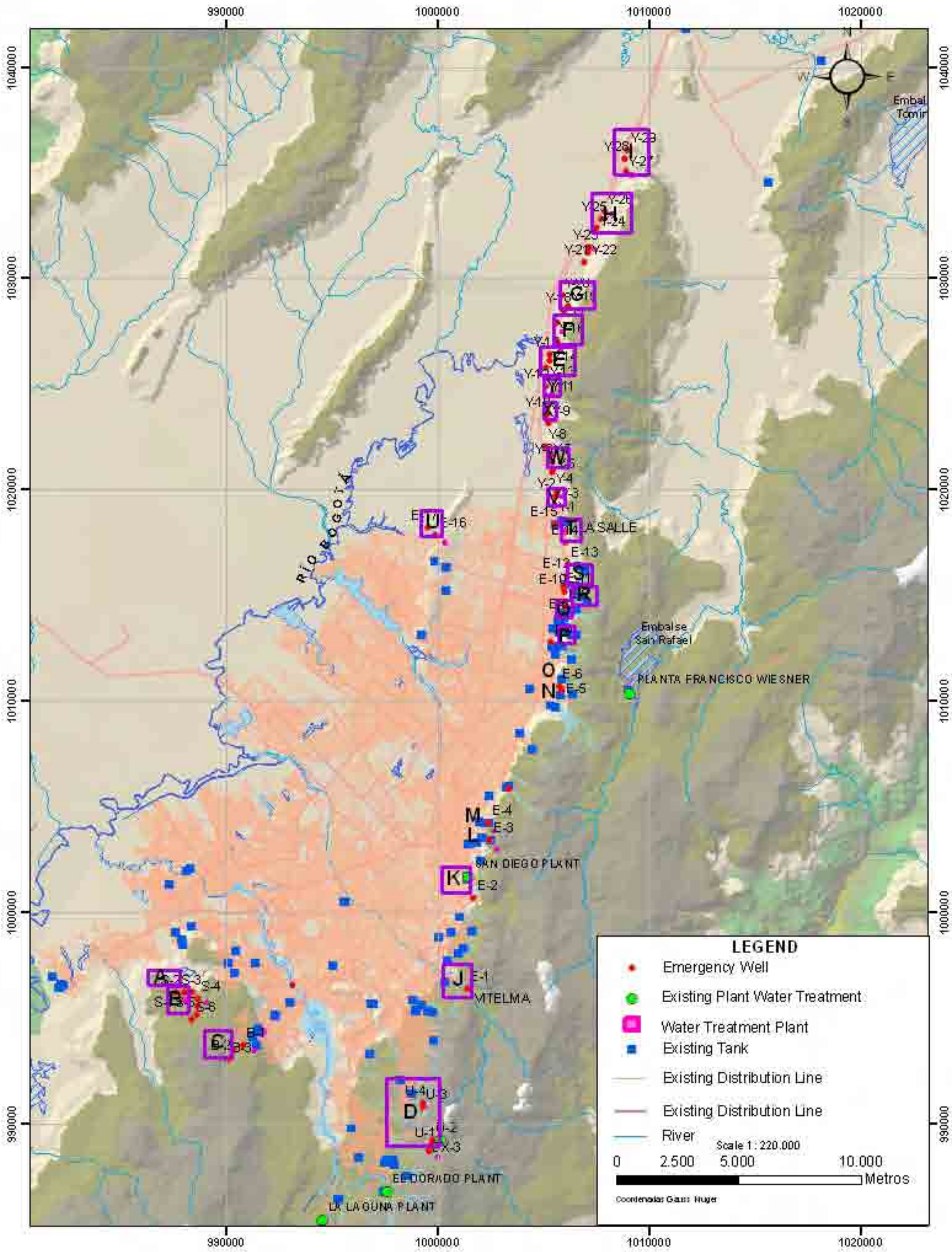
Source: JICA Study Team

Table-2.5-38(2) Composition of Emergency Water Supply Unit (2)

Phase & Region	Well No.	Conveyance pipe		Water Treatment		Transmission		Connection Point (existing facilities)	Purpose[1)]	Legend[2)]
	New	Size (inch)	Length (m)	Capacity (m^3/day)	Facility	Size (in)	L (m)			
Phase-III Eastern hill	E-1	6		-	-	-	-		E/N	J
	E-2	6	20	2,000	Chlorine	-	-		E	K
	E-3	6	104	2,000	Chlorine +pressure filter	6	117	Tank Paraiso	E/N	L
	E-4	6	106	2,000	Chlorine +pressure filter	6	73	Tank Pardo Rubio	E/N	M
	E-5	6	20	2,000	Chlorine	-	-	-	N	N
	E-6	6	20	2,000	Chlorine	-	-	-	N	O
	E-7	6	20	2,000	Chlorine	-	-	-	N	P
	E-8	6	20	2,000	Chlorine	-	-	-	N	Q
	E-9	6	20	2,000	Chlorine	-	-	-	N	R
	E-10	6	117	8,000	Chlorine +pressure filter	12	127	Tank Cerro Norte I	E/N	S
	E-11	6	290							
	E-12	6	774							
	E-13	6	1,347							
	E-14	6	1,567	4,000	Chlorine +pressure filter	8	157	Tank Codito I	E/N	T
	E-15	6	125							
	E-16	6	50	4,000	Chlorine +pressure filter	8	1,750	Tank Alto Suva	E/N	U
	E-17	6	1,125							
	Y-1	6	1,079	6,000	Chlorine +pressure filtrate	8	247	60 in Tibitóc main line	E/N	V
	Y-2	6	680							
	Y-3	6	472							
	Y-4	6	1,318	10,000	Chlorine +pressure filter	12	219	60 in Tibitóc main line	E/N	W
	Y-5	6	1,165							
	Y-6	6	828							
	Y-7	6	522							
	Y-8	6	121							
	Y-9	6	349	4,000	Chlorine +pressure filter	8	323	60 in Tibitóc main line	E/N	X
	Y-10	6	169							
	Y-11	6	814	4,000	Chlorine +pressure filter	8	315	60 in Tibitóc main line	E/N	Y
	Y-12	6	169							

Note 1) E: Point water supply, N: Network water supply

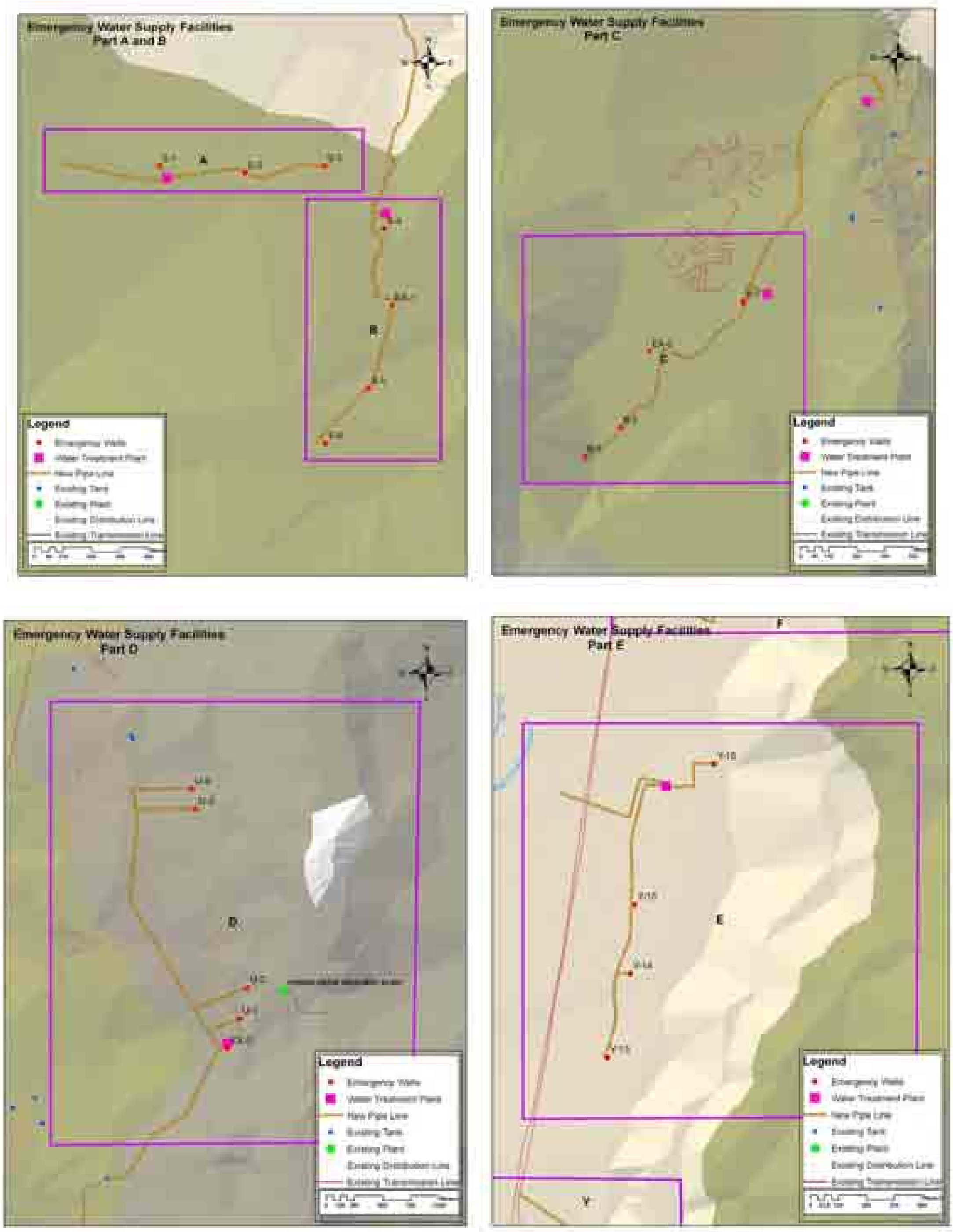
Source: JICA Study Team



Note 1) E: Point water supply, N:Network water supply

Source: JICA Study Team

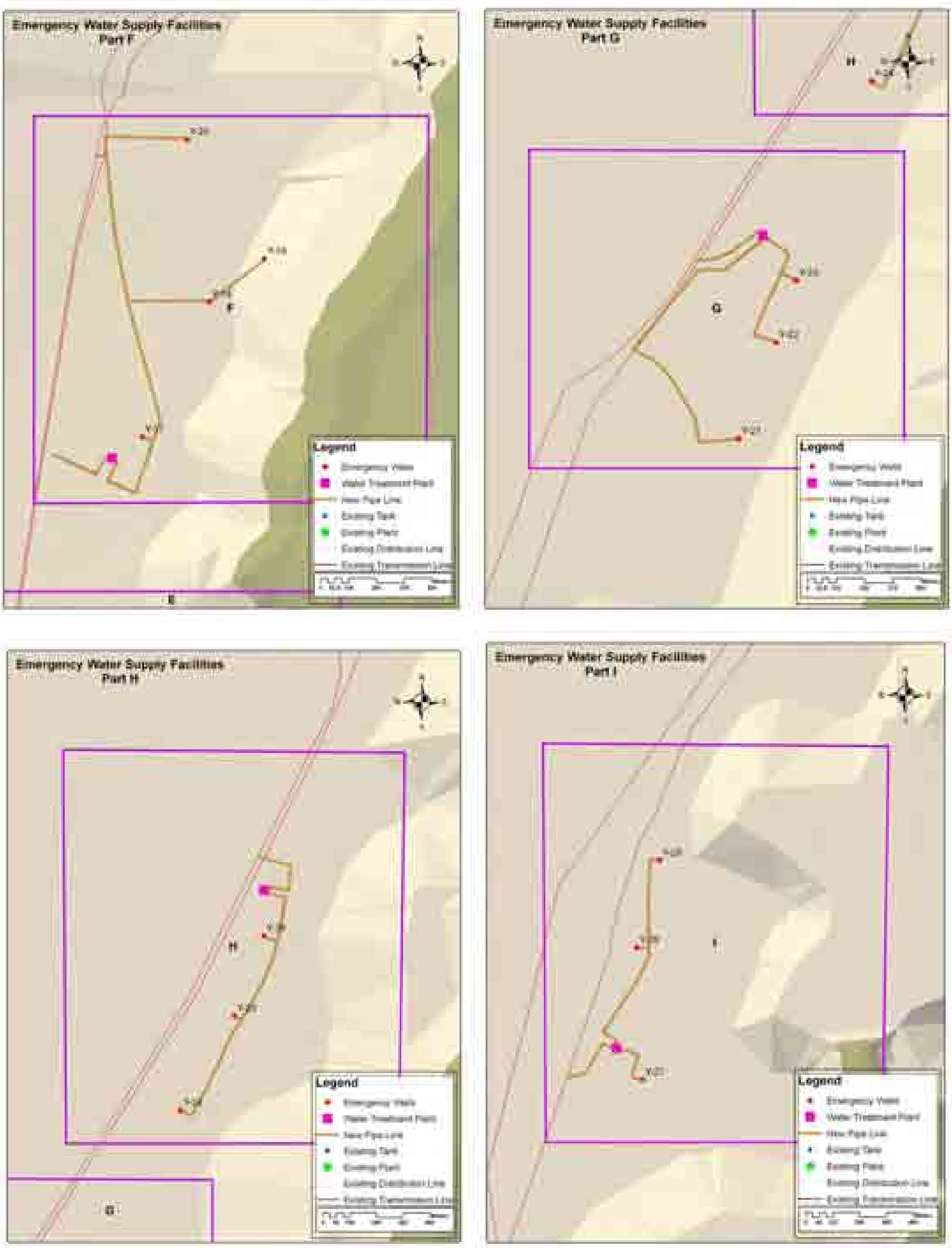
Figure-2.5- 35 Distribution of Emergency Water Supply Unit



Source: JICA Study Team

Note 1) E: Point water supply, N:Network water supply

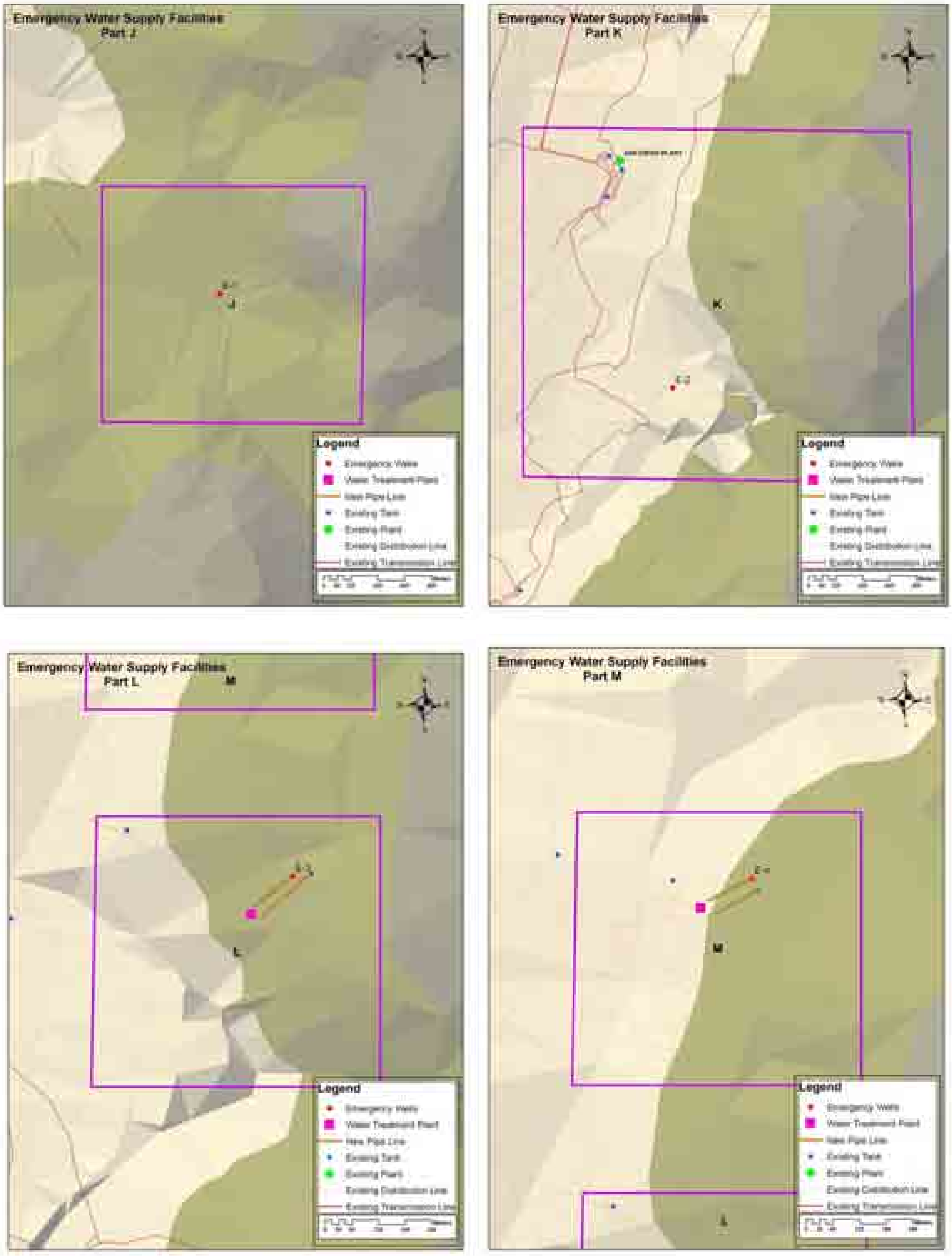
Figure-2.5- 36 Emergency Water Supply Unit (1)



Note 1) E: Point water supply, N Network water supply

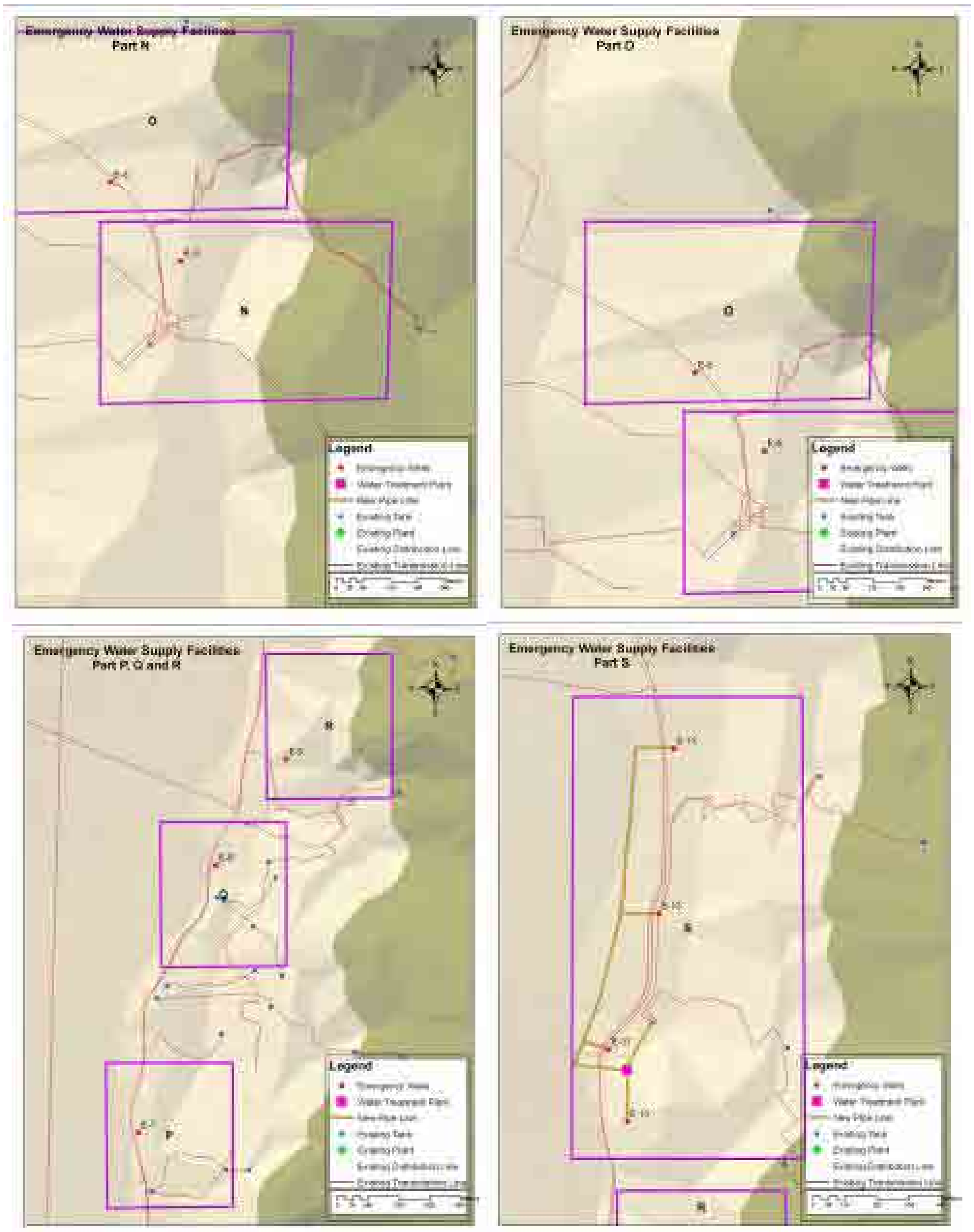
Source: JICA Study Team

Figure-2.5-36 Emergency Water Supply Unit (2)



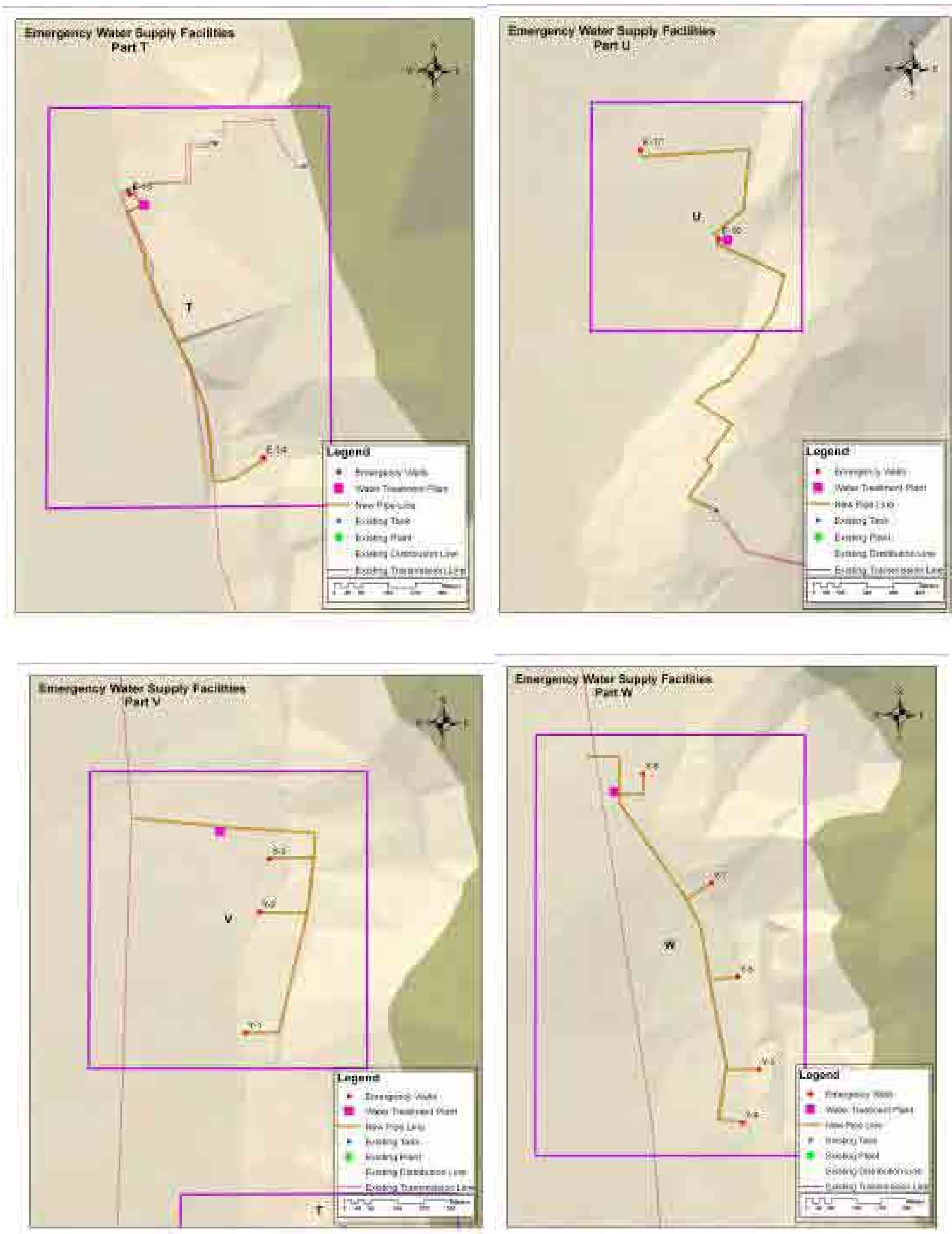
Note 1) E: Point water supply, N: Network water supply
Source: JICA Study Team

Figure-2.5-36 Emergency Water Supply Unit (3)



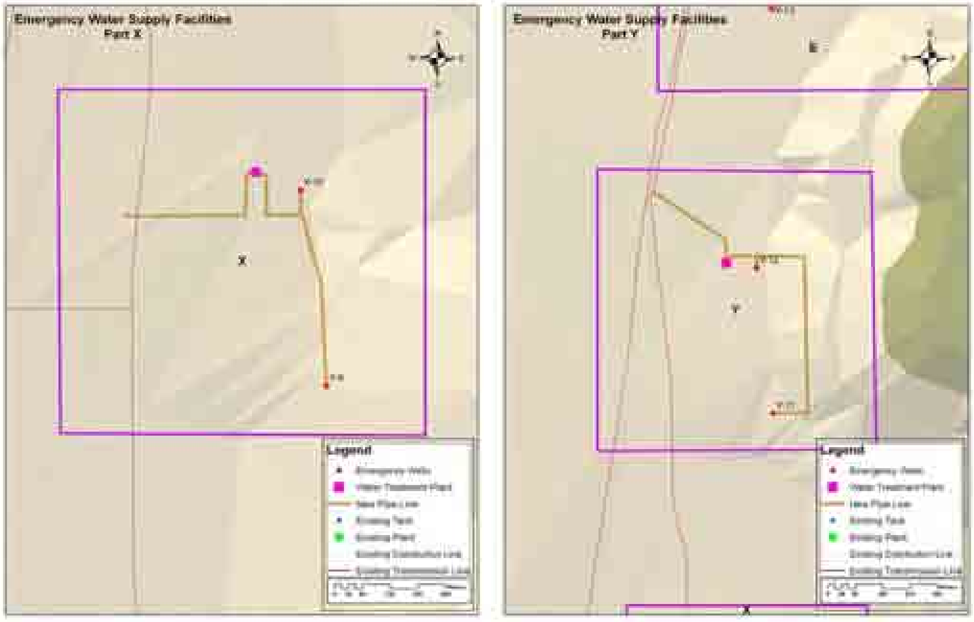
Note 1) E: Point water supply, N:Network water supply
Source: JICA Study Team

Figure-2.5-36 Emergency Water Supply Unit (4)



Note 1) E: Point water supply, N:Network water supply
Source: JICA Study Team

Figure-2.5-36 Emergency Water Supply Unit (5)



Note 1) E: Point water supply, N:Network water supply
Source: JICA Study Team

Figure-2.5-36 Emergency Water Supply Unit (6)

(4) Specification of Facilities

The principal facilities for proposed project, groundwater development, in Southern hill, Eastern Hills, and Yerba Buena Area of Bogotá are shown in Table-2.5-39.

Table-2.5- 39 Facility Design (1)

Location		Facility	Size/Specifications	Unit	Quantity
Phase-I Southern area	Soacha area	Production Well	Casing Diameter/Length 8 in/ 150 m, 6 in/ 150-300 m (including in JICA Exploratorium well, EX-1)	No.	7
		Submersible Pump	Pump size 6 in, 45 kW, H = 190m, Q=2,000 m^3/day 440V, 3 phase 4 wires, 60 Hz	No.	7
		Electric Facility	Incoming overhead line: 11.4 kV, 3 phase	m	3,850
			Step-Down Transformer: 11.4 kV – 440 V, 125 kVA	No.	9
			Diesel Engine Generator: 440 V, 125 kVA, 1,800 rpm	No.	9
		Pipeline	6 in, PVC 1.38 Mpa	m	4,129
			8 in, PVC 1.38 Mpa	m	500
			12 in, PVC 1.38 Mpa	m	3,897
		Purification Facilities	Chlorination: 2,000 m^3/day	No	7
			Chlorination + Pressure Filtration: 6,000 m^3/day	No	1
			Chlorination + Pressure Filtration: 8,000 m^3/day	No	1

Table-2.5-39 Facility Design (2)

Location		Facility	Size/Specifications	Unit	Quantity
Phase-I Southern area	Ciudad Bolívar area	Production Well	Casing Diameter/Length 8 in/150m, 6 in/ 150-300 m (including in JICA Exploratorium well, EX-2)	No.	4
		Submersible Pump	Pump size 6 in, 45 kW, H=190m, Q=2,000 m^3/day 440V, 3 phase 4 wires, 60Hz	No.	4
		Electric Facility	Incoming overhead line: 11.4 kV, 3 phase	m	700
			Step-Down Transformer: 11.4 kV-440V, 125 kVA	No.	5
			Diesel Engine Generator: 440V, 125 kVA, 1,800 rpm	No.	5
		Pipeline	6 in, PVC 1.38 Mpa	m	2,803
			8 in, PVC 1.38 Mpa	m	1,383
		Purification Facilities	Chlorination: 2,000 m^3/day	No	4
			Chlorination + Pressure Filtration: 8,000 m^3/day	No	1
	Usme area	Production Well	Casing Diameter/Length 8 in/ 150m, 6 in/ 150-300 m (including in JICA Exploratorium well, EX-3)	No.	5
		Submersible Pump	Pump size 6 in, 45 kW, H=190m, Q=2,000 m^3/day 440V, 3 phase 4 wires, 60 Hz	No.	5
		Electric Facility	Incoming overhead line: 11.4 kV, 3 phase	m	1,900
			Step-Down Transformer: 11.4 kV-440V, 125 kVA	No.	6
			Diesel Engine Generator: 440V, 125 kVA, 1,800 rpm	No.	6
		Pipeline	6 in, PVC 1.38 Mpa	m	7,368
			12 in, PVC 1.38 Mpa	m	1,688
		Purification Facilities	Chlorination: 2,000 m^3/day	No	5
			Chlorination + Pressure Filtration: 10,000 m^3/day	No	1
Phase-II Yerba Buena area		Production Well	Casing Diameter/Length 8 in/150m, 6 in/ 150-300 m	No.	17
		Submersible Pump	Pump size 6 in, 45 kW, H=190m, Q=2,000 m^3/day 440V, 3 phase 4 wires, 60 Hz	No.	17
		Electric Facility	Incoming overhead line: 11.4 kV, 3 phase	m	3,050
			Step-Down Transformer: 11.4 kV-440V, 125 kVA	No.	22
			Diesel Engine Generator: 440V, 125 kVA, 1,800 rpm	No.	22
		Pipeline	6 in, PVC 1.38 Mpa	m	12,817
			8 in, PVC 1.38 Mpa	m	860
			10 in, PVC 1.38 Mpa	m	284
			12 in, PVC 1.38 Mpa	m	591
		Purification Facilities	Chlorination: 2,000 m^3/day	No	17
			Chlorination + Pressure Filtration: 6,000 m^3/day	No	3
			Chlorination + Pressure Filtration: 8,000 m^3/day	No	2
Phase-III Eastern hill		Production Well	Casing Diameter/Length 8 in/ 150m, 6 in/ 150-300 m (including in Acueducto Exploratorium well, E-2 & E-6 and Existing well, E-1)	No.	29
		Submersible Pump	Pump size 6 in, 45 kW, H=190m, Q=2,000 m^3/day 440V, 3 phase 4 wires, 60 Hz	No.	28
		Electric Facility	Incoming overhead line: 11.4 kV, 3 phase	m	4,350
			Step-Down Transformer: 11.4 kV-440V, 125 kVA	No.	33
			Diesel Engine Generator: 440 V, 125 kVA, 1,800 rpm	No.	28
		Pipeline	6 in, PVC 1.38 Mpa	m	12,817
			8 in, PVC 1.38 Mpa	m	860
			12 in, PVC 1.38 Mpa	m	591
		Purification	Chlorination: 2,000 m^3/day	No	28
			Chlorination + Pressure Filtration: 2,000 m^3/day	No	2
			Chlorination + Pressure Filtration: 4,000 m^3/day	No	4
			Chlorination + Pressure Filtration: 6,000 m^3/day	No	1
			Chlorination + Pressure Filtration: 8,000 m^3/day	No	1
			Chlorination + Pressure Filtration: 10,000 m^3/day	No	1

Source: JICA Study Team

5.11.2. Cost Estimate

Cost of the project proposed in this Master Plan, emergency water supply by use of groundwater in Southern hill, Yerba Buena area (1st and 2nd stage) and Eastern hill, are roughly estimated as follows:

- Cost Estimate Standards: CONSTRUDATA CIELOS RASOS 124 SEPTIEMBRE NOVIEMBRE 2002, PUBLI LEGIS

- Unit Cost As of November 2007
- Exchange Rate US$ 1 = Col$2,009.81

(Reference US$ 1 =118.04 and JPY, 1 JPY=17.03 Col$)

Average of May to October 2007 (6months)

Project cost is comprised of the following items. Tax (IVA) is included in each items.

- Construction Cost: Cost of Construction of main facilities and auxiliary facilities including preparatory works and installation of equipment.

(Cost for: Materials + Equipment + Labor + Overhead)

- Land Acquisition Cost: Cost for acquisition of land required for facility construction, including compensation cost.
- Engineering Fee: Fee to be paid to consultants required for detail design, cost estimate, tendering and supervision of execution of works, is 10% of the Construction Cost
- Administration Cost: Cost for project owner to administer the project, is 1% of the cost for construction, land acquisition, and engineering fee.
- Contingency: 10% of cost for construction, land acquisition, engineering fee and administration.

The Project cost of 3 phases that was estimated under above condition is shown as follows (see Table-5.40):

Phase- Ⅰ, Southern area: 31.250 million Colombian pesos

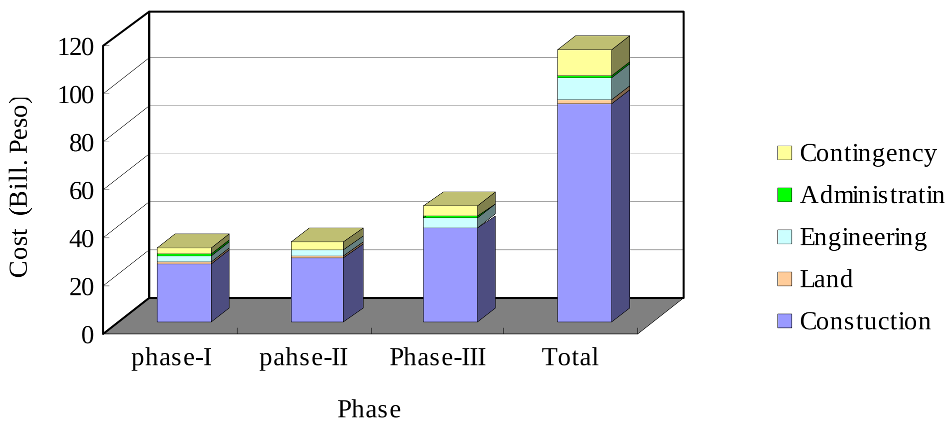
Phase- Ⅱ Yerba Buena area (first stage) 33.770 million Colombian pesos

Phase-Ⅲ Yerba Buena area (second stage) and Eastern hill 48.540 million Colombian pesos

Table-2.5- 40 Rough Cost Estimation (unit: million Col$)

Item	Phase-I Southern area	Phase-II Yerbabuena	Phase-III Eastern hill	Amount
1. Construction Cost	23.010	26.950	36.610	86.570
2. Land Acquisition	0.610	0.500	1.140	2.520
3. Engineering Fee	2.300	2.700	3.660	8.660
4. Administration cost	0.260	0.300	0.420	0.980
5. Contingency	2.620	3.050	4.210	9.880
<Total>	28.800	33.500	46.310	108.610
	14.33 million US$	16.67 million US$	23.04 million US$	54.04 million US$
	1,691 million JPY	1,967 million JPY	2,719million JPN	6,378 million JPN

Note: IVA is included in each items; unit: billion Col$; Source: JICA Study Team



Source: JICA Study Team

Figure-2.5- 37 Cost of Project

5.11.3. Cost Evaluation

We compared this project cost (2007) with 2002, see Table-2.5-41.

Table-2.5- 41 Project Cost Evaluation

Item	2002		2007		Cost Increase and %		Evaluation
	Col$ m*	US$ m	Col$ m	US$ m	Col$ m	US$ m	
1. Construction Cost	60360	22,36	86570	43,07	+26210 (+43, 4%)	+20.71 (+92, 6%)	Note-1
2. Land Acquisition	1650	0,61	2520	1,25	+870 (+52, 7%)	+0.64 (+104, 9%)	Note-2
3. Engineering Fee (10% of 1)	6040	2,24	8660	4,31	+2260 (+43, 4%)	+2.07 (+92, 4%)	Note-3
4. Administration cost (1% of 1+2+3)	670	0,25	980	0,49	+310 (+46, 3%)	+0.24 (+96, 0%)	Note-4
5. Contingency (10% of 1+2+4+4)	6710	2,49	9880	4,92	+3170 (+47, 2%)	+2.43 (+97, 6%)	Note-4
<Total>	75430	27,95	108610	54,04	+33180 (+44, 0%)	+26.06 (+93, 3%)	Note-5

Note-1: Construction cost increased (+Col$10940m) and additional buildings for the equipment (+Col$15270m).
Note-2: Increase land cost and reviewed land space for the building (+Col$870m)
Note-3: Due to above Note-1
Note-4: Due to above Note-1 and Note-2
Note-5: Construction cost increased (+Col$14060m), additional building works for the equipment (+Col$1815m) and increased land cost (+Col$ 970m). *m= million; Source: JICA Study Team.

5.12. Initial Enviromental Examination (IEE)

The Initial Environmental Examination (IEE) was conducted based on the JICA Guidelines for Environmental and Social Consideration ("JICA Guidelines"), for the proposed project, emergency water supply by use of groundwater. The IEE was carried out to assess possible adverse impacts and to recommend mitigation measures for such impacts. Screening at the IEE level was followed, by analyzing results of assessment on the impacts to be caused by the proposed projects, while taking into account the recipient country's institutional requirement for environmental impact assessment (EIA).

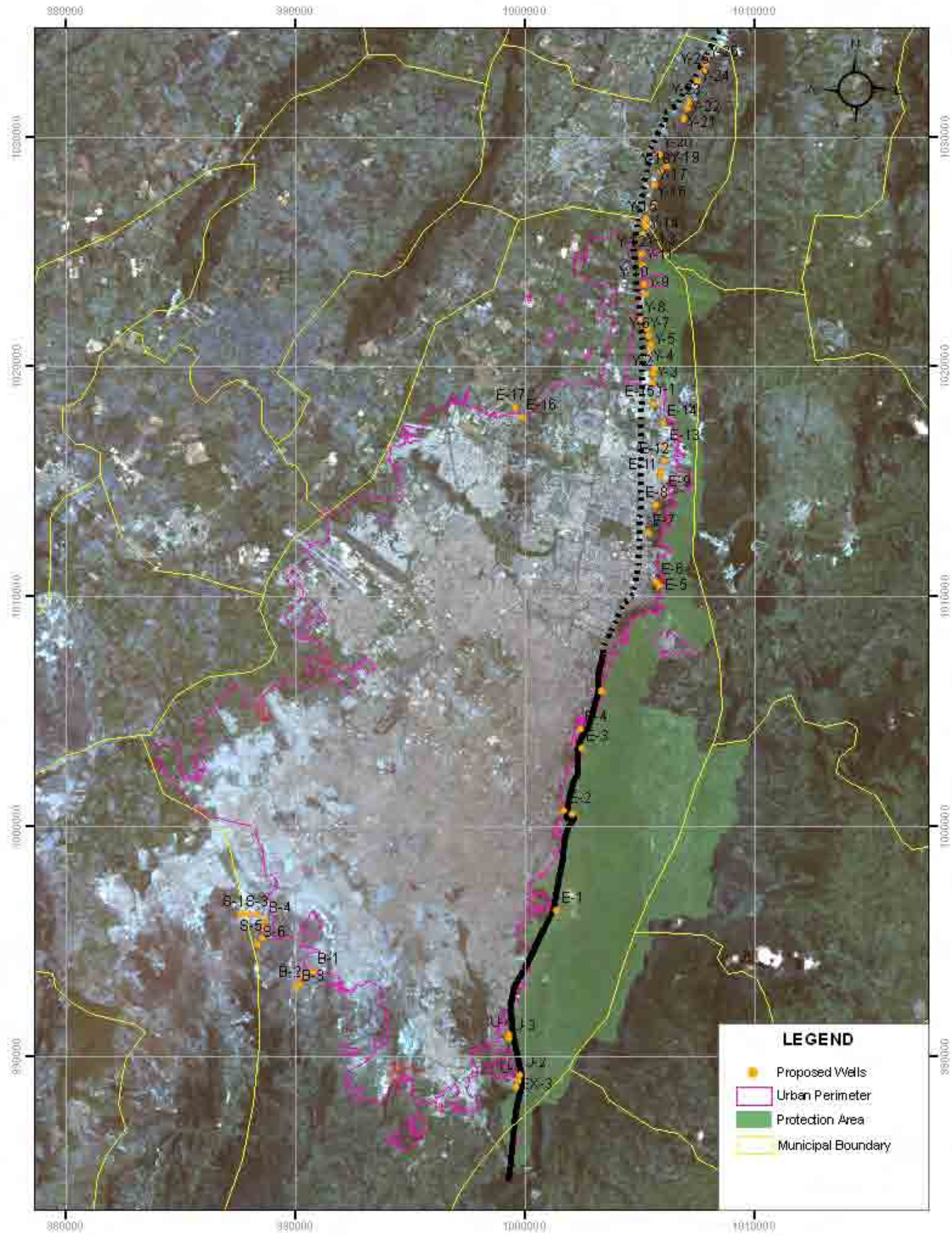
5.12.1. Condition Environmental and Social Current Inside of around the Area of the Project

The current environmental and social conditions in and around the Project sites are described in Table-2.5-42. The locations of the Project sites are shown in Figure-2.5-38.

Table-2.5- 42 Current environmental and social conditions in and around the Project sites

	Item	Project sites	
		Eastern hill area	Southern hill area
Social Environment	Local inhabitants	The Project area designated as Bogotá urban zone exhibits growing development as middle and high income housing communities. Although southern zone of the Eastern hill is a low income residential area, people in this area are regular residents. Few people live in the northern zone outside Bogotá urban area as Chía and Sopó municipality. No resettlement occurs within the Project area.	The Southern hill urban zone comprises almost entirely low income residences and commercial establishments. Some residents are not regular. However, the area under the Project is at a higher altitude than the above described area, and serves as grazing land for livestock. There are no habitations within this Project area.
	Social infrastructure	In the case of urban zone, an almost 100% rate for home-wise water supply is in effect. Likewise, there is almost a 100% sewage collection line coverage rate for the area. However, only a portion of this sewage is treated. Electrification and gasification rates are around 100%.	Although there is almost a 100% rate for water supply, there is a limit on water use due to a rapid increase in population in the area. Even if Soacha municipality is under the Project area, almost water distribution net work is not administrated by Acueducto. Electrification and gasification rates are around 100%.
	Sanitation	Water supply and sewage service is roughly 100% established. However, wastewater goes untreated. Nevertheless, there are no outbreaks of waterborne contagious disease.	Water supply and sewage service is roughly 100% established. However, wastewater goes untreated. Nevertheless, there are no outbreaks of waterborne contagious disease.
Natural Environment	Topography and geographical features	The Project area is located on the Bogotá Plain at 2,600 m elevation and in mountain and hill area at 2,600-3,000 m. The Bogotá Plain (basin) is generally soft foundation comprising an alluvial layer and Quaternary diluvial layer. The eastern hill zone comprises a Tertiary layer and Cretaceous period layer, forming steep mountainous slopes rising from the Bogotá fault as a boundary. The Project area is basically located atop the Cretaceous layer. A portion of the northern sector is Tertiary layer.	The southern hill zone is gently rolling terrain at elevation of 2,700-3,000 m. Geologically, the entire hill area is covered by a Cretaceous period layer. The Project area lies atop this layer.
	Groundwater / hydrological conditions (lake and river system)	A forest preserve (*protección forestal*) is located at an elevation of 2,700-3,000 m. The Project area is located to the inside of this preserve. In the case of Bogotá urban area, natural greenery has disappeared. Catchment area is small in the Eastern hill area, and there are no large rivers. Some intake is performed from small streams; however, this accounts for only about 1% of water supply. Although the Bogotá Plain originally comprised lake and marsh, this has disappeared as development has proceeded.	The southern hill zone is urbanized, with concentrated human settlement. Natural lake and marsh are not present. In the case of the Project area which is currently used for livestock grazing, natural forest is completely absent. Vegetation cover is pasturage planted to accommodate cattle grazing.
	Fauna, flora and biodiversity	The Project area has been urbanized, and accordingly there are no endangered/rare species in the area. Although there remains natural vegetation within the northern sector of the Project area, this is secondary forest growth.	The southern hill zone is densely populated urban area, and endangered/rare species are not present. The Project area specifically comprises grazing land for cattle and no endangered/rare species are observed.
Pollution	Complaints	None	Surface water pollution is significant. There are complaints about water supply restrictions. However in the wells located near the Tunjuelo River, it is confirmed that the pollution of the river has an influence on the groundwater quality.
	Countermeasures	None	None
Others		None	None

Source: JICA Study Team



Source: JICA Study Team

Figure-2.5- 38 Project Location Map

Figure-2.5- 39 Southern hill zone (view of southern sector)

Project area is located above urban area. Comprises grazing land for livestock and is not subject to resettlement.

Figure-2.5- 40 Southern hill zone (S-1 point)

Expansion of grazing land for livestock.

Figure-2.5- 41 Eastern hill area (view of southern zone)

Urbanization has extended up to the forest protection boundary. The Project area is located at the boundary between the forest protection line and residential area. There is no resident resettlement involved.

Figure-2.5- 42 Eastern hill zone

U-1 point in the southern sector.

Figure-2.5- 43 Eastern hill Urban zone: E-11

Figure-2.5- 44 Eastern hill Northern zone: E-40

Source: JICA Study Team

5.12.2. Environmental and Social Impact

Project scoping results are indicated in Table-2.5-43, based on field survey, in line with JICA

Guidelines of Environmental Consideration for Development Study (1994). Based on these results, the project executing entity is required to carry out appropriate measures for items described below, assuming the environmental and social impacts.

Table-2.5- 43 Scoping Check List (1)

No.	Likely Impact	Check Point	Rating	Conclusion
1.	**Social environment**			
1.1	Land acquisition / Involuntary resettlement	Whether resettlement will be necessary as a result of land acquisition / appropriation.	B	Planned Project area has been selected so as to avoid the need for resettlement. Nevertheless, there will be a need for land acquisition. The southern hill zone is grazing land and will entail no resettlement. This grazing land belongs to a single owner, which will necessitate discussions and agreement with that owner regarding either procuring or leasing the land.
1.2	Local economy	Loss in land productivity or other change in the local economic structure.	D	The Project will not lead to any loss in productivity in the project areas.
1.3	Traffic / existing public facilities	Impacts on transportation infrastructure (increased incidence of traffic jams), or impacts on schools and medical facilities.	B	The eastern hill area is residential area, and there is a certain level of traffic in the area although this is not as significant as within the urban zone. To access the southern hill zone, it is necessary to transit urban area.
1.4	Split of communities	Split-up of communities as a result of implementing the Project.	D	There will be no community splitting as a result of the Project.
1.5	Cultural heritage	Loss or degradation of cultural ruins, assets, etc., as a result of implementing the Project.	D	There are no cultural heritage sites in or around the Project areas.
1.6	Fishing rights, water rights and right of common	Infringement on existing fishing rights, water rights or right of common.	B	Existing water rights will not be infringed upon by the Project. Nevertheless, drilling permission and water right concessions must be obtained from CAR and SDA with regard to groundwater development.
1.7	Sanitation	Whether the sanitary environment will be compromised as a result of contamination, pathogens or other disease vectors generated due to Project implementation.	D	This does not apply to the Project.
1.8	Wastes	Industrial waste, excavation waste soil or other general waste products generated as the result of implementing the Project.	D	There will be no industrial waste generated under the Project. Waste soil in the course of well drilling can be disposed of by conventional means.
1.9	Hazards (risk)	Hazards, potential accidents, etc., during Project construction or post-construction operation.	D	Safety measures will be formulated during construction based on the appropriate safety manuals.

Source: JICA Study Team

Table-2.5-43 Scoping Check List (2)

No.	Likely Impact	Check Point	Rating	Conclusion
2.	**Natural environment**			
2.1	Topographical and geographical features	Subsequent changes in precious topography or geology under the Project.	D	There will be no topographical or geographical changes under the Project.
2.2	Soil erosion	Surface soil erosion due to rainfall after landscaping and forest clearing.	D	The Project area is largely urbanized, and accordingly not subject to forest clearing.
2.3	Groundwater	Impact on groundwater as a result of Project implementation.	C	Lowering of groundwater level and depletion of the aquifer may possibly be envisioned as a result of groundwater pumping
2.4	Hydrological conditions (lake and river system)	Changes in inflow and bedding to the lake and river system due to landfill or drainage as a result of Project construction.	D	There are no lakes, marshes or rivers in and around the Project areas.
2.5	Fauna, flora and biodiversity	Impact on animal and plant ecology as a result of implementing the Project.	D	The Project area is largely urbanized, and no direct effect on existing animal and plant ecology will occur.
2.7	Landscape	Impact on scenic appearance of the Project areas as a result of structure construction.	D	The Project area scenery will not be compromised by the Project.
3.	**Pollution**			
3.1	Air pollution	Air pollution as a result of gas emissions from vehicles or plants.	D	The Project will not cause air pollution. Generated dust will be contained by sprinkling.
3.2	Water pollution	Whether water quality (turbidity) will be affected by water drainage during construction works.	C	It is possible that contaminated/turbid water intrusion may occur with a lowering of the groundwater level. Also, turbid water runoff is anticipated to result from construction works. This, however, can be addressed through conventional measures.
3.3	Soil contamination	Soil contamination by dust or soil improvement agents under the Project.	D	The Project will not generate this type of soil contamination (soil improvement agents will not be used under the Project).
3.4	Noise and vibration	Noise and vibration generated by vehicles or construction equipment.	B	Because the Project area includes construction within urban zone, it is anticipated that there will be an impact in terms of noise on the immediate surrounding area.
3.5	Ground subsidence	Ground subsidence in conjunction with ground changes and drop in groundwater level.	C	Possibility of land subsidence is low because groundwater will be pumped from Cretaceous aquifer of hard rock.
3.6	Offensive odor	Generation of substances with offensive odor under the Project.	D	This does not apply under the Project.
Overall rating			B	Impact to natural and social environment will be small by the implementation of the Project, compared with the other types of large development projects. However, possibility of lowering of groundwater level and land subsidence is anticipated by pumping from 62 wells of the Project.

Rating Criteria:A: Serious impact is expected.
B: Some impact is expected.
C: Extent of impact is unknown (Examination is needed. Impact may become clear as study progress).
D: No impact is expected.
Source: JICA Study Team

(1) Social Enviroment

1) Land acquisition / involuntary resettlement

Project area of the southern hill is located in vacant (grazing) land where no resettlement is involved. Nevertheless, land acquisition is necessary because the area is private land. Accordingly, it is necessary to consult with the land owners as to purchase or lease of the land for the Project.

2) Traffic / existing public facilities

It is anticipated that there will be an impact on the traffic condition around the project site, as a result of transportation of equipment and materials for construction into the sites, well drilling works and the construction of water supply facilities, etc.

(2) Natural Enviroment

1) Lowering of Groundwater Level

Pumping of groundwater from wells will cause a lowering of the groundwater level of the aquifers.

2) Land Subsidence

There is possibility of land subsidence by over pumping. The mechanism of land subsidence by groundwater pumping under the Project should be clarified.

3) Noise and Vibration

Noise and vibration is anticipated under almost every type of projects, and can be dealt with by conventional measures. Also, because the size of facilities under the Project is small, there is flexibility in positioning of the facility to mitigate the impact.

5.12.3. Compliance with Laws, Standard and Plans of Colombian Goverment and Categorization

(1) Compliance with Laws, Standard and Plans of Colombian Goverment

Projects must comply with lows, ordinance and standards relating to environmental and social considerations established by the governments that have jurisdiction over the project site (including both national and local governments), conclusion of which is as follow:

Groundwater development does not require the issuance of an environmental license or permission as stipulated under MAVDAT (2005 government order 1220). Also, it is not necessary to draft an Environmental Impact Assessment report (EIA). Authorization required in the case of groundwater development comprises a concession (water right) for constant water pumping in the case of a production well, and permission to carry out groundwater survey.

The necessary permission and concession will be issued by SDA if the Project area is within the Bogotá urban area (stipulated by POT), and issued by CAR if the Project area is outside the above area. Necessary documentations in the environmental and social considerations are as follows:

i) Environmental Management Plan (Prevention Plan, Mitigation Plan, Improvement Plan, Compensation Plan for the Impacts).

ii) Contingency Plan (Risk analysis).

iii) Monitoring Plan.

Furthermore, CAR authorization is required where Project area is located within forest protection area (*Proteccion Forestal*). However, there is little possibility that development project is allowed within the forest protection area.

(2) Categorization

The Project will have relatively minor environmental impacts compared to large scale development projects. The proposed projects are categorized Category "B", which means that they may not cause significant adverse impact (= JICA Category "A") on the surrounding environment and society. Nevertheless, drilling of 62 new wells is expected to give some impact on both lowering of the groundwater level and land subsidence. On the other hand, according to the relevant regulation of the Government of Colombia, the groundwater development project proposed in this Master Plan is not required Environmental license and Environmental Impact Assessment (EIA), since it does not cause significant adverse impact on surrounding environment. Therefore, the proposed project is finally estimated as JICA Category "B". However, a detailed analysis of lowering of groundwater level and land subsidence may be necessary at the Feasibility Study stage.

5.12.4. Recommended Mitigation Measures

The mitigation measure for the anticipated adverse impacts, by the implementation of the proposed projects, are recommended as listed below.

(1) Social Enviroment

1) Land Acquisition

Public land should be used as much as possible for the Project. Nevertheless, in cases where Project area lies on private land, the Project executing agency will need to negotiate with land owner and take procedures to acquire the land. If compensation is required, a consensus with the land owner must be reached.

2) Water rights and right of entry

Applications for drilling permission and water right concessions must be made to SDA in the case of the Project area within the Bogotá urban area, and to CAR in the case of the Project areas outside the Bogotá urban area. Necessary documentation for the application is as follows:

- Property registration, letter of agreement and location map for land acquisition.
- Document of geological survey.
- Project plan and location map.
- Construction cost estimate.
- Study and approval by technical missions from CAR and SDA.

Necessary documents in the environmental and social considerations are as follows (including the Project Plan above):

i) Environmental Management Plan (Prevention Plan, Mitigation Plan, Improvement Plan, Compensation Plan for the Impacts).

ii) Contingency Plan (Risk analysis).

iii) Monitoring Plan.

3) Transportation and Daily Living Infraestructure

It is anticipated that there will be an impact on the traffic condition around the project site, as a result of transportation of equipment and materials for construction into the sites, well drilling works and the construction of water supply facilities, etc. Consequently, it will be necessary to have people controlling traffic during the project's execution. Additionally it is necessary to take the appropriate security measures during the period of construction works according to the safety manuals.

Se anticipa un impacto en el flujo vehicular dentro del área alrededor del proyecto, debido al transporte a los sitios de perforación de equipos de construcción, materiales, trabajos de perforación de pozos, construcción de instalaciones de abastecimiento de agua, etc. Por consiguiente, será necesario tener personal de control del tráfico durante la ejecución del Proyecto. Adicionalmente, se deben tomar las medidas de seguridad correspondientes durante el periodo de construcción con base en los manuales de seguridad.

(2) Natural Environment

1) Lowering of Groundwater Level

Currently groundwater is pumped mainly from Quaternary aquifer. However, proposed project is planned to pump groundwater from Cretaceous aquifer. According to groundwater simulation of this Study, lowering of groundwater level of Quaternary aquifer by pumping from Cretaceous aquifer is very small and practically negligible. This prediction is concluded from the assumption that groundwater use is limited for only emergency water supply. This prediction should be examined further to improve its accuracy. At the same time, monitoring plan should be proposed. Continuous observation of the groundwater level by the monitoring should be fed back to operation of the Project.

2) Land Subsidence

Land subsidence will occur by lowering of groundwater level. It is in Quaternary formation that land subsidence will occur. According to analysis of land subsidence of this Study, amount of land subsidence by pumping of the proposed project is predicted small and practically negligible. As well as lowering of groundwater level, accuracy of prediction of land subsidence should be improved and monitoring plan should be proposed.

5.13. Project Evaluation

5.13.1. Economic Evaluation

The objective of groundwater development is to secure and supply water in emergencies caused by the natural disasters especially in the Chingaza areas. However, economic evaluation for emergency is hardly worked out in monetary terms. Accordingly, the evaluation is carried out in this Master Plan from the viewpoint of comparative advantages that groundwater development has.

The followings can be judged the advantages of the groundwater development.

- Diversification of risks.
- Lower development cost.
- Well location closer to demand area.
- Postponement of investment for foreseeable shortage of water in 2022.

(1) Diversification of Risks

Development of fifty nine (59) wells is suggested for the emergency water supply in this Master Plan. In addition, three (3) JICA exploratory wells are to be utilized also for the emergency water supply. In total, sixty two (62) wells can be utilized in emergencies. The production amount of 62 wells is planned 124,000 m^3/day (1.435 m^3/s) as presented in Table-2.5-44.

Table-2.5- 44 Planned Production Amount

Area	District and Municipality	Supply Method in Emergency Case	Number of Wells			Production (m^3/day)
			Development	Exploratory	Total	
Eastern Hill	Bogotá D.C.	Point	6	-	6	12,000
		Point & Network	11	-	11	22,000
		Total	17	-	17	34,000
Yerba Buena	Bogotá D.C.	Point & Network	12	-	12	24,000
	Chía M.	Point & Network	9	-	9	18,000
	Sopó M.	Point & Network	8	-	8	16,000
	Total		29	-	29	58,000
Usme	Bogotá D.C.	Point & Network	4	1	5	10,000
C. Bolivar	Bogotá D.C.	Point & Network	3	1	4	8,000
Soacha	Soacha M.	Point & Network	6	1	7	14,000
Total			59	3	62	124,000

Note: Point & Network: Point water supply is also possible as well as network water supply.
Source: JICA Study Team.

Acueducto relies heavily on the Chingaza water conveyance system. The natural disasters may damage this conveyance system. The development of groundwater shall diversify the risks against the disasters.

At present, the production capacity of the Weisner plant is 13.5 m^3/s. Accordingly, the groundwater development shall diversify the risks *arithmetically by 10.6%* (=1.435 /13.5).

(2) Lower Development Cost

Groundwater development cost is studied in Chapter 5.7 and estimated at Col$ 108.6 billion that is equivalent to US$ 54.0 million: unit cost is US$ 37.7 million/m^3/s.

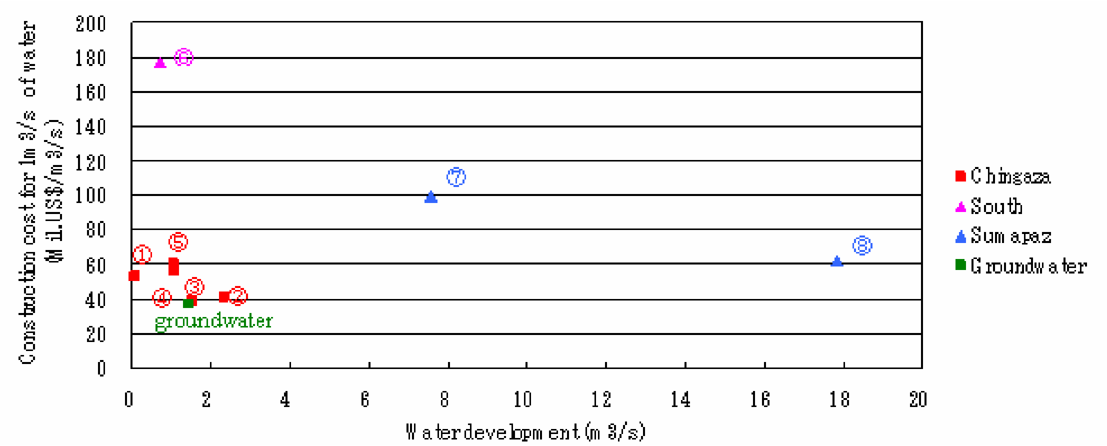
Meanwhile, Acueducto has planned eight (8) water supply expansion projects in the "*Plan de Expansión de Abastecimiento de Agua*, 2005". These projects are to develop 32.23 m^3/s of surface water as shown in Table-2.5-45. Total investment cost amounts to US$ 2,277 million: average unit cost is US$ 70.6 million/m^3/s.

Table-2.5- 45 Water Supply Expansion Plan

Expansion Projects	Investment Cost (Million US$)	Flow to be secured (m^3/s)
1. Over flow of Chuza dam	5.30	0.10
2. Chuza north water channel, Stage 1-2	96.46	2.33
3. Chuza north water channel, Stage-3	61.77	1.57
4. Playa dam	59.11	1.05
5. Southeast Chingaza water channel	65.19	1.08
6. Regadera dam II	123.60	0.70
7. Sumapaz upper-stream water channel	756.45	7.58
8. Sumapaz middle-stream water channel	1,109.26	17.82
Total	2,277.14	32.23
Average Investment Cost	70.6 million US$/m^3	

Source: JICA Study Team based on the "Plan de Expansión de Abastecimiento de Agua" (Acueducto).

In terms of development cost per m^3/s, the groundwater is obviously *evaluated lower by US$ 32.9 million* than surface water in Bogotá D.C. Relation between amount of development (m^3/s) and development cost per m^3/second is shown in Figure-2.5-45.



Source: JICA Study Team

Figure-2.5- 45 Water Development and Cost for 1 m^3/s

(3) Well Location Closer to Demand Area

In a few days immediately after disasters, the point water supply predominates among others for measures to sustain human life. Development of 62 wells is planned near the residential areas, which enables to make a quick delivery and distribution of water to citizens. This quick delivery *reduces the transportation costs as well as saving the time*.

(4) Postpone of Investment for Foreseeable Shortage of Water 2022

According to the "*Plan de Expansión de Abastecimiento de Agua, Acueducto, 2005*", water demand will exceed water right (18.8 m^3/s) in 2022, water potential (22.12 m^3/s) in 2033 and capacity of facilities (25 m^3/s) in 2042.

The production amount of 62 wells is planned 1.435 m^3/s as presented in Table-5.44. This enables to postpone the implementation of expansion plan *for 3 years* when taking into consideration the usual utilization of groundwater as well as utilization in emergencies.

5.13.2. Financial Analysis

(1) Actual Financial Condition of Acueducto

It should be noted that Acueducto acquired a high credit rate of "AA^{+}" from credit rating company (Duffs & Phelps de Colombia) for the corporate bond issued in 2002-2004. Moreover, BRC Investors Services rated another corporate bond at "AAA" that was issued to securitize loans from WB and domestic banks in October 2006 (see *4)* of this chapter).

1) Profitability

"Profit and Loss Statement" of Acueducto from FY 2003 to 2006 is presented in Table-2.5-46. The table clearly indicates that Acueducto has performed excellent operation results every year.

- Net income of Acueducto has grown every year in line with the operational revenue increase. The ratio of net income to operational revenue of FY 2006 recorded a remarkable high level of 18.7% (see VI-2 of Table-2.5-46).
- Interest coverage ratio of Acueducto is 3.4 on average over the period of 4 years from 2003 to 2006. It is obvious that Acueducto has earned enough operational income to cover the interest payment.

Table-2.5- 46 Profit and Loss Statement (million Col$)

Account Items		2003	2004	2005	2006	For Ref.: Sept./2007
I. Operation	1. Revenue	858,980	892,875	969,885	987,449	814,942
	2. Expenditure	759,686	766,317	843,618	728,448	618,346
	3. Op. Income	99,294	126,558	126,267	259,001	196,596
II. Non-operation	1. Revenue	221,808	198,856	259,864	190,238	111,126
	2. Expenditure	240,987	151,182	158,262	172,616	198,792
	3. (interest)	(73,029)	(71,747)	(80,168)	(73,445)	(34,694)
	4. Non-op. Income	-19,180	47,674	101,602	17,622	-87,666
III. Income before Tax		80,114	174,232	227,869	276,623	108,930
IV. Income Tax 1)		25,361	53,802	73,303	92,035	-
V. Net Income		54,753	120,430	154,566	184,588	-
VI. Ratio						
1. Op. Income/Op. Revenue (=I.3÷I.1)		11.6%	14.2%	13.0%	26.2%	24.1%
2. Net Income/Op. Revenue (=V÷I.1)		6.4%	13.5%	15.9%	18.7%	-
3. Interest Coverage Ratio 2)		2.8	3.0	3.1	4.7	

Note: 1) Income tax that was presented in the operational expenditure of the Statement is exposed separately in IV by the Study Team according to the international standards. 2) Interest coverage ratio = (Operational Income + Interest Received) + Interest Paid.

Source: Acueducto (Financial Department).

2) Financial Safety and Stability

"Balance Sheet" of Acueducto from FY 2003 to September 2007 is presented in Table-2.5-46. The table reveals continuous financial safety and soundness of Acueducto.

- Current ratio means short-term safety and is required in general at 120-140%. Current ratio of Acueducto indicates 242-522% that means Acueducto retains sufficiently cashable assets against short-term due.
- Operational fixed assets such as land, equipment, machinery, vehicles and buildings are necessary to run the business for long term. So, the acquisition of such fixed assets generally requires long-term funds as well. Fixed ratio of Acueducto indicates 84-92% that means all fixed assets for operation have been acquired by utilizing long-term funds.

- Equity ratio to assets indicates a high level of 55-58% that means more than half of assets have been acquired with its own funds.

3) Cash Flow

Cash flow projection of Acueducto is presented in Table-2.5-47. The table represents that operation activities generates positive net cash flow and helps a good cash flow balance every year.

- Net cash flow of the operation activities continues to grow.
- Total of net cash flow from the operation and investment activities turns positive in 2010.
- Net cash flow of the year turns positive in 2011.
- Net cash flow of the financial activities turns positive in 2014 due to decrease of debt.

Table-2.5- 47 Balance Sheet (billion Col$)

Assets							Liabilities and Equity					
Items		'03	'04	'05	'06	'07	Items	'03	'04	'05	'06	'07
Current Assets		694	899	1,097	1,211	1,344	Current	287	205	229	232	465
Fixed Assets	Land	150	163	187	200	223	Fixed	2,170	2,360	2,508	2,502	2,615
	Depreciable	2,854	2,931	3,062	3,178	3,403	Total Liabilities	2,457	2,565	2,737	2,734	3,080
	Others	1,750	1,766	1,744	1,844	1,945	Equity	2,991	3,194	3,353	3,699	3,835
	Total	4,754	4,860	4,993	5,222	5,571						
Total		5,448	5,759	6,090	6,433	6,915	Total	5,448	5,759	6,090	6,433	6,915
Ratio												
1. Equity/Assts		55%	55%	55%	58%	55%						
2. Fixed Ratio 1)		92%	88%	85%	84%	86%						
3. Current Ratio 2)		242%	439%	479%	522%	289%						

Note: 1) Fixed Ratio=Fixed Assets (Land + Depreciable Assets)÷(Fixed Liabilities + Equity), 2) Current Ratio=Current Assets ÷ Current Liabilities.

Source: Acueducto (Financial Department).

Table-2.5- 48 Cash Flow Projection (billion Col$)

Items	Source of Cash Flow	Forecast			Projection		
		2007	2008	2010	2011	2014	2017
Net Cash Flow	1. Operation Activities	362	332	548	596	641	727
	2. Investment Activities	555	677	524	453	547	493
	3. = 1-2	-193	-345	**24**	143	94	234
	4. Financial Activities	152	123	-49	-49	**16**	94
	5. of the Year	-41	-222	-25	**94**	110	328
Previous Year Balance		549	446	112	87	408	1,090
Final Balance of the Year		508	224	87	181	518	1,418

Source: "Plan Financiero Plurianual 2008-2017" of Acueducto.

4) Financial Cost Cut by Securitization

Furthermore Acueducto has challenged the measures to reduce cost in spite of good earning. With regard to this, Acueducto launched Col$ 250 billion of corporate bond in October 2006. The objective is to reduce the interest payment and exposure of foreign exchange risks by repaying in advance the outstanding loan from domestic bank and World Bank. As a result, the interest rate has fallen from 12.3% to 9.8% at initial stage. The following box is summary of this launch.

First Launch of "Titularización de Acueducto de Bogotá"
1. Issue Amount: Col$ 250 billion in October 2006.
2. Term of Securities and Issue Amount.

1) 10 years: Col$ 100 billion.
2) 11 years: Col$ 50 billion.
3) 12 years: Col$ 100 billion.

4.Interest Rate: CPI (consumer price index) + spread (4.95%, 5.09% and 4.94% respectively), payable every 3 months.
5. Credit Rate: AAA (priority provision from operational revenue as a guarantee).

(2) Financial Evaluation of Project

1) Development Cost

Groundwater development cost is studied in Chapter 5.11 and estimated at Col$ 108,610 million in 3 years as shown in Table-2.5-49. Average annual development cost is Col$ 36,200 million.

Table-2.5- 49 Development Cost by Year (million Col$)

Area	Development of Wells	Phase-1	Phase-2	Phase-3	Total
		2011	2012	2013	
Usme, C. Bolivar and Soacha	13	28,800	-	-	28,800
Yerbabuena	17	-	33,500	-	33,500
Eastern Hill	12	-	-	46,310	46,310
	11	-	-		
Total	53	28,800	33,500	46,310	108,610

Source: JICA Study Team.

<Reference: Investment Plan of Acueducto>

According to the "*Plan Financiero Plurianual 2008-2017*" of Acueducto in October 2007, Col$ 5,000,000 million of investment is planned over the 10 years. Annual investment amounts to Col$ 500,000 million on average. Annual groundwater development cost of Col$ 36,200 million represents 7.2% of it.

2) Funding

The development cost is assumed to be funded by domestic bank with following condition.

- Term of Loan: 12 years.
- Grace Period: 3 years.
- Interest Rate: 12%.

This loan condition is considered rather conservative compared to actual loan condition of Acueducto. Weighted average interest rate would be 3.7% if 80% of above construction cost could be funded by the international donor's soft loan (assumed to be Japanese ODA Loan: 1.4% of interest rate, 25 years of loan term).

3) Ability of Debt Payment

The Debt payment (repayment of loan and payment of interest) of the above loan is presented in Table-2.5-50. The table shows that the annual maximum payment is Col$ 23,900 million and Col$ 17,800 million on annual average. This payment represents only 8.2% of Col$ 216,000 million of actual debt payment of Acueducto in 2006.

Table-2.5- 50 Debt Payment (million Col$)

Items	Loan Amount	Loan Condition（Assumption）			Debt Payment of Year	
		Interest Rate	Loan Term	Grace Period	Maximum	Average
Domestic Bank Loan	109,000	12.0%	12 years	3 years	23,900	17,700
Reference: Current Outstanding Loan（year 2006）		Repayment: 136,000 (Excluding 250,000 of advance repayment)	Interest paid: 86,000		-	216,000

Source: JICA Study Team.

Acueducto considers affording the debt judging from the sufficient level of cash flow balance and high level of "ability to pay" as presented in Table-2.5-51.

Table-2.5- 51 Ability to Pay (million Col$)

Items	Forecast	Projection				
	2007	2008	2010	2011	2014	2017
a. Final Balance of Cash Flow of the Year (Ref: Table-5.47)	508,000	224,000	87,000	181,000	518,000	1,418,000
b. Debt Payment	-	-	-	-	13,000	23,900
c. Ability to Pay = a/b	-	-	-	-	**40 times**	**59 times**

Source: JICA Study Team.

4) Profitability Analysis

Profit and Loss projection of Acueducto is presented in Table-2.5-52. Operation revenue grows every year. Net income results in positive also every year.

The table indicates that incremental cost including interest and depreciation by the groundwater development is Col$ 19 billion in 2014 and Col$ 18 billion in 2017. It is obvious that these costs are very small and do not affect seriously the projected profit of Acueducto.

Table-2.5- 52 Profit & Loss Projection (billion Col$)

Items		Forecast	Projection				
		2007	2008	2010	2011	2014	2017
Operation	Revenue	1,064	1,113	1,213	1,269	1,474	1,700
	Income	199	262	250	285	368	550
Others	Income	-111	-17	-39	-30	44	131
Income before Tax		88	245	211	255	412	681
Tax		0	0	13	52	82	170
Net Income		88	245	198	203	330	511
EBITDA		462	513	565	597	720	960
Incremental cost by groundwater development							
1. Interest		-	-	-	-	13	12
2. Depreciation		-	-	-	-	6	6
3. Total		-	-	-	-	19	18

Note: EBTDA=Earning before Interest, Tax, Depreciation and Amortization.
Source: "Plan Financiero Plurianual 200-2017" of Acueducto.

5) Investment Cost Recovery

The groundwater development project aims principally at the emergency supply but not the expansion of consumers. So Acueducto cannot generate the additional operational income from this project and recover the development cost theoretically during the period when the water supply capacity surpasses the water demand.

Meanwhile, in terms of water tariff, Acueducto could recover the development cost if incorporating it into the tariff according to the following existing formula, although the tariff change largely depends on the top management decision.

<u>Formula of establish tariff</u>
Tariff = Fixed Tariff + Tariff by Consumption
1) Fixed Tariff: CMA
2) Tariff by consumption: CMO + CMI + CMT
Note: CMA: average cost of administration, CMO: average cost of operation, CMI: investment cost, CMT: average cost of environmental duties

5.13.3. Social Evaluation

The project is expected to generate several social benefits to the project areas as follows.

(1) Increase of Served Population in Emergencies

Two methods of water supply in emergencies are considered in this Master Plan: one is point water supply and another is network water supply. Among 62 wells, 6 wells are exclusively for point water supply, while 56 wells are designed as both point supply and network supply. The served population by both methods is estimated respectively as below (see Table-2.5-53);

- 8,300,000 inhabitants can be served by the exclusive use of point supply: this is the same level of estimated population of 2011.
- 706,000 inhabitants can be served by the exclusive use of network supply: this corresponds to 10% of 2007 population and 7% of 2020 population.

Table-2.5- 53 Possible Served Population

Supply Method	Production (m^3/day)	Water Loss Rate 1)	Consumption (m^3/day)	Unit Consumption Rate (liter/day/person)	Possible Served Population
Exclusive Use of Point Supply	124,000	-	124,000	15 2)	8,300,000
Exclusive Use of Network Supply	112,000	37%	70,600	100 3)	706,000

Note: 1) Water loss rate: actual data of first 6 months in 2006, 2) 15 liter/day/person: target rate of point supply of Acueducto, 3) 100 liter/day/person: estimated average consumption rate of year 2006.

Source: JICA Study Team.

(2) Water Supply to Forest Fire Fighting

Forest fires occur at eastern and southern hills every year especially during the dry season from January to February. Firehouse of Bogotá City fights the fires. The project plans to construct tanks and distribution pipes which enable to take water for firefighting operation.

(3) Increase of Employment Opportunity

In implementation of the project, the construction works would offer a new labor opportunity to the people unemployed and under-employed of the region for construction sector itself and the related sectors. And, the consumption by the workers would stimulate the business activities of the region. Thus, this increased consumption by new workers will induce a multiplied economic effect to the region, which activates the regional economy as a whole.

CHAPTER 6 RECOMMENDATIONS

- Water Supply Master Plan of Acueducto was reviewed in this Study. It was made clear that there is vulnerability in water supply in case of emergency. To overcome this vulnerability, many projects for emergency water supply were examined and proposed. Based on examination above, Master Plan for emergency water supply by use of groundwater was finally proposed.
- In this Master Plan, groundwater development in the Easter and Southern Hills of Bogotá, and emergency water supply by use of above groundwater was proposed. In this Mater Plan, promising aquifer to be developed, type f facilities and optimum location of them project cost and operation/maintenance methods were proposed. Following the project design, project evaluation was done in economy, financial, social and environmental aspects. Proposed projects were finally justified by the evaluation.
- Three (3) projects for emergency water supply were proposed in the Master Plan. Each of three projects has urgent, necessary and unique advantages. On the other hand, 3 projects have strong relation with each other. Moreover, these projects were judged to be affordable enough for Acueducto to implement it in financial aspect.
- Implementation of Feasibility Study is necessary to get further information for more detail design of the projects, which will be used to judge whether proposed projects are feasible or not.
- Several options for emergency water supply should be prepared. The proposed projects, emergency water supply by use of groundwater, are one of them, which have unique and different advantages from the other options. By employing every option for emergency water supply, damage by natural disaster, to water supply for Bogotá city and the surrounding area, will be mitigated.