DRAFT

URBAN ENVIRONMENTS AND WATER SUPPLY IN LATIN AMERICA

Danilo Anton

Montevideo, April 1990

TABLE OF CONTENTS

URBAN ENVIRONMENTS AND WATER SUPPLY IN LATIN AMERICA

Chapter 1 INTRODUCTION

One of the main characteristics of the recent historical and geographical evolution of Latin America and the Caribbean (*) has been the fast processes of urbanization in most densely populated regions of the continent, which is increasing at the fast rate of 3.6% per year (Bartone, Carl R.; 1990).

By the end of the eighties, there are more than 280 cities with a population in excess of 100.000 inhabitants, with a total of around 210 M.; this figure represents approximately 46% of the region's population. Of these cities, about 70 exceed 0.5 M with a total of 160 M. people (35% of the total population).

The extreme cases of concentration can be observed in the 13 largest urban centers of the continent with population in excess of 3 M. inhabitants (see Table 1). The total population of these megalopolis is of 105 M. people (23% of the Latin American total).

The observation of the demographic statistics (see Table 1) shows that this sector of the population (the urban sector that lives in large cities) has experienced the largest growth of all, and the data from the last years do not leave too much hope for any immediate reversal of the present trends.

If this level of growth continues, it can be estimated that by the year 2020, Latin America will have more than 540M. inhabitants in cities with more than 100.000 (over a total of around 762 M.).

The overconcentration has reached alarming levels in the three macro-cities of the continent: Ciudad de Mexico (21.2 M.), Sao Paulo (18.8 M.) and Buenos Aires (12.2 M.), and most forecasters predict that, in the first two above mentioned cities, the population level will reach respectively the 32 M. and 26 M. mark well before the year 2010. By that time, several other cities would have reached the 10 M. figure, including Rio de Janeiro (22 M.), Lima (14-15 M.), and Bogota (10-11 M.), and many more would have exceeded the 5 M. level (Caracas, Santiago, Guadalajara, Monterrey, Belo Horizonte, Recife, Porto Alegre, Salvador, Fortaleza and Brasilia).

Undoubtly, these figures are much larger than the type of urban

---

* Throughout the text, and in order to simplify the terminology, we will use indistinctly the expressions "Latin America", "Latin America and the Caribbean" and the acronym LAC, as synonymous, including in "Latin America" also the non-latin countries of the continent (i.e. Jamaica, Guyana, Surinam, Trinidad, Belice, Bahamas and other smaller Caribbean nations/islands).

concentrations expected for the larger cities in the developed countries (whose growth is much slower). It is interesting to notice also that those figures seem to be much higher that the type of concentration expected for the largest macro-cities of the most densely populated countries in the Third World. The Popular Republic of China -with a population in excess of 1.1 B. - does not possess any city exceeding the 15 M. mark (Shanghai, the largest city in PRCh has "only" 12 M.). Sao Paulo and Mexico City are larger (population-wise), in spite of the much smaller population of their countries (14 and 9 times smaller, respectively). A similar statement applies to India, with a population of 800 M., in which the two largest cities (Calcutta: 15 M. and Bombay: 14 M.) also possesses a population considerably smaller than the two largest Latin American megalopolis.

This uncontrolled growth of Latin American urban areas is occurring simultaneously with one of the worst financial crisis of the continent's history. Practically all Latin American countries have experienced a continued increase of their foreign debt at a pace still more accelerated than the growth of their urban population. This problem is particularly acute in Brazil (foreign debt of 116.9 B.), Mexico (105.6 B.) and Argentina (56.2 B.) (*), but is also found in many more smaller countries of the continent. In some cases, the lack of resources has been such, that no payments of interests were made during a relatively long period of over a year (i.e. Peru and Argentina in 1988-89). In other countries net transfers of resources as a result of profit repatriation and debt servicing/ payment have also dried up the availability of funds in the public coffers and has seriously jeopardized the obtainment of new credits.

In summary, very little (if any) new money is available for infrastructural investments of some magnitude.

Unfortunately, this is happening when these investments are most needed to provide the required services for the booming urban population.

Perhaps one of the public services most affected by this lack of investments is the urban water supply. Historically, Latin American cities have turned to their closest sources of water, which in most cases were (originally) nearby freshwater streams, lakes or springs. Very soon, the cities exhausted or degradated these resources and were forced to invest considerable funds to build dams and/ or pipelines to store and bring water from more remote water sources. The continued growth of the cities has outdated most water supply systems and new sources need to be

---

* Data from 1988

tapped in order to provide the water required to satisfy the needs of the population. However, now the much needed funds are not available. Very few new reservoirs are being built and very few new pipelines are being installed. In fact, the expansion of the systems has been almost completely halted. That means less water per capita and this phenomenon is gradually becoming worse.

In addition, the distribution systems (originally designed for a much smaller population , and obviously for a limited duration) are becoming -not only insufficient- but also obsolete, requiring increasing repairs in the moment in which less money is available to carry them out. As a result, leakage is gradually increasing augmenting the "consumption" of the system. On top of that, breakages (and subsequent water losses) are more common with frequent falls of pressure increasing the risks of contamination of the waterlines.

Simultaneously, the old reservoirs are also "decaying". Their storage capability is gradually reduced due to silting, the basins watersheds are invaded by urban and rural dwellers, and uncontrolled industrial activities are carried out producing changes both in the hydrological regime and water quality. There are a large number of reservoirs serving the urban areas of the continent that have become useless, due to the inadequate use of their basins.

To make things still worse, the new reservoirs will be much more expensive than the old ones. In fact, the new dams normally need to be built in basins unaffected by the urban phenomena which often are further away; in some cases there is need to pump up the water from lower lying valleys (as in Mexico City); in some other cases interbasin water transfer may be needed (i.e. Lima); in practically all cases, increased distance and water conduction costs are unavoidable.

The sewerage situation is not much better. According to WHO (1987) estimates, only 41% of this urban population has access to sewerage, and more than 90 % of the wastewaters are discharged into the environment without any treatment. By the year 2000 an additional amount of about 141 millions will require these services. It is not very likely -given the financial crisis- that the LAC countries will be able to obtain, not even a significant part of the required resources to finance these badly needed investments.

Therefore, in summary, the future does not look very rosy: rapidly increasing needs with rapidly decreasing financial means and as a result, less water production of much unsafer quality.

It is obvious that the consequences of this situation can become catastrophic. Millions of people are being left out from the water distribution systems, forcing many urban communities to utilize various (often imaginative) procedures to obtain their water (which at the end will be obtained in very small volumes and of poor quality). Many more millions are becoming increasingly exposed to various types of health hazards that are certainly affecting the mortality rates in these populations.

In spite of all these apparently hopeless problems, in many cases, there are means by which water could be obtained at a much lesser cost and of a much better quality, by using the available groundwater reservoirs laying close to the urban areas.

Groundwater volumes are normally much greater than surface water ones, its vulnerability to contamination is much less and the required starting investments are only a fraction of those that are needed in order to develop analogous surface water resources.

There are large volumes of groundwater available close to many of the larger Latin American cities, which in some cases is heavily used but in many others is only marginally utilized.

The largest Latin American city (Mexico City) draws about 55 m3/sec. (80% of its consumption) from groundwater sources located underneath the urban area and from a neighboring basin. The city also obtains water from surface sources from the basin of the river Cutzamala, at a much higher cost and reducing water availability downstream for the population living in those basins. (*)

The second largest city of the continent -Sao Paulo- obtains its urban water supply from surface water resources (43 m3/ sec. form six reservoirs located in the Upper Tiete basin). However, about 1/3 of the suburban and urban population and industrial establishments draw their water from groundwater resources. It is expected that gradually, the suburban areas of the city will become increasingly dependant on groundwater for their water supply. Available volumes of groundwater in the Sao Paulo and neighboring basins are relatively large, and their utilization would require smaller investments, compared to the ones needed to expand the surface water system.

The city of Buenos Aires, capital and largest city of Argentina is located next to the huge surface water body of the river Plate estuary, and draws the bulk of its water supply (about 80 m3/sec.) from this source. However, due to the rapid expansion of the city towards the countryside, many suburban communities of the city have developed groundwater -based systems tapping a relatively shallow alluvial aquifer that underlies the urban area. The city of La Plata, (600,000 inhabitants), capital of the province of Buenos Aires and now practically a suburb of Buenos Aires, depends on groundwater for about 40% of its needs. This resource is of higher quality than the river water due to the high contamination levels of the river Plate near the shore.

---

* A more detailed description of the main environmental and water supply problems affecting the Latin American cities is given in Chapter 4.

The city of Buenos Aires ejects its effluents untreated into the river Plate estuary. It is anticipated, therefore, that groundwater use will gradually increase in the Buenos Aires-La Plata region as a result of increased contamination of surface water near the shore (and subsequent increased treatment and conduction costs). At the same time, inadequate severage systems are endangering the groundwater qualtity in many suburban areas of the metropolitan area.

The city of Lima is also heavily dependant on groundwater for its water supply. The city obtains its water from the rivers Rimac and Chillon from which about 12 m3/sec. are being utilized after treatment at La Atarjea plant. The rest of the water consumed by the city (about 9 m3/sec.) is drawn from an underlying shallow aquifer which is in turn recharged by the above mentioned rivers. Surface water utilization has become more difficult due to the increased load of suspended sediments and pollutants (including the upstream mining areas) which increase considerably the treatment costs.

On the other hand, the aquifer has been overpumped producing a widespread phenomenon of saline intrusion along the coastal zones. In addition, the recharged volumes to the groundwater reservoir have diminished due to the reduction of the irrigation areas and urban impermeabilization of the river beds. The final result has been a gradually augmenting water crisis that will require a very careful fine-tuning of the utilization of the existing water resources. It is considered that an adequate water management of these resources should include artificial recharge of relatively large volumes of surface water into the aquifer and intelligent distribution of the abstraction levels throughout the groundwater reservoir.

In addition to the above mentioned cities, there are many other urban areas in the continent which obtain part or most of its water supply from groundwater sources. This is particularly true in the Caribbean region where surface water resources are very scarce, but which instead possess excellent aquifers that are often suited for urban water supply (mainly aquifers of karstic nature). This is the case of Havana, where almost 100% of the water supply is drawn from groundwater sources, Kingston and Montego Bay in Jamaica, San Juan in Puerto Rico, Miami in Florida (which by the way can be considered in many senses a "Latin American" city), Merida and Monterrey in Mexico, Port-au Prince in Haiti and in the smaller islands of the Caribbean region (Nassau in the Bahamas, Bridgetown in Barbados among others).*

---

* List of references on these cities is included in the last section of the document.

Many other cities in volcanic areas are also well endowed to draw their water supply from groundwater sources. This is particularly true in the cities located close to thick pyroclastic and associated formations (which are often very permeable, with reduced run-off and high storage capacity) and to lava rocks (with frequent "cooling" open fractures allowing important groundwater flows). Mexico City, Managua, Guatemala, Quito and San Jose are some examples of cities with important volcanic aquifers that are used for municipal water supply. In fact, Mexico, Managua, San Jose and Guatemala actually withdraw most of their water from their groundwater reservoirs. In the case of Quito, the city satisfies about 40% of its needs from groundwater sources.

A large number of other cities depend partially or totally on alluvial valley aquifers, particularly in the Andean region. Some examples of cities using groundwater in alluvial mountain valleys are Cochabamba in Bolivia, Valencia and Maracay in Venezuela, and Queretaro and San Luis de Potosi in Mexico.

In some cases, the actual water supply is obtained from surface resources but these resources are being gradually exhausted and it is anticipated that groundwater supply will become the main source for expansion of the urban water supply systems. These are, among others, the cases of Montevideo in Uruguay, Bogota in Colombia and Recife and Salvador in Brazil.

In summary, in many Latin American and the Caribbean cities, groundwater resources are one of the principal options -if not the only one- that is available for expansion of the urban water supply system.

Often, groundwater is the only safe alternative; surface water quality is being seriously affected throughout all Latin American urban environments, practically without exception. In some cases, when stream flows are very large (cases of Asuncion, next to the Paraguay river and Manaos next to the Amazonas river), the effects of the various types of waste discharges may be small, even negligible. In some other cases, when river flows are of less volume, or waste discharges very large, surface water may be gradually deteriorated and additional/ increased treatment is required. Beyond a certain level of quality degradation, water treatment becomes very costly (and sometimes technically unfeasible) and other options need to be considered.

Alternative surface water sources are -normally- further away than the outdated ones, requiring considerable infrastructural expenditures of the order of hundreds of millions dollars (that would be the case of Lima or Mexico City, if new surface sources were to be tapped and conducted to the city site). In those cases, there is -almost always- a nearby groundwater source that could be exploited at a much lesser cost.

In many other cities, there is also a problem of quantity. Surface sources do not provide the required volumes and underground sources are the best available alternative.

Very often, even when the main sources of water supply for the urban core are surface water bodies, the utilization of groundwater can be the most economical and feasible option for some sections of the city. It is the case of Bogota, where although the surface water supply is the best solution for the northern and central neighborhoods it becomes very expensive and unpractical in some of the fast growing southern suburbs, where it could be more economically convenient to use the underlying aquifer. Although this solution has not been implemented yet, it remains as a distinct possibility repeatedly suggested by Colombian hydrogeologists.

In Buenos Aires and Sao Paulo, many of the new neighborhoods and industries, get their water from wells, because the distance to the municipal system and the density of population does not justify yet the lengthening of the municipal waterlines, or because the financial resources of the water companies are insufficient to install the connections. In all cases, when potable groundwater is easily available, there are a number of fringe communities that utilize this resource, even in cities in which surface water is abundant, cheap and of good quality (i.e. in Asuncion, Paraguay, there are many industrial establishments depending on wells, in spite of the good quality and reliability of the river water available in the core of the urban area).

The volume of people suffering these limitations is also gradually increasing, not only due to the growth of the urban population, but also as a consequence of the financial difficulties of the water companies to obtain the required funds for the expansion of the municipal water systems.

Whatever the reason, the regional trend is clear, Latin American urban water supply will depend more and more from groundwater reservoirs. Presently (1990), it can be estimated that almost 1/3 of the water consumed in Latin American cities comes from nearby aquifers. At the present and projected rate of growth of the continent groundwater abstraction, it can be anticipated that by the year 2020 up to 40% of the urban water will come from aquifers exploitation (see Table 3).

That will mean that, at that time, a volume of the order of 850 m3/sec. will need to be pumped from the ground **only** to satisfy the requirements of the urban population of the big cities. The above mentioned figure is 3 1/2 times larger than the present abstraction rates (about 260 m3/sec. for the whole urban groundwater supply for cities in excess of 100,000 people).

If the irrigation agricultural growing needs are added (present abstraction from several sources for this purpose is severalfold bigger: about 2,500 m3/sec.), one could easily comprehend the key importance that groundwater exploitation is going to have during the XXI century.

In spite of that, the Latin American continent, as a whole, is not even prepared to start dealing with the issue. In fact, the lack of awareness about this resource is -to say the least- appalling.

Firstly, very few trained hydrogeologists or groundwater engineers can be found throughout the continent. There are less than 200 formally trained hydrogeologists in the 30 countries of the Latin American and Caribbean region (of which almost half are in Brazil); one every 3 million people, one every 3,000 wells. There are not many more groundwater engineers.

Secondly, and in part as a consequence of the former, groundwater resources are very poorly understood. This lack of knowledge frequently gives place to an underutilization of the resource.

Sometimes, large amounts of money are spent in surface water supply schemes, when easily available groundwater (of good quality and at a much lesser cost) would be within the reach of the financial and technical means of the city authorities.

In other cases, the opposite happens, the aquifers are misutilized (normally overexploited) and degradated due to improper management, lack of protection of the recharge areas and overpumped. As a result, some groundwater reservoirs may become irreversibly contaminated, or processes of unwanted subsidence or saline intrusion may take place.

It was said in previous paragraphs, that groundwater is much less vulnerable to degradation than surface water. However, this may at the end become a double edged sword. In many cases, this apparent vulnerability may give a sense of false security and no protective measures may be taken when it would be required.

In fact, although groundwater has a low vulnerability to contamination (compared to surface water), with time it may become also contaminated in such a way as to render it unusable for any practical purpose.

The lack of understanding of the actual groundwater dynamics may ultimately result in the destruction of the resource. On the long term, the underground water resources can be damaged more irreversibly than the surface water bodies, because the clean-up of the hydrogeological "environmental messes" is more difficult, expensive and often impossible.

How is the continent going to cope with the need to understand the nature, dynamics and vulnerability of the groundwater systems? How is the continent going to cope with the contradiction between the growing needs, the growing environmental degradation phenomena and the lack of expertise and financial resources? The purpose of this essay will be to try to deal with these issues using the limited available information and some common sense. We certainly hope that the results will bring a little more light into the not-easily predictable future of Latin American cities during the next century.

TABLE 1 POPULATION OF THE LARGEST CITIES (*)

COUNTRIES	CITIES	POPUL. 1980	GROWTH %/YEAR 1980-1990	POPUL. 1990	GROWTH %/YEAR 1990-2000	POPUL. 2000	GROWTH %/YEAR 2000-2010	POPUL. 2010	GROWTH %/YEAR 2010-2020	POPUL. 20
ARGENTINA	Buenos Aires	10,500	1,50	12,186	1,40	14,003	1,40	16,092	1,40	18,492
	Cordoba	1,100	1,50	1,277	1,40	1,467	1,40	1,686	1,40	1,937
	Rosario	1,000	1,50	1,161	1,40	1,334	1,40	1,533	1,40	1,761
BOLIVIA	La Paz	1,000	4,00	1,480	3,50	2,088	3,00	2,806	2,50	3,592
BRAZIL	Sao Paulo	12,700	4,00	18,799	3,50	26,518	3,00	35,638	2,50	45,620
	Rio de Janeiro	9,150	3,50	12,907	3,00	17,346	2,50	22,204	2,00	27,067
	Belo Horizonte	2,580	5,00	4,203	4,50	6,526	4,00	9,661	3,50	13,627
	Recife	2,400	4,50	3,727	4,00	5,517	3,50	7,782	3,00	10,459
	Porto Alegre	2,300	4,50	3,572	4,00	5,287	3,50	7,458	3,00	10,023
	Salvador	1,800	4,50	2,795	4,00	4,138	3,50	5,837	3,00	7,844
	Fortaleza	1,600	4,50	2,485	4,00	3,678	3,50	5,188	3,00	6,973
	Curitiba	1,500	4,50	2,329	4,00	3,448	3,50	4,864	3,00	6,537
	Belem	1,020	5,00	1,661	4,50	2,580	4,00	3,819	3,50	5,388
	Brasilia	1,000	7,00	1,967	6,00	3,523	5,00	5,738	4,00	8,494
CHILE	Santiago	3,800	2,00	4,632	1,90	5,591	1,80	6,684	1,75	7,950
COLOMBIA	Bogota	3,800	4,00	5,625	3,50	7,935	3,00	10,663	2,50	13,650
	Medellin	1,500	4,00	2,220	3,50	3,132	3,00	4,209	2,50	5,388
	Cali	1,300	4,00	1,924	3,50	2,714	3,00	3,648	2.50	4,670
	Barranquilla	1,000	4,00	1,480	3,50	2,088	3,00	2,806	2.50	3,592
CUBA	Habana	1,800	2,00	2,194	1,90	2,649	1,80	3,166	1,75	3,766
DOMINICAN REP.	Santo Domingo	1,200	4,50	1,864	4,00	2,759	3,50	3,891	3,00	5,229
ECUADOR	Guayaquil	1,300	4,50	2,019	4,00	2,988	3,50	4,215	3,00	5,665
	Quito	1,000	4,00	1,480	3,50	2,088	3,00	2,806	2,50	3,592
GUATEMALA	Guatemala C.	1,400	4,00	2,072	3,70	2,980	3,30	4,123	3,10	5,595
HAITI	Port au Prince	1,000	3,00	1,344	2,80	1,771	2,60	2,290	2,40	2,903
MEXICO	Mexico City	15,000	3,50	21,159	3,20	28,993	2,80	38,214	2,50	48,917
	Guadalajara	2,500	4,00	3,701	3,50	5,220	3,30	7,222	3,00	9,706
	Monterrey	2,200	4,00	3,257	3,50	4,594	3,30	6,356	3,00	8,542
	Puebla	1,200	4,00	1,776	3,50	2,506	3,00	3,367	3,00	4,525
PERU	Lima	4,800	4,00	7,105	3,80	10,317	3,60	14,694	3,40	20,528
URUGUAY	Montevideo	1,250	1,50	1,451	1,40	1,667	1,40	1,916	1,40	2,201
VENEZUELA	Caracas	2,800	4,20	4,225	4,00	6,254	3,70	8,994	3,50	12,687
	Maracaibo	1,000	4,00	1,480	3,80	2,149	3,50	3,032	3,30	4,195
TOTAL		99,500		141,558		195,849		262,604		341,116

(*) Adapted from Statistical Abstract of Latin America, 1988; Estimates and Projections of Urban, Rural and City Populations: 1950-2025, 1985 U.N.; and several other statistical sources (see also References Section).

TABLE 2 GROUNDWATER AND SURFACE WATER CONSUMPTION

WATER CONSUMPTION IN M3/SEC

		Total water consumption groundwater + surface water				Groundwater/ surface water distribution				Groundwater production		Surface water production	
	Watcap m3/day	1990 m3/sec	2000 m3/sec	2010 m3/sec	2020 m3/sec	1990 %grwater	2020 %grwater	1990 %srwater	2020 %srwater	gw 1990 m3/sec	gw 2020 m3/sec	sw 1990 m3/sec	sw 2020 m3/sec
ARGENTINA	0.45	104.66	120.28	138.22	158.83	30	40	70	60	31.40	63.53	73.27	95.30
BAHAMAS	0.30	0.62	0.76	0.93	1.12	80	70	20	30	0.50	0.79	0.12	0.34
BARBADOS	0.30	0.38	0.46	0.55	0.65	60	50	40	50	0.23	0.32	0.15	0.32
BOLIVIA	0.20	6.26	8.83	12.11	16.11	25	35	75	65	1.57	5.64	4.70	10.47
BRAZIL	0.35	306.60	453.85	646.41	868.72	20	30	80	70	61.32	260.62	245.28	608.11
CHILE	0.40	35.90	43.77	52.83	63.15	10	15	90	85	3.59	9.47	32.31	53.67
COLOMBIA	0.25	53.66	75.70	101.73	130.22	10	20	90	80	5.37	26.04	48.30	104.18
COSTA RICA	0.30	2.76	3.71	4.84	6.14	30	50	70	50	0.83	3.07	1.93	3.07
CUBA	0.40	17.96	21.68	25.92	30.83	80	80	20	20	14.37	24.66	3.59	6.17
CURACAO	0.20	0.37	0.46	0.56	0.67	30	30	70	70	0.11	0.20	0.26	0.47
DOMINICAN REPUB.	0.30	8.28	12.02	16.63	21.92	20	30	80	70	1.66	6.58	6.62	15.35
ECUADOR	0.25	12.68	17.88	24.04	30.77	30	40	70	60	3.80	12.31	8.88	19.46
EL SALVADOR	0.20	2.36	3.29	4.51	6.18	30	40	70	60	0.71	2.47	1.65	3.71
GUATEMALA	0.20	4.84	7.17	10.01	13.46	70	80	30	20	3.39	10.76	1.45	2.69
GUYANA	0.20	0.58	0.70	0.84	0.98	40	50	60	50	0.23	0.49	0.35	0.49
HAITI	0.15	2.31	3.05	3.94	4.99	40	50	60	50	0.92	2.50	1.39	2.50
HONDURAS	0.15	1.78	2.58	3.64	4.99	30	40	70	60	0.53	1.99	1.24	2.99
JAMAICA	0.30	3.45	4.37	5.38	6.44	40	50	60	50	1.38	3.22	2.07	3.22
MARTINICA	0.30	0.36	0.45	0.54	0.66	30	30	70	70	0.11	0.20	0.25	0.46
MEXICO	0.35	170.70	252.68	356.43	479.01	60	70	40	30	102.42	335.31	68.28	143.70
NICARAGUA	0.20	2.58	3.74	5.28	7.23	90	90	10	10	2.32	6.51	0.26	0.72
PANAMA	0.30	2.42	3.18	4.15	5.27	10	15	90	85	0.24	0.79	2.17	4.48
PARAGUAY	0.30	2.07	2.89	3.92	5.17	5	10	95	90	0.10	0.52	1.97	4.66
PERU	0.25	30.91	44.88	61.49	81.05	30	40	70	60	9.27	32.42	21.63	48.63
PUERTO RICO	0.40	5.52	6.41	7.36	8.38	50	50	50	50	2.76	4.19	2.76	4.19
SURINAM	0.20	0.37	0.46	0.56	0.67	40	40	60	60	0.15	0.27	0.22	0.40
TRINIDAD AND TOB.	0.25	1.01	1.23	1.47	1.72	10	20	90	80	0.10	0.34	0.91	1.37
URUGUAY	0.35	5.84	6.71	7.71	8.86	10	20	90	80	0.58	1.77	5.25	7.09
VENEZUELA	0.40	45.72	67.68	95.01	127.69	20	25	80	75	9.14	31.92	36.58	95.77
		832.94	1170.86	1597.01	2091.85					259.10	848.93	573.84	1242.96

Chapter 2 THE ENVIRONMENT

2.1 Environmental settings

The larger Latin American cities are located in a wide array of environmental settings. As we can expect from the considerable geographic heterogeneity of the continent, the reliefs of the region show large variety of contrasts. There are extensive deeply dissected mountain areas, large plateaux, steep scarpments, extensive undulating areas and vast plains of continental dimensions.

The climates of the region are also highly varied. They range from extremes of minimum pluviosity (nearly 0 mm. of rainfall along the coastal Pacific desert) to hyperpluvial zones in the Eastern slopes of the Andes facing the Amazonian region. The extreme and average temperatures are also very different throughout the various areas, depending on the elevation, latitude, orography and zonal location in relation to the atmospheric and oceanic circulation systems.

There are very high elevation glaciated mountainous areas close to the Equator and glaciated zones almost at the sea level, in the Andes Patagonicos and Fueguinos. On the other thermal extreme, there are regions of permanent high temperatures in the Amazonian basin and of relatively strong seasonal thermal variations in the middle latitude semi-deserts of the Argentinian Pampas and Patagonia and of the Northern Mexican Mesas. The distance to the sea is also highly variable, some cities are located next to the seashore, experiencing a considerable maritime climatic influence (high humidity and rainfall, weak seasonal variation of temperature, etc.), and others are very far inland with well defined semi-continental or continental climates (drier with strong diurnal and seasonal thermal contrasts, etc.).

Geological settings are also extremely heterogeneous. There are very ancient crystalline shields (as the Brazilian and Guyana shields), old sedimentary platforms and basins (i.e. the Patagonia Platform and the Parana sedimentary basin), volcanic zones (as the Mexican transversal volcanic belt), huge sedimentary plains (like the Amazonia, the Chacos, the Pampas and the Llanos), deeply folded and fractured landscapes (as in the Andes and the Mexican Sierras) and many other geological structures of varied nature.

The hydrological resources of the continent are also extremely varied. There are humid regions with strong hydrological superavits (i.e. most of the Amazonian basin, some sectors of the Colombian-Venezuelan Llanos, and the humid Pampas), and other areas in which water is a permanent limitant for the establishment of communities (i.e. the North of Mexico, the Peruvian-Chilean coastal desert, the dry Pampa, the Patagonia, the arid Chaco, the Brazilian "nordeste", Northern Mexico, etc.).

There are also many other intermediate cases in which neither a large deficit nor an important superavit of water exist, but in which it is required an adequate management of the available water resources in order to avoid that they could become in the future a limitant for the development of communities.

The soils of the continent also vary widely between thin, poorly developed, rocky, sandy and salty extremes to well-developed deep soils of ferrallitic or fersialitic natures with a large variety of intermediate possibilities including many types of horizon differentiation, permeability, chemical composition, organic matter content and fertility.
The vegetation is as varied as the climate and the soils. There are tropical humid forests with several strata, large prairies, extensive forested and non-forested savannas, steppes of varied density, bush-type vegetation, coniferous forests, ciperaceous swamps, high-mountain grasslands, periglacial tundras of altitude and various types of coastal communities.

It is in this natural landscape diversity that the Latin American cities have developed during their historical evolution. Some cities have grown in humid zones, some others in arid regions, some in plateaux, other in mountain valleys or in forested areas.

Obviously, the urbanistic solutions for the various challenges that were offered by the local landscapes were almost as varied as the landscapes themselves. The degree of adaptation to the environment of the different methods of urban planning is also varied. Some cities seem to be well adapted to their environment, sometimes using technology inherited from the preceding indigenous societies. In other cases, the environmental adaptations are more arguable, especially having in mind the profound demographic and social changes that have occurred during the last few decades.

On the same token, the water supply resources available in the different urban settings were very varied and their suitability has significantly changed with the booming growth experienced by many cities during the XXth century. Local streams, that provided enough quantities of good water for many cities when these cities were smaller, today are insufficient and contaminated and new sources had or need to be found. Local springs and wells that used to fulfill all the needs, are often exhausted or irremediably degradated. The problems of adaptation of the new megalopolis to their -often fragile- environments are enormous and these problems will not go away on their own.

The purpose of this chapter is to describe succinctly the basic environmental features that have provided the background and framework for the development of the Latin American cities of today and will determine their realistic developmental potential for the future.

2.2 Geology and geomorphology of urban sites

The geology and geomorphology of the Latin American continent are very complex (see Fig. 1). Basically, the region is composed of:

1) a very long mountain range (Andes, Central American ranges, Mexican Sierras) with intercalated or associated plateaux (Bolivian Altiplano, Peruvian Highlands, Cundi-Boyacense Plateaux in Colombia, Mexican Mesas, etc.) and active volcanic zones (transversal volcanica belt in Mexico, Central American volcanic belt, Andean volcanic belt);

2) an intermediate large plain longitudinally oriented in the center (Colombian-Venezuelan Llanos, Amazonian Plains, Chaco Plains and Pampas);

3) an extensive shield region on its Eastern flank (Brazilian and Guyana Shields) with associated palaeo-volcanic and sedimentary basins;

4) a complex island arch and related continental reliefs in the Northeastern portion (Caribbean Islands, Caribbean coast of South America and associated North and Central American terranes); and

5) a sedimentary platform in the Southern tip of South America (Patagonia).

The Western ranges have planetary dimensions, extending from 32 degrees latitude North in Northern Mexico (although they continue further North within the United States and Canada Western regions to Alaska) to 66 degrees Latitude South in Southern Argentina and Chile. That is (not counting the USA - Canada portion) an extension of roughly 86 degrees in Latitude and well over 11,000 Km. in length. These mountain ranges are very wide in the North of Mexico and Bolivia, where internal basins and plateaux develop and much narrower in other areas. The width of the Mexican highlands is of about 800 Km. close to the United States border.

Towards the South, these rugged highlands narrow down to a few tens of km. in the Tehuantepec Isthmus, in Eastern Nicaragua and in Panama (this fact was taken into consideration to select the location of the interoceanic canal in this last site).

Southward, in Colombia, the ranges are divided in three roughly parallel mountainous chains: the Eastern, the Central (of strongly volcanic nature) and the Western ranges, between which very deep hydrographic valleys have developed (the Magdalena and the Cauca rivers valleys).

Still further South, in Pasto (Colombia), these ranges merge and in Ecuador they narrow to less than 200 km. wide. In the Peruvian both sides of the Bolivian Altiplano (Plateau) between the parallels of 17 and 20 degrees South. This Altiplano is a very large semi-arid plateau with internal basins in which several freshwater and salty lakes have formed (Lake Titicaca, Lake Poopo, Salar de Uyuni, Salar de Coipasa, etc.).

Further South, towards the 30-40 degrees Latitude South, the Andes narrow again and rise to maximum elevations neighboring the 6500-7000 m. above sea level. In this area the highest mountains of the whole American continent are encountered (including the highest point of the Americas in the Aconcagua peak at about 6959 m. a.s.l.).

Continuing towards the South, the summits of the mountains are lower and in the extreme South they do not exceed 5,000 m. at any point. These Southern most mountainous areas are heavily eroded by the action of glaciers and gelifraction phenomena.

The general elevation of the Latin American ranges is practically always below 6,500 m. and normally much less, with variations between 2,000 and 3,000 in Mexico and 5,000 to 6,000 m. along the South American sections of the ranges. Towards the South, these highlands are still lower with elevations of the order of 3,000 to 4,000 m.

Throughout the whole range there are volcanic cones exceeding the average height of the surrounding non-volcanic highlands (cases of the Popocatepetl, Ixtaccihuatl and Orizaba volcanos in Mexico, several volcanic cones in Guatemala, El Salvador and Nicaragua, Nevado del Ruiz in Colombia, Chimborazo and Cotopaxi in Ecuador, Misti in Peru, Tronador and Osorno in Chile, Illimani in Bolivia and many others) frequently reaching elevations well in excess of 5,000 m.

The elevation of the plateaux in Mexico ranges from about 1,500 m. in the North to more than 2,000 m. in the valleys of Mexico, Toluca and Puebla. The narrow plateaux in Colombia are located at about 2,500 to 2,800 m. The large Peruvian-Bolivian plateau reaches elevations surpassing 4,000 m.

In addition to these features, there are a large number of valleys throughout the mountainous regions of Latin America. In some cases, they are wide valleys, tectonically originated, elevated to high altitudes through epeirogenic phenomena. In many other cases, these valleys are the results of fluvial erosion and deep dissection landscapes develop with widespread steep slopes and soil instability. Geologically, the Western (Latin American) ranges are composed of relatively young formations, and the orogenesis as well as the associated folding, fracturing and metamorphism do not go beyond the beginning of the Cretaceous period of the Mesozoic era. Most often, they were risen during the Tertiary and in some cases there are still active epeirogenetic phenomena taking place today.

The blocks composing these heterogeneous mountainous areas are also very varied. Frequently, there is a core of crystalline rocks (often granitic and metamorphic of older age) surrounded or partially covered by a dipping mantle of more or less folded and fractured sedimentary rocks. Normally, the stratigraphic column starts with marine limestones (i.e. the Morelos formation in Mexico, the formation El Molino in the Bolivian Sierras, and Rio Las Vacas limestones in Guatemala), followed by detritic marine, coastal and continental fine-grained sedimentary rocks (flysch-type) (as is the case in the Mescala formation in Southern Mexico and the formation Santa Lucia in Bolivia), which in turn are covered by coarse-grained sedimentary rocks (normally conglomerates and molasse-type conglomeratic sandstone: i.e. Balsas Group in Southern Mexico and the formation Morochata in Bolivia). This sequence is normally related to the "continentalization" of the sedimentary environment during the orogenic process.

These molasses, flysches, limestones and underlying granitic and sedimentary rocks have been heavily eroded and they may be found at different elevations in different places of the ranges. In many cases, volcanic rocks have been ejected or flew out and several types of volcanic deposits can be found (see Section 3.2).

Very frequently, there are thick accumulations of pyroclastic materials as it happens in the valley of Mexico, in the Valley of Guatemala, in the Managua region and in Quito, Ecuador. In those cases, lava flows and construction of volcanic cones are also observed. The types of volcanic rocks are very variable ranging from very acidic (rhyolithes and trachytes) to more basic types as andesites and basalts.

These volcanic formations frequently possess a relatively high surface permeability and a very poorly developed hydrographic network (due to lava obstruction and accumulation of ashes and mantles of miscellaneous pyroclastic materials on the developing thalwegs.) For this reason, run-off in volcanic regions can be very limited, infiltration high, and large underground reservoirs develop. Due to the good availability of groundwater and to the high feritily of the constantly and rapidly weathering glass-mineralogy soils (with its high rate of release of valuable nutrients) the volcanic regions of Latin America have been a priority site for human occupation and urban development in which many of the larger cities of the continent are located (in spite of the ever present volcanic and seismic risks).

In the eroded valleys, recent alluvial deposits were accumulated. In some cases, these accumulations are very narrow and relatively unimportant. In other cases, they formed sedimentary basins of large dimensions. These valleys are normally filled with coarse-grained sediments with high permeability on which surface streams flow with varied regularity depending on the type of environment and the size of the basin. These valleys have also relatively flat and friable soils in which agricultural activities and urban construction can be carried out without too many complications. Due to the availability of water and productive soils, mountain valleys have become priority areas for human occupation and urban development in the Andean and Sierras regions. Many of the larger cities of the continent are located in intramontane valleys of the Latin American Western mountain ranges. Some examples of cities located in this type of environment include Cochabamba in Bolivia, Cali and Medellin in Colombia and Caracas and Merida in Venezuela.

Towards the Eastern facade of the continent a large zone of crystalline shields is observed. In the intertropical zone, South of the Equator there is a large shield mass: the Brazilian Shield. This shield extends for about 27 degrees longitudinally and 20 degrees latitudinally, with an area in excess of 3,000,000 km2. In its Southern tip, there is a small crystalline shield (the Uruguayan-Rio Grandense Crystalline Island) and still some smaller crystalline islands in the Sierras Pampeanas, Cordoba and Tandil in Argentina.

The Brazilian shield is a medium elevation undulating and hilly plateau with altitudes ranging from 200-300 m. to slightly more than 1,000 m. above sea level. It is mainly composed of rocks of Pre-Cambrian age, with associated younger sedimentary basins. The largest of those are the peripheric Parana basin in the Southwast which reaches depths in excess of 5,000 m., the Maranhao sedimentary basin in the North and the Bahia sedimentary basin towards the Northeastern part of the shield region.

There are also some other sedimentary basins of smaller size but also of considerable economic importance due to the high density of population (i.e. the Sao Paulo basin, the Taubate basin and the Alagoas-Sergipe basin). These basins range in age from the Late Palaeozoic Era to the Miocene-Pliocene Epochs of the Tertiary Period. The topographic configuration of the Shield is asymmetric, with a steep East-facing scarpment overlooking a large number of discontinuous narrow strips of coastal plains and with the highest waterdivides located very close and roughly parallel to the coastline. As a consequence of that, there are a large number of alluvial valleys flowing westward to the interior, both towards the Parana and the Amazonas hydrographic basins, in which Late Tertiary and Quaternary deposits have accumulated.

On the other hand, the Eastwards -flowing streams are very short, torrential and their deposits are of foothills-type interdigitated with the littoral and marine sediments of the coastal areas.

The main limitants for city development in the Shield are generated by the rain forest tropical environment, with soils of limited fertility and inappropriate for intensive agricultural activities.

Because the country (Brazil) was colonized along the coast, at the beginning the cities developed on the narrow coastal strip, located on small coastal plains between the sea and the Eastern scarpment. Most of these cities obtained their water originally from the scarpment streams and springs. The growth of the coastal cities forced some of them to start utilizing the coastal aquifers or to build reservoirs in the neighboring highlands. Some examples of coastal cities with this type of evolution include Rio de Janeiro, Maceio and Santos among others. A number of cities developed in the immediate interior, just a few tens of km. of the coast but on top of the scarpment (cases of Sao Paulo and Curitiba).

These cities were located in a relatively inappropriate position for water supply purposes, due to the proximity to the headwaters and the small size of the upper basins. The city of Sao Paulo, today, is having serious problems to meet the water needs of the population, due to this awkward location. Instead of solving the problem with one large reservoir or two, the city was forced to build a complicated system of dams and pipelines to take advantage of all the small basins upstream of the city site. In the case of Sao Paulo, there is the option of using the small hydrogeological Tertiary basin on which the city is located, and in fact, a significant volume of the water utilized in the metropolitan area comes from this aquifer (see Section 4.2).

Further to the interior, the cities have been founded and/ or developed in the proximity of rivers, in some cases for water supply purposes, in others to utilize the rivers as ways of transportation. This is the case of most of the cities in the Amazonas basin (Manaos, Santarem, Belem). In other locations the cities developed near mineral exploitations and often available local water resources may have become scarce (i.e. Belo Horizonte in Minas Gerais).

In the Northeast of the South American continent another large shield region is encountered: the Guyana Shield. This sparsely populated region is undulating to hilly and covered with a dense rain forest vegetation. Only a few cities are found and most of them are located in its periphery. Along the coastal plains only few settlements developed (Georgetown, Paramaribo, Cayenne) which utilize the nearby rivers mainly for transportation purposes (and only secondarily for water supply) due to their brackish water composition near the coastline. These cities also utilize the foothills alluvial aquifers which are normally interdigitated with various types of coastal sedimentary formations. In the neighboring alluvial plains of the Orinoco in the Northwest a few other cities have recently developed: i.e. Ciudad Bolivar and Ciudad Guayana in Venezuela. These cities have developed on the boundary between the Guyanese region and the large Llanos plains and utilize the large Orinoco river for water supply and transportation purposes, although the local alluvial aquifers are also utilized.

Along the central zone of the South American continent, from the Patagonias to the Venezuelan Andes there is a large area of vast flatlands (Pampas, Chaco, Amazonia and Llanos) which is mainly composed of Quaternary and Tertiary sediments. These plains are the geomorphological expression of subsident areas in which huge sedimentary basins have developed. These basins are relatively continuous with a few interruptions due to less-subsident or non-subsident blocks (as it can be seen in the hills of Sierra La

Macarena in Colombia or the Sierras Pampeaneas in Argentina). This gigantic "graben" is in reality composed of several sub-basins which include the Northern "Llanos" basins, the large Amazonian basin, and the Parana basin (which is only partly underlaying the Plains, the rest of the basin is the geological substratum for the Planalto plateau).

These sub-basins are composed of a wide array of sedimentary formations ranging from Devonian (normally in the bottom of the graben, but also locally outcropping) to Quaternary. The shallow formations of the plains are frequently of Quaternary and Tertiary age and are composed of relatively thin veneers of finer alluvial, aeolian and/ or lacustrine sediments covering coarser alluvial units which cross the plains forming wide and shallow belt-shaped basins. This succession is clearly visible in the Argentinean Pampas and Southern Chaco near the Parana river where a well defined extensive alluvial basin (Arenas Puelches) underlies aeolian and lacustrine deposits (Pampeano Formation). Similar local sequences are observed in the Llanos and Amazonian regions.

The above sedimentological units are normally also good aquifers characterized for their easy access (due to their shallow depth: a few tens of meters), the relatively large volumes of water available in spite of their relative thinness and due to their large areal extension, and high renewability (related to the size of the recharge area, and that also in spite of the presence of overlying aquitards throughout most of the plains region).

The plains are crossed by many large rivers of quasi-continental dimensions. The Llanos are drained by the Orinoco and its many large tributaries; the Amazonian region is largely a "fluvial" region in which the high rainfall values, the huge areal extension and its location downstream of the Andean Eastern slopes converge to generate a number of very large fluvial waterways (the Amazonas, the Maranon, the Negro river, the Madeira, the Tapajoz, and many other large rivers (which together form the largest (flowwise) hydrographic system of the planet); the Chacos and the Pampas are traversed by the mighty Parana river and their tributaries (the Paraguay, the Pilcomayo, the Bermejo and the Salado rivers among others).

Due to the advantages for transportation purposes (and in a lesser degree for water supply reasons), many cities were founded or have developed along the shores of some of these rivers (Ciudad Guayana and Ciudad Bolivar next to the river Orinoco; Belem, Santarem, Manaos and Iquitos on the Amazonas; Rosario, Santa Fe, Parana, Resistencia, Corrientes, Posadas, Foz do Iguacu on the other river Parana; Asunciòn on the river Paraguay, Buenos Aires-La Plata on the confluence of the Parana river with the fresh water (at the city site) River Plate, etc.). Most of these cities utilize the rivers water for their water supply although the presence of an easily accessible aquifer has promoted the use of groundwater in suburban areas and for industrial purposes.

In some cases the actual utilization of groundwater is very intense and significant (as it is the case in Buenos Aires-La Plata in which large urban Municipalities depend on a considerable measure from their groundwater resources; i.e. the La Plata and Quilmes municipalities with a combined population in excess of 1 million).

In other cities of the plains located far from the main river, local streams cannot provide the necessary volumes or they flow in an irregular way, or they present excessive suspended material or contaminants. In many of those cases, the local water companies are utilizing or are planning to utilize the available groundwater resources instead. This is the case of a number of cities in Argentina (Rio Cuarto, San Nicolas, Junin, etc.), in Paraguay (Mariscal Estigarribia), and in Brazil (Corumba).

Near the Andean foothills there is an increase of the general altitude and the topography gradually slopes up towards the valleys descending from the mountains. This "foothills" regions forms a belt along the Eastern edge of the mountain ranges of about 100-200 km. across, in which an interdigitation of alluvial formations of varied grain size (but normally predominantly coarse) is found. On a geological map, these alluvial formations adopt the form of fans which diverge from the valleys outlets towards the lower parts of the flatlands. In many cases, the fans were buried by younger formations (frequently due to local subsidence relative to the neighboring mountains) and presently constitute interesting potential reservoirs with large water storage capacity and high hydraulic conductivity values.

In fact, there is a string of good aquifers located along the Eastern foothills of the Andes from Venezuela to Southern Argentina and a number of cities have developed taking advantage of this resource. Many more cities have started recently or are planning to start the utilization of this groundwater resource in order to compensate for the growth of water consumption and the deterioration of the quality in the surface water sources in the proximity of the city sites. Some examples of cities using these "foothills" alluvial aquifers include Villavicencio in Colombia, Santa Cruz de la Sierra in Bolivia and San Juan and Mendoza in Argentina.

The Andean Eastern foothills also enjoy good sources of surface waters as a result of the flow of many rivers descending from the neighboring mountainous areas, which are frequently humid due to their exposure to the Easterlies (intertropical trade-winds) and often possess large volumes of water stored as snow (particularly in the middle latitude regions).

Several reasons, however, have promoted the development of groundwater supply in some of the previously mentioned urban areas: **firstly**, the surface sources, which in general terms had a seasonal and/ or irregular flow, have seen their flow regularity further diminished due to deforestation and landscape degradations in the upper basins; secondly, various types of human activities in the

Andean highlands have had deleterious effects in the water quality of the streams flowing towards the plains. This is particularly problematic in the case of a number of mining activities which not only generate devastated landscapes (and therefore are important sources of (eroded) transported soil materials) but also are the sources of a number of toxic substances (as mercury and cyanide in the widespread gold mining areas) which may seriously affect the drinkability of the available surface water and finally, the growth of the city may make more difficult or uneconomical the continued or expanded utilization of these traditional water resources.

The Caribbean-Gulf of Mexico region presents characteristics completely different to the previously described zones. It is composed by a large island arch, constituted by several hundred islands of varied size and geological characteristics and an extensive flat, lowlying coastal zone located in the mainland continent. The islands may have a crystalline core (as is the case of Cuba and Hispaniola), they may be mainly volcanic (as Martinique) or sedimentary (frequently calcareous (as the Bahamas, Barbados and Grand Cayman). In several cases they may have a complex landscape composed of various types of geological formations (as it is the case in all the largest islands: Cuba, Hispaniola, Jamaica, Puerto Rico and Trinidad). By and large the water in the islands is obtained from two sources: reservoirs in the highlands (as in Kingston, Jamaica; Port Spain, Trinidad and San Juan, Puerto Rico) or aquifers in the (coastal) plains normally of karstic characteristics (cases of Havana in Western Cuba, Bridgtown in Barbados, Nassau in New Providence island in the Bahamas and also in Kingston, Jamaica and the Northern coast of Puerto Rico).

The Caribbean-Gulf of Mexico mainland region is a relatively narrow belt extending for several thousand km. along the coast through Northern South-America, Central America (from Panama to Honduras), Yucatan (including Belice, the Guatemalan Peten and the Mexican state of Yucatan), the Gulf of Mexico coastal plains (from Campeche through Veracruz to Tamaulipas/ Nuevo Leon in Mexico) and along the states of Texas, Mississippi, Louisiana to Florida in the continental United States. Generally speaking, the region is a typical coastal region with foothills alluvial deposits, intercalated with sedimentary basins (including locally elevated sedimentary blocks and various types of marine and palustrian formations).

The surface water resources are normally related to the relatively short rivers descending from the neighboring highlands. In some cases, the volumes of water are considerable (i.e. the Usumacinta river in Mexico, the San Juan river in Nicaragua), but in others they are below the requirements of the existing cities. This is what happens in the karstic areas in which run-off is extremely limited due to the high infiltration rates (i.e. the Yucatan peninsula, the Nuevo Leon/ Monterrey region and the Florida peninsula in the United States). These last three areas depend almost exclusively on groundwater for municipal water supply, which they extract from high productivity limestone aquifers (karstic aquifers provide practically all the consumed water for the cities of Merida in Yucatan, and Miami in Florida).

In the Southern tip of the Latin American continent there is a relatively large sedimentary platform (the Patagonia) which due to the sparse population density does not have, presently, significant requirements for urban water supply. The region is arid (with precipitations of less of 400 mm. per year), but because of the proximity of the very humid Pacific Andean region, it receives part of the fluvial outflow from this last mentioned zone. A considerable amount of the water supply for the few cities of the Patagonia comes from this surface source. Although there are aquifers containing significant volumes of water this water is not yet heavily utilized due to the previously mentioned factors.

Chapter 3 HYDROGEOLOGICAL ENVIRONMENTS AND URBAN WATER SUPPLY

3.1 Suitability of Groundwater Reservoirs urban water supply

The hydrogeological environments of the Latin American continent are as varied as its geography, and in that respect they behave - as it can be expected- in a very similar manner to other regions of the world.

Taken from a merely academic point of view, the aquifers in Latin America (and elsewhere for that matter) have a very wide range of hydrogeological properties: they can be highly permeable or less permeable, they may be porous and/ or fractured, they can contain only few thousands of m3 of water or many billions, their waters can range from very fresh to brines, they may be pristine or highly contaminated with one or more types or unwanted substances, in brief, they are a very heterogeneous natural resource.

However, when groundwater is considered as a potential or actual source of water supply, for urban or suburban communities with high consumption requirements, the spectrum of possibilities is considerably reduced.

Generally speaking, the main limitants for groundwater utilization for urban purposes are of economic nature. This is so, due to the costs associated to their exploration, extraction, conduction, treatment, storage and distribution.

Groundwater costs are normally compared to the costs of other types of available water resources; when the utilization of groundwater is economically beneficial, there is a great likelihood that the groundwater resource is going to be tapped, if it is not already; if the cost of groundwater is higher than the cost of other available, comparable water resources, then the opposite will probably happens. When groundwater is the only water resource readily available, it is very likely that it will be extracted anyway even if its cost is high.

There are many geological/geographical conditions which favour the actual utilization of groundwater for urban water supply.

Some of them are the following:

1) Location close to the consumption area;
2) Large groundwater reservoir;
3) Shallow depth, shallow piezometric levels;
4) High water yields;
5) Renewability;
6) Acceptable water quality for urban consumption;
7) Low risk of unwanted effects due to intense pumping.

1) Location close to the consumption area

One of the higher costs associated to water supply for the cities is its conduction from production to consumption areas (particularly when this conduction is uphill or through some geographic obstacles such as mountains, canyons, etc.).

Consequently, aquifers are more conveniently located, if they are closer to the cities that are going to utilize them. The ideal condition is found in aquifers that underlay the consumption area, particularly when they are artesian (piezometric level above the ground surface) due to smaller abstraction costs and less risk of contamination.

This is (or was) the case in many cities of the world. However, very commonly, urban utilization of artesian aquifers lowers the water levels below the well head, artesianism disappears and pumping may be required. In spite of that, even with this added cost, the economic convenience of having the groundwater reservoirs underneath the city outweighs easily the pumping costs.

Some cities in which the aquifers underlay the consumption areas are Mexico City, Buenos Aires-La Plata (Argentina), Bangkok (Thailand), Lima (Peru), etc.

In other cities, a considerable amount of the groundwater utilized must be brought from aquifers located at a distance from the urban contours (i.e. Guadalajara and Monterrey in Mexico, Havana in Cuba and Jakarta in Indonesia).

In all cases, the distance from the wells, springs or galleries to the consumption areas is a major factor of the cost of the water, and as a corollary, a major factor for the initial and subsequent development of the well fields.

2) Large Groundwater Reservoirs

A second required condition for an underground reservoir to be suitable for urban use, is the existence of large volumes of water, which must be enough for its utilization for relatively long periods of time (let's say, 10 years or more).

In order to provide with some graphic (and quantitative examples) let's consider the requirements of a 100,000 inhabitants city with a 500 liters per day per person consumption rate. A city with those characteristics would consume in excess of 18 M. m3 per year. If we assume an annual average recharge of 1/10 of the stored volume, at least ten times as much stored water (180 M. m3) are needed in order to satisfy the requirements without undermining existing reserves. In order to contain that volume of water, any geological formation must have a total volume several-fold bigger (i.e. ten times for an effective porosity of 10%). This would amount to about 1.8 billion M.3, which would be, for instance, the volume of a 180 Km2 formation with an average thickness of 10 m.

If we consider the requirements of a large megalopolis (i.e. Mexico City) with daily consumption rates of about 7 M. m3 (annual: 2,500 M. m3) the actual exploitable volumes (not considering for the time being the normal variation of the various hydraulic parameters) will need to be about 150 times larger that the former mentioned example, in order to accommodate the city medium and long term needs (i.e. a 2,700 Km2 formation with an average productive thickness of 100 m.). As it is shown in Section 4.1, the aquifer of the valley of Mexico -to some extent- meets the above mentioned requirements (with some limitations to be discussed in the mentioned chapter).

Obviously, all these figures are arbitrary, and the actual calculation of available water volumes is not (unfortunately) so simple, but they can give a general idea of the type of aquifer size that may be required to satisfy the water supply requirements of a large city).

3) Shallow depth, shallow piezometric levels

In order to be utilizable for urban water consumption purposes, water must be easily (and/ or economically) available. When the aquifers are located at great depths (i.e. beyond several hundred meters) drilling costs increase considerably. These costs are is still vastly increased if in addition, piezometric levels (static levels) and pumping water levels (dynamic levels) are far from the ground surface. In this later case, operational costs can be radically augmented due to increased pumping costs.

Normally, with depth, there is a tendency towards compaction and consolidation of sediments, as well as an associated decrease of storativity and hydraulic conductivity, with augmentation of water mineralization. For this reason and costs, most deep aquifers are unusable for water supply purposes.

However, in a number of cases, deep aquifers can possess good drinking waters with high well yields. One example of an excellent aquifer, meeting these conditions is given by the Botucatu sandstone of Brazil, Uruguay, Paraguay and Argentina with well over 1 M. Km2 of extension and several hundred meters thickness (see Section 3.5).

This sandstone contains one of the largest aquifers of the world with very high permeability and poorly mineralized waters. The main problem is related to its difficult access due to the aquifer depth (which frequently exceeds 1,000 m.) and the presence of basaltic rock very expensive to drill through. On the other hand, due to the high piezometric levels (frequently giving place to artesian conditions) extraction costs are low. In spite of these special favorable characteristics, this aquifer has been used in a limited way in the areas in which its access (through drilling) is more difficult and expensive. Only recent a relatively significant number of wells have been drilled for urban water supply purposes.

4) High water yields

A key element for the utilization of an aquifer for urban water supply are the sustainable well yields. The yield is the main element to define how many wells may be needed to obtain the required volumes. For example, in order to satisfy the needs of a city of the size described in Par. 2 (yearly consumption of 18 M. m3, daily consumption of about 50,000 m3) it would be necessary to build 200 wells producing 1,750 liters/ min. each, or 1,000 wells at a rate of 350 liters/ min/ well.

The city of Mexico obtains 55,000 liters/sec. from 5,000 wells spread throughout the city area (about 10-12 liters/sec. or 600-720 liters/min. per well).

The main intrinsic property that determine the yield of the well(s) is the hydraulic conductivity (permeability) of the aquifer. High permeability formations provide the conditions for construction of high yield wells.

5) Renewability

One of the most important features of an aquifer allowing its intense and long term exploitation is its renewability.

Renewability can be defined as the capacity of an aquifer to sustain its general volumes under a given level of abstraction. The renewability of an aquifer is related to the balance of the water recharged and discharged from and to the surface and the inflow and outflow from and to other contiguous water -bearing hydrogeological units.

In most cases, the key element for renewability of an aquifer, for urban water supply is given by the volumes recharged from the surface (streams, lakes, direct infiltration from rainfall or snowmelting, etc.), which in turn are the result of precipitations in the recharge areas or in the basin headwaters.

This recharge not only depends on the volume of precipitations (height of water fallen x area) but also on the infiltration conditions (permeability and state of the ground surface, slopes, hydrographic network development, vegetation, artificial structures, depth of the water table, etc.).

Some aquifers have a high rate of renewability (i.e. due to high rainfall, large recharge area, or poorly developed outflowing drainage) and they can be heavily used with little harm. Others, on the other hand, have a limited rate and are -therefore- easily subject to overpumping. Assessing the renewability of an aquifer is a basic element for the appraisal of its potential for urban use.

6) Acceptable water quality

Another element to take into consideration when evaluating the potential for water supply for cities, is the water quality. The aquifer water must be of a level of quality compatible with the use to which it is intended (i.e. human consumption). For this purpose, water must have a low level of dissolved solids, must be within the required standards of microbiological contents, and be free of other impurities (i.e. miscellaneous organic or inorganic gases liquids or suspended solids), excessive radioactivity or other health hazards.

Water with qualities below standards, can often be submitted to treatment and its quality brought to standards. However, there are normally high costs associated with treatment of heavily contaminated or unsuitable waters that may make economically prohibitive their utilization.

The location of the recharge area of an aquifer, underlying a densely populated area, often makes the aquifer vulnerable to contamination from anthropogenic causes. This fact needs to be addressed when an aquifer is or will be under utilization for human water consumption purposes, in order to protect the groundwater from external pollution and control the state of the water quality of the aquifer during its utilization.

In some cases the causes for degradation of the water quality are related also to connection to lesser quality aquifers or surface water bodies (i.e. sea water, salty lakes, etc.). In those cases, heavy pumping may induce the incoming of poor quality (i.e. salty) water, both through upwelling from deeper horizons and/ or from lateral intrusion. This phenomenon (generally called "saline intrusion") is main cause of aquifer degradation in coastal areas.

7) Unwanted effects due to intense pumping

In some cases, intense pumping -as it is normally required for urban water supply purposes- may provoke some unwanted effects (i.e. subsidence, induction of unsuitable recharge to the aquifer, intrusion of contiguous undesirable underground waters of poor quality or other fluids, etc.). Although, assessments on these and other potential problems are not always carried out in advance, there are many examples in which overpumping has caused degradation, not only of the aquifer, but also of the overlying land over which the city is located.

In most cases, the effects of pumping are related to dewatering or decreasing water pressure in the aquifer. The serious problems of subsidence identified in Mexico City, Bangkok, Shanghai and Venice, are the result of consolidation of dewatered sediments due to intense pumping (exceeding the aquifer's renewability). These phenomena have shown, to what extent, intense pumping can become a very damaging activity when the hydrogeological conditions are not appropriate for the pumping rates, depths and volumes being abstracted.

In brief

Only a few hydrogeological environments meet the requirements for urban water supply in the volumes, well yields, renewability, accessibility and water quality necessary for that purpose.

For this reason, the list of water-bearing formations of interest for the urban supply hydrogeologists is much shorter than is normally shown in hydrogeological surveys. In the next few chapters a brief description of the main high production aquifers, suitable for urban utilization will be presented.

3.2 Aquifers in volcanic regions

3.2.1 The volcanic aquifers

Volcanic regions contain some of the most productive aquifers suitable for long term urban use. There are several large Latin American cities obtaining a significant part of their water from volcanic aquifers.

Mexico city's main sources of water supply (about 80%), are the aquifers contained in the complex pyroclastic (and genetically associated) units filling the Valley of Mexico basin. Guatemala City is also dependant in a large measure (approximately 70%) from the groundwater reservoirs found in the Tertiary and Quaternary pyroclastic and lava formations of the Guatemala valley in this country volcanic highlands. Managua, capital of Nicaragua, extracts all its required water for urban consumption (both directly from well batteries and indirectly through the crateric lake of Asososca) from the pyroclastic "Las Sierras" formation. The city of Quito, Ecuador, obtains nearly 40% of the consumed water from the colluvial and alluvial deposits of pyroclastic origin and tuffs of the "Callejon Internadino" valley.

Other cities utilizing to some degree volcanic or related aquifers include Guadalajara, Puebla and Toluca in Mexico, Quetzaltenango in Guatemala, Riobamba in Ecuador, La Paz (El Alto) in Bolivia, and San Jose in Costa Rica.

The volcanic complexes of Latin America are of three main types:

1) the mesozoic basaltic vulcanism of Serra Geral;
2) the island arch vulcanism of the Caribbean region; and
3) the mountain ranges vulcanism.

1) The basaltic areas of Southern Brazil, Northern Uruguay and Northeastern Argentina are composed of a relatively compact rock several hundred meters thick, which only contains minor volumes of water in the fractures, in the intercalated sandstones, in the interflow porous zones and in the surface weathered material. These water -bearing zones are not only difficult to find (particularly in the three first mentioned cases), but normally they do not provide sufficient water volumes to sustain long term high abstraction rates.

2) The volcanic areas of the Caribbean islands occupy a relatively reduced area above sea level in several of the smaller Caribbean islands (Santa Lucia, Dominica, Montserrat, Martinique, etc.). As a result of the limited extension and of the presence of better aquifers in most volcanic islands, these formations are mostly used for water supply, only in small towns and farms.

3) The volcanic zones of the mountain ranges, on the other hand, are extremely important as sources of groundwater supply, both due to the high densities of population, and to the frequent presence

of excellent and abundant groundwater resources suitable for urban water supply. These zones, extend along the whole Eastern Pacific "arch of fire" close to the Pacific coast, from Southern Chile through Bolivia, Peru, Ecuador, Colombia, Central America and Mexico (continuing further North through the Western United States, Western Canada and Alaska).

They consist of a wide array of rocks of varied composition, petrography and structures, including acid, neuter and basic magmatic compositions. In that, there is a difference with the trap basalts of Serra Geral, which are systematically basaltic. Rock types that are found in the mountain volcanic districts include rhyolithes, trachytes, dacites, andesites and basaltic lavas, widespread pyroclastic formations and associated alluvial and lacustrine deposits.

From a geological perspective, these volcanic regions can be extremely heterogeneous, and that is mainly because of the complexity of the petrogenesis associated to volcanic processes.

Depending mainly on their content in silica, the ascending magma may solidify before reaching the ground level (this is normally the case in rhyolithic and trachytic magmas), or it can exit to the surface and flow downhill until it cools down and hardens.

The effusion of lava is normally accompanied by degasification, with ejection of various types of magmatic products to the atmosphere. In the case of acid magmas, gas pressure builds up behind the solidified rocks, and explosions may take place with widespread ejection of solid fragments and fluid materials of varied size, which may fall as large fragments (bombs, escoria), medium size fragments (lapilli), or ashes. These materials can also flow downhill embedded in hot fluids: various hot gases (of which, by far, steam is the most common), liquid water (often from phreatic sources or sometimes from snowmelt) and in fluidized soils (which, in turn, are normally composed of preexistent volcanic materials of varied types). The above mentioned volcanic formations are frequently reworked by water erosion, and transported downstream where alluvial and lacustrine deposits may develop in the accumulation areas.

In the less exposed or more gentle slopes, weathering processes may rapidly develop and the volcanic glasses and proto-crystals may be transformed in clay with liberation of various chemical substances, among which there could be a number of important plant nutrients. Soil formation in loose volcanic deposits can take place very quickly (a few years). In the case of more compact volcanic rocks, soil formation processes normally proceed at a much slower rate (tens or hundred of years).

Soil formation is very important also from a hydrological point of view, because of the increased impermeabilization that takes place, as a result of the argillization of the glasses. One of the main obstacles to the recharge of the aquifers (and to vertical flow in general) in volcanic areas, is related to the presence of a succession of buried palaeo-soils, mainly as a result of the weathering of the pyroclasts, while they were exposed to atmospheric and biological action.

The main volcanic rock formations found in the mountain ranges volcanic areas of Latin America are the following:

1) Agglomerates and Breccias;
2) Ash-flow Tuffs;
3) Ash-fall Tuffs;
4) Mud-flow and Laharic Tuffs;
5) Alluvial Reworked Tuffs;
6) Lacustrine Reworked Tuffs;
7) Lavas

1) Agglomerates and Breccias

They form near the foothills of volcanoes as a result of local landslides, rolling of large and medium size rock fragments (blocks and lapilli) and fall of various types of pyroclasts in the proximity of the volcano (including also bombs, miscellaneous escoria, pumice, blocks, lapilli and ashes of various types and grain size). Hydrologically, this unit can be very productive, but its reduced areal extent greatly limits the use for water supply purposes.

2) Ash-flow Tuffs

These pyroclastic units are the result of downslope flow of pyroclasts, fluidized by water and/ or volcanic gases often giving rise to thick accumulations in the valleys and depressions.

The pyroclastic materials formed in this way can be composed from solidified "live lava", fragments of preexisting "dead lava", pyroclasts from previous eruptions, or fragments of rocks ripped from the substractum "walls" during the ascension (exit) of the volcanic fluids.

These tuffs can be "welded" or "non-welded" depending on the degree of their consolidation. Non-welded tuffs are frequently water-rich units (in available volumes, due to their thickness, areal extent and effective porosity, which according to data presented in USGS 1370-A* may average about .35) but their yields are somewhat smaller than welded tuffs in which the porosity is secondary (related to fracturing) and much smaller (of the order of .03).

---

* Studies of Geology and Hydrology in the Basin and Range Province, USGS 1370-A.

According to data summarized in the above mentioned paper, mean K values of tuffs range from 1 x 10-0 meters per day, for welded and fractured tuffs, to 4 x 10-5 meters per day for non-welded and friable tuffs. However, the average values do not give always a good idea of the high hydrological potential of some tuff deposits which may be suitable (and are in fact often utilized) for urban water supply. Data from the 83.5 percentile from the same above mentioned bibliographic source show figures ranging from 5 x 10-0 to 5 x 10-3 m/d. with effective porosity values almost identical to the mean values (.04 for welded tuffs, .37 for non-welded tuffs).

In brief, it can be said that, by and large, tuffs offer a good hydrogeological potential (particularly when fractured), with high yields, and when the available volumes are large enough, they may become a possible source for urban water supply.

3) Ash-fall Tuffs

These wind-driven tuffs can extend throughout large areas accumulating as a thin blanket over the pre-existing topography. Normally, they are composed of fine pyroclastic particles, and their grain size decreases with the distance to the volcanic source.

In spite of their large areal extension, their water supply importance is very limited due to their thinness (seldom more than 10 m.).

4) Mud-flow and Laharic Tuffs

Mud-flows and lahars are catastrophic phenomena, which may happen regularly in some locations, giving rise to important accumulations of poorly sorted sediments, downstream of the volcanic slopes.

Sometimes, these phenomena can extend for many tens of km. through the descending valley, down to areas with less steep slopes.

Mud-flow and lahar sediments are frequently weathered, becoming highly productive agricultural soils and at the same they may contain abundant good groundwater suitable both for urban water supply and irrigation (when their areal extent and thickness are large enough). As a result of these characteristics, mud-flow and lahar zones are often densely populated, sometimes with cities built on their areas of occurrence. In those cases, these catastrophic phenomena can be a permanent threat for the local populations, and actual losses of life may occur.*

5) Alluvial Pyroclasts and Reworked Tuffs

Because recently deposited tuffs are devoid of any vegetation cover, they are exposed to various processes of ablation (particularly water erosion), and their particles can eroded and transportated by local streams, towards neighboring lower-lying areas producing accumulations of varied thicknesses.

Alluvial pyroclasts of this nature are found, very frequently intercalated and interdigitated, with other "in situ" volcanic formations.

They can present high values of hydraulic conductivity and be satisfactorily used as aquifers. When their volumes and renewability rates are sufficient, they could also serve as good sources of water for urban areas.

6) Lacustrine (reworked) Tuffs

Lakes are very common features in volcanic areas due to the frequent obstruction of pre-existing fluvial waterways by volcanic accumulations of varied types.

In most volcanic areas, many lakes of various sizes and stages of evolution can be found. The last stage of the evolution of volcanic lakes (or of any other lake for that matter) is their colmatation and transformation in a lacustrine plain. As a result of that, lacustrine plains are also common in volcanic areas (together with lakes in younger stages of evolution).

Lacustrine sediments are normally finer than alluvial ones. For this reason, lacustrine formations tend to act more as aquitards (or quasi-aquicludes) than as aquifers. Their groundwater yields are normally small to nil.

---

* In 1985, the city of Armero in Central Colombia was buried by a very destructive "lahar" caused by sudden snowmelt in the slopes of the Nevado del Ruiz volcano as a result of which 20,000 people were killed. There are several other cities located in similar high risk environments (as it is also the case of Ibague not far from Armero, but with a population of 400,000 people).

7) Lavas

Lavas can be considered the "primary" volcanic rocks. They form through solidification of magmas, under atmospheric or quasi-atmospheric conditions. Lava rocks formation takes place inside the volcano apparatus, in the case of silica-rich high-viscosity magmas, or outside, as lava flows in the case of silica poor low viscosity magmas. Magmas of intermediate composition have an intermediate behavior.

Rhyolithic, trachytic, and dacitic magmas frequently produce explosive eruptions, while basaltic and andesitic magmas give rise to more peaceful volcanic episodes.

Lava flows are heterogeneous, with a vitreous crust of solid rock forming on their rapidly cooling external surfaces, and a more crystalline core of slowlier cooling materials, forming towards the centre and base of the flow. Gas bubbles are normally trapped under the solid crust, developing high porosity materials where vacuoles and vesicles may form. In some cases, these empty spaces can be interconnected, giving rise to high effective porosity, in which water circulation can easily take place (high hydraulic conductivity). In some other cases, the vacuoles and vesicles remain isolated and water circulation can be more difficult. In addition, the base of the flow normally includes fragments of rocks, and therefore, the final solidified material can end with many anfractuosities and empty spaces, giving rise to high permeability materials.

As a result of these cooling contractions processes, lavas can develop a network of open fractures, which are normally interconnected, allowing the flow of significant volumes of water, and therefore, high local yields.

In brief, lavas can be hydrological units of high productivity when they possess(ed) large volume of gases, experience(d) intense contraction phenomena, or flow(ed) over loose rocky surfaces. On the other hand, when there is little gas contained (as in most basaltic flows), contraction fissures are fewer and smaller or when few foreign rock fragments are contained in the flow floor, the hydrological potential can be limited. One example of low productivity lavas is provided by the plateau lavas of Serra Geral in Southeastern South America.

Data from lava flows of various types from mountain ranges volcanic areas in North America (USGS 1370-A), show effective porosities averaging .15 for cavernous and fractured lavas, and .01 for moderately dense to dense ones. Hydraulic conductivity values (K) average 5 x 10-1 m/d. in the first case and 4 x 10-4 m/d. in the second one.

3.2.2 Groundwater renewability in volcanic aquifers

One important element that facilitates groundwater exploitation in volcanic areas, is the normal high rate of renewability. This is due to the continued "youth" of the hydrographic system in these areas. Fluvial valleys do not have time to form, because of the continued obstructions in their courses, as a result of the various volcanic accumulations (mainly lava flows, landslides, mud-flows, lahars, ash-flows, etc.).

The various types of lakes and depressions formed in volcanic regions, frequently become recharge areas ("sinks") for existing aquifers. In many volcanic aquifers, actual infiltration can amount to more than half of fallen precipitations. From this point of view and others, volcanic regions have a number of common traits with karstic areas (see Section 3.4): poorly developed hydrographic drainage, presence of "recharge" lakes or depressions, common fracture flow through open fractures (as in lavas and welded-tuffs), etc. The main difference is the much less important role of dissolution along the fracture wells.

3.3 Alluvial aquifers

3.3.1 General

Alluvial aquifers are those contained in sediments of alluvial origin. For the purpose of this Section, only the less consolidated Cenozoic alluvial formations will be addressed here, other older alluvial formations will be included in Section 5 of this same Chapter.

Alluvial formations are widespread throughout the Latin American region from Punta Arenas in Southern Chile to Tijuana in Northwestern Mexico, and from Trujillo in Peru to Fortaleza in Brazil. By and large, they are the most abundant type of aquifers both in numbers and area extension (see Fig. 2).

They can be found at high elevations, sometimes above 4,000 m. above sea level, as in the Peruvian-Bolivian Altiplano, or several hundred m. below sea level (as in number of coastal subsident areas throughout the continent margins).

These aquifers have a wide range of characteristics, they can vary in size from very small reservoirs of a few km2 or less, with small productive volumes, to extensive aquifers of tens of thousands of km2, extending over large areas, with huge actual or potential production capacities. Yields can also be very variable, in some cases, well productivity may be low (of a few liters per minute), in others it can reach hundreds or even thousands of liters per minute.

Obviously, not all alluvial aquifers can provide a sustainable output of good quality water as required for widespread urban utilization. In fact, most alluvial aquifers don't.

However, there are still a large number of alluvial formations containing enough renewable groundwater resources, as to be able to meet the water demand (partially or totally) in many cities throughout the continent.

Some cities obtaining a significant part of their water from alluvial aquifers include: Buenos Aires-La Plata, San Nicolas, Junin and Rio Cuarto in Argentina; Cochabamba and Santa Cruz in Bolivia; Lima, Trujillo, Piura and Ica in Peru; Santa Marta, Sincelejo and Villavicencio in Colombia; Valencia and Maracay in Venezuela; Mexicali, La Paz, Aguas Calientes, Queretaro and San Luis Potosi in Mexico, and Olinda, Natal and Pelotas in Brazil.

A large number of other cities that obtain most of their water from surface sources, still draw some of their water from alluvial aquifers, often for industrial use (as it is the case in Santiago, Chile; Montevideo, Uruguay; and Asuncion, Paraguay; among many others).

In addition, many aquifers that in this text will not be classified as alluvial, were deposited as a result of alluvial action, and the reason why we have classified them otherwise, is because of other characteristics with more significance to define their properties and dynamics. This is the case of many alluvial carbonate sediments, alluvial deposits of pyroclastic origin, some coastal alluvial sediments interfingered with marine littoral deposits, and pre-Tertiary consolidated conglomerates and sandstones of alluvial origin, which were included under different headings in spite of their alluvial genesis (see Chapter 1 and Sections 1, 3, 5 and 6 of Chapter 3).

Alluvial formations are composed mainly of detritic sediments of varied grain size and composition. Granulometrically speaking, they can be gravelly, sandy, silty or clayey, and may possess any intermediate or composite grain size, between and/ or including the previously mentioned granulometric fractions.

In general terms, the larger is the predominant grain size, the higher is the intergranular porosity of the material. Also, well sorted alluvial sediments have a higher porosity than poorly sorted sediments of comparable mean grain size dimensions.

Consequently, only the coarser sediments (fine sandy to gravelly) may contain enough water and have a high enough permeability as to give rise to aquifers utilizable for urban use. Effective porosity and hydraulic conductivity values of coarse alluvial sediments in North American aquifers according to USGS 1370-A have ranged between .12 and .25 (effective porosity) and 1 x 10-0 and 7 x 10-1 m./day (hydraulic conductivity). Similar analyses for alluvial aquifers in Latin America have given similar results.

Silty and clayey alluvial formations are not normally good aquifers, possessing an aquitard or aquiclude hydraulic behavior (low hydraulic conductivity).

Obviously, the above described characteristics not only apply to alluvial sediments, but to any other sediment of similar granulometric properties. However, because, by and large, the vast majority of detritic sediments containing aquifers in Latin America are of alluvial origin, we have dealt with the matter in this section (see also, Sections 2, 3, 4, 5 and 6 of Chapter 3).

3.3.2 The problem of classification of alluvial aquifers according to their age

Generally speaking, detritic sediments suffer considerable changes with age. The older any sediment it is, the more chances there are that it could have experienced stronger consolidation and/or diagenetic processes. These processes are often, but not necessarily, associated to the depth in which the sediments have been buried, at some point of its geological history. The older a sediment it is, the more chances there are that it could have been buried at a deeper crustal level, and consequently the likelihood of greater consolidation and/or digenesis is higher. We must state, however, that the above rule is not straight-forward and admits many exceptions.

The consolidation processes are of varied nature, including general compaction, hydrolysis of ferro-magnesian minerals and feldspars, with formation of clays and other secondary minerals, cementation with silica, iron hydroxides/ oxides and/or carbonates and several other analogous phenomena.

At a deeper level, when temperatures and lithostatic pressures increase beyond a certain degree, other petrogenetic phenomena of a more diagenetic nature occur (including neo-formation of clays and micas, anhydritization of calcium sulphates, formation of some sulphides (as pyrites), crystallization of graphites and magnetites, hematitization and goethitization of limonites, etc.).

All these processes act in the direction of decreased porosity, decreased hydraulic conductivity and decreased storativity. Due to slower groundwater flow, there is simultaneously an augmentation of the mineralization (due to the increased time of contact between the underground fluid and the mineral surfaces and to higher temperatures at depth).

Therefore, as a rule, modern detritic formations contain better aquifers than older formations of the same type. However, it must be noted that -with consolidation- there is a change in the type of porosity and flow. Consolidated sedimentary rocks have a greatly diminished intergranular porosity (and flow) but -when fractured- they can develop a relatively high secondary (fracture) porosity and fracture flow, behaving in that case as a fracture aquifer (i.e. similar to fracture aquifers in crystalline rocks, etc.).

For the purpose of this paper, we have arbitrarily divided the detritic alluvial formations in three categories according to their age: the younger alluvia, still associated with present fluvial valleys/basins; the older alluvia having suffered some consolidation processes, normally of Tertiary age, only (infrequently) related to the largest present orographic and hydrographic features; and the older sedimentary rocks of alluvial origin, generally pre-Tertiary, without any direct association with existing reliefs, having often experienced a relatively high degree of consolidation and some digenesis.

3.3.3 <u>The problem of classifiying alluvial sediments according to their geomorphic location</u>

Another key criterium to classify alluvial sediments is the general geomorphological location of the deposit under consideration. Alluvial sediments from the foothills of the Andes are extremely different from the sediments of the large central South American plains. On the other hand, alluvial deposits form the undulating shield plateaux are also very different from the sediments from the intramontane Andean or Sierras basins. To the effect of this document we have classified all "modern" sediments (let's say Late Pliocene to Present), in which the present relief is still a determinant factor on the formation geological and hydrogeological characteristics, according to their geomorphic location. We have "lumped" the Tertiary alluvial basins (which are only related to present reliefs in a limited way) into a different type, within the alluvial aquifers sub-section, and have included the pre-Tertiary sedimentary rocks with other sedimentary rocks of similar age but different genesis in a separate section.

3.3.4 Types of alluvial aquifers

There are several types of alluvial formations containing aquifers being used or with potential for urban water supply.

They are the following:

1) Tertiary alluvial and molassic basins;
2) Intramontane alluvial basins;
3) Foothills alluvia;
4) Plains alluvia;
5) Shields and platforms alluvia;
6) Coastal alluvia

1) Tertiary alluvial and molassic basins

Throughout the Latin American continent there are a large number of older alluvial deposits, more or less consolidated, that can be utilized for water supply purposes.

Several cities draw their waters from this type of aquifers (i.e. Aguascalientes in Mexico and Sao Paulo in Brazil). These aquifers are often very thick (frequently exceeding 200-300 m.), and possess waters with a relatively high degree of mineralization, particularly towards the deeper zones.

In addition, due to their older age, they are frequently cemented with various types of cement and matrix (clay, silica, carbonates, iron oxides and hydroxides, sulphates, etc.) reducing considerably the actual and effective porosity and therefore the permeability of the formations.

However, due to the volume of these deposits, even with a not-so-large portion suitable for groundwater utilization, they can provide sufficient water resources for many heavy water abstraction activities (as urban water supply or irrigation).

2) Intramontane alluvial valleys

These are alluvial valleys located throughout the mountain ranges regions. They can be relatively narrow valleys with steep longitudinal profiles, steep lateral slopes and narrow alluvial plains on their bottoms, or wider valleys with more gently sloping thalwegs and less steep lateral slopes.

Normally, narrow and deep valleys are the result of stronger river bed erosion, as opposed to slope erosion, which usually tend to produce wider valleys and more important valley-bottom accumulations.

Consequently, the largest alluvial deposits are built in fluvial valleys downstream of semi-arid or arid (or periglaciar) upper basins, where slopes are devoid of vegetation cover and therefore suffer higher erosion.

In humid areas, valleys are narrow and deep, and alluvial deposits are less important. However, even in (presently) humid areas, large alluvial deposits inherited from more arid geological periods can be found.

In any case, when large and wide accumulations of alluvial type are found in humid or sub-humid regions, they are frequently related to tectonic origin. It is the case of the lake Valencia graben in Central-Northern Venezuela (Ref. 65) or the Cauca graben in Colombia, or the longitudinal valley graben South of Santiago in Chile, in all of which important alluvial aquifers are found.

Intermediate types of valleys are found in other locations: the Cochabamba valley in Bolivia (Ref. 86) and the upper Magdalena valley near Neiva, Colombia, are relatively narrow and steep (although they appear to be also tectonically generated); the valleys of Queretaro and San Luis Potosi in Mexico are, on the other hand, wide, with relatively gentle longitudinal and lateral slopes.

These intramontane valley aquifers normally provide good groundwater, but not always the volumes are large enough for urban water supply or irrigation. In the cases of Cochabamba and Cali, large amounts of water are withdrawn (for urban use and irrigation in Cochabamba; mainly for irrigation of sugar cane crops in Cali). In a number of cases, the presence of significant volumes or surface water was limited the development of groundwater resources utilization (cases of Cali and Neiva in Colombia which use respectively the rivers Cauca and Magdalena for most urban uses).

In other cases, the irregularity of the flow of the river(s) (case of Cochabamba) or the degradation of the surface water (cases of Lake Valencia near Valencia and Maracay in Venezuela) has determined an almost exclusive utilization of groundwater for urban water supply purposes (and sometimes for irrigation too).

3) Foothills alluvia

The foothills alluvial aquifers are mainly located on both sides of the Andean and Sierras mountain ranges beyond the boundary with the neighboring low(er) lands.

Similar aquifers can be found in the foothills of the mountainous areas of the Shields (Brazilian, Guyanese), and of the coastal scarpments of these crystalline regions, or of the basaltic plateaux of Southeastern South America (i.e. the foothills of the Serra do Mar scarpment in the states of Sao Paulo, Parana, Sta. Catarina and Rio Grande de Sul in Brazil).

The characteristics of the foothill alluvial formations, containing the above mentioned aquifers, are relatively similar throughout the region. Normally, they are formed of coarse deposits (agglomerates/conglomerates, gravelly sands/gravelly sandstones and various other types of sandy deposits with varied degrees of consolidation and silt and clay contents).

These formations are normally the result of the coalescence of a number of alluvial fans at the outlet of the mountain valleys, immediately after they reach the plain level.

Locally, the presence of less subsident (in relation to the plain) or less elevated (in relation to the mountains) crustal blocks next to the foothills (frequently covered with older sedimentary formations), may prevent the accumulation of foothill formations in appreciable thicknesses. In other cases, the existence of active faulting and strong subsidence processes, can determine the accumulation of very thick volumes of foothill alluvial deposits.

The thickness of these sedimentary units is variable, but it normally increases gradually, beyond the boundary between the mountainous areas and the neighboring lowlands. Maximum thickness of the coarse alluvial formations (which usually contain the water) are found a few km. or tens of km. far from the foot of the scarpment. Locally, they may reach several hundred m. thick.

Further away, although the actual thickness of the whole sedimentary sequence increases, the alluvial formations become thinner and finer, with lower hydraulic conductivities and poorer well yields.

There are many cities which obtain their water from foothills alluvial aquifers: Villavicencio in Colombia and Santa Cruz in Bolivia are perhaps the most representative examples.

4) Plains alluvia

A very important part of the South American continent (as much as 1/3) is occupied by the vast regions of flatlands extending from the Llanos in the Orinoco delta to the lower Pampas, South of Buenos Aires.

In a large measure, the upper parts of these basins were filled during the last geological epochs (Pliocene to Holocene), by alluvial (but also lacustrine and aeolian) deposits transported from the neighboring highlands (Andes in the West and North, Brazilian and Guyana Shields and Basaltic Planalto in the East).

Toward the South, these deposits are related to the flow of semiarid, irregular streams from the foothills of the Andes, through the dry Pampas, and therefore they are formed of intercalated layers of coarse and finer fluvial deposits, often including very fine grain size sediments and salts (as halite, gypsum and anhydrite), or lenses of lacustrine and/or aeolian sediments. Toward the North, the climates are more humid, and therefore the intercalated deposits include more sandy and finer lenses and less very coarse layers (except close to the mountains or those related to channel deposits in the larger rivers).

This type of sedimentation is the result of the variation of successive local environments (i.e. flood plain and channel deposits), or to climatic variations (sometimes providing a record of fluvial activity of Pleisto-Holocene times) during the Quaternary.

Similar plain accumulations are found in the plain rivers draining Planalto or Shield basins (i.e. Parana and tributaries), in which alluvial deposits are also a succession of more or less sandy formations (which include frequent lenses of finer elements and carbonate-cemented or silicified lenses or layers).

A large number of Argentinean cities draw part (or all) of their municipal water from these aquifers. This is the case of San Nicolas, Junin and several municipalities of the Greater Buenos Aires-La Plata region (La Plata, Quilmes, etc.).

Other cities obtaining part of their water from the Parana "sands" or correlative formations (generically called the Arenas Puelches in the Southern Parana region) are Asuncion in Paraguay, and Santa Fe, Rosario and other smaller urban centers in Argentina. (*)

(*) Ref. 4, 27, 47.

Similar alluvial deposits (although devoid of silica or carbonates) are found near the Orinoco floodplains, in which sandy (mainly quartzic) accumulations are found, both as a result of sediment transport by the main river, and of lateral supply provided by the tributaries descending from the Guyana shield or the mountain regions of the North and the West.

Two of the largest plain cities of the Llanos (Ciudad Guayana and Ciudad Bolivar in Venezuela) utilize alluvial aquifers of this type to complement the water drawn directly from the river (Ref. 57).

5) Shields and platforms alluvia

Quaternary alluvial formations are found throughout the shields area, both in the valleys dissected within the shields themselves, and in their periphery next to the outlet of the alluvial streams (present and ancient). These outlets are located in the proximity of the boundaries between the Shield terrains and the lower lying neighboring plains (which could be both the inland large flatlands or in the narrow coastal plains).

These deposits are of varied thickness, but somewhat thinner than analogous deposits found in the intramontane valleys of the mountain/sierra region and its foothills. They are particularly well developed in the semi-arid Brazilian Northeast, along the Brazilian coastal plains (where they are frequently expressed as foothill deposits of the Serra do Mar scarpment and its Northwards prolongation) and the fluvial valleys of the Uruguayan-Rio Grandense crystalline island.

These formations, which are frequently formed of quartzic or arkosic sandy or gravelly materials, may contain significant volumes of groundwater and can deliver relatively high yields due to their high porosity and hydraulic conductivity.

Several cities of the Brazilian Northeast and in the Atlantic coastal plains utilize groundwater from this type of aquifer. In the Northeast, groundwater is widely used due to the lack of surface water resources. Along the coastal areas there are few large rivers, because the waterdivides are very close to the shoreline, not allowing the development of large river systems (Ref. 33).

Coastal rivers in Brazil (with only a few exceptions) are short, with very small basins, and the base flows are rather limited (in spite of the locally high precipitations levels). This fact has helped to promote the utilization of groundwater in many coastal areas, sometimes provoking the intrusion or upwelling of saline water.

Some of the larger alluvial valleys of the States of Sao Paulo and Minas Gerais also utilize alluvial groundwater for water supply purposes, but in a lesser degree, due to the presence of permanent flowing streams (due to the higher precipitation volumes), which are of easy access or relatively dependable.

Some examples of alluvial aquifers utilized locally for urban water supply, include the aquifers contained in the alluvial deposits of the rivers Tiete, San Francisco, Guaiba and Maranhao in Brazil and of the Demerare and Esequibo rivers in Guyana.

In Uruguay and Rio Grande de Sul (Brazil), alluvial deposits are relatively thin. However, there are several cities which utilize them for municipal water supply. In Uruguay, several small cities surrounding the metropolitan area of Montevideo utilize the Plio-Pleistocenic (sandy-gravelly) Raigon aquifer and there is still potential for complementary utilization for the main water supply system for the city of Montevideo itself.

In a similar way, there are other cities which utilize alluvial aquifers of similar characteristics and ages in Southern Brazil (Pelotas from the Graxahim formation underlying the river Sao Gonzalo waterway and Uruguaiana on the margins of the river Uruguai).

6) Coastal alluvia

These aquifers are found practically throughout all the coastal areas of the continent: from Northwestern Mexico (Tijuana, Mexicali, La Paz), through the Pacific coastal plains of South America (Trujillo, Lima, Valparaiso) and the Southern Pampas (Mar del Plata, next to the crystalline islands of Tandil and La Ventana), and from Northeastern Brazil and Guyanas (i.e. Sao Luis island, Fortaleza, Maceio and Georgetown), to the coastal regions of the Caribbean and the Gulf of Mexico (i.e. Santa Marta, Colombia, in Maracaibo, Venezuela, and Veracruz, Mexico, among others).

These alluvial coastal deposits are frequently interfingered with sediments of littoral origin, which when coarse (case of beaches, bars, aeolian ridges, etc) can also be aquifers with good yields, often without any relevant break of the hydraulic continuity.

By and large, these complex groundwater reservoir are of easy access, normally with shallow water levels and good yields.

However, these aquifers suffer often of problems of saline intrusion (or upwelling), due to overpumping, when water is heavily abstracted for urban use or irrigation purposes.

Some coastal cities having serious problems of salinization of wells include Lima in Peru, Santa Marta in Colombia, Coro in Venezuela, Rio Grande and Natal in Brazil and Mar del Plata in Argentina. Buenos Aires-La Plata also have a salinization problem, but in this case the increased salinity is due to inherited salts contained in a coastal formation (see Section 4.3).

3.3.5 Conclusion

Alluvial aquifers are the most common type throughout the Latin American region. They are of varied dimensions, grain size and petrographic composition. Their porosities and hydraulic conductivities, as well as their yields, are also extremely variable. However, on the average, these units are hydrologically highly productive, with frequent good urban water supply potential.

On the minus side, it must be observed that their shallowness (which is an economic advantage for their utilization) may facilitate contamination from surface sources.

In brief, moderately high yields, easy access and high vulnerability to pollution are the main traits of alluvial aquifers of the various kinds found in Latin America. Their use requires special care, but if the exploitation is properly carried out their potential as a water resource for urban use can be very high.

3.4 Carbonate aquifers

3.4.1 General

Carbonate rocks are very abundant throughout the world, with very varied genetic and depositional histories. Some originated in sea bottoms and near-shore environments at varied depths (various oceanic organic muds, reefs, tidal plains, calcareous beaches, etc.), some in lacustrine, palustrean or even alluvial environments, some can be of igneous origin (as in the cases of carbonatites) or suffered metamorphic transformations (as in the case of marble).

Generally speaking, carbonate aquifers can range between materials with high primary porosity and relatively less important fracture porosity (cases of reef and lumachelle formations, calcarenites and carbonate tuffs and miscellaneous carbonate detritic sedimentary materials) and those in which porosity is mostly of secondary nature developed through processes of fracturation and/or chemical dissolution (cases of most aquifers developed in compact limestones and dolostones).

Carbonate rocks are often very dynamic hydrogeological environments. With time, diagenetic processes tend to reduce the primary porosity, through dissolution and recristallization at the local level of the various carbonate minerals contained in the formations. On the other hand, circulation of water through fractures tend to dissolve the minerals of the wells "eroding" them, and forming underground water paths which gradually develop and grow.

As a result of these processes, which often take place simultaneously, some carbonate aquifers have at the same time a relatively high primary porosity (still not completely affected by diagenetic processes) and a secondary porosity (in fractures) under development.

These rocks can contain considerable volumes of water, both in their intergranular space or in their fractures. As a result of water action the fractures can be enlarged and therefore water circulation can be facilitated. These processes of development of open fractures through dissolution in carbonate rocks are known as karstic processes. Consequently, the aquifers contained in these formations are therefore called "karstic aquifers".

When the wells (or springs) happen to connect with the main karstic waterways, karstic aquifers can be extremely productive with enormous yields. In those cases, very frequently, they are used for various activities requiring large volumes of water, as it is the case with urban water supply and agricultural irrigation.

However, there are a number of limitations for the utilization of this type of groundwater resource. Firstly, because of its frequently discontinuous characteristics, not all boreholes are productive, and a number can result dry if they don't happen to hit the main fracture system(s). Secondly, although the yields can be impressive, not always the available volumes may allow the sustained utilization of large quantities of water. In many cases, the aquifers reservoirs possess less (even much less) water than other formations of other nature with smaller yields.

An additional element of concern, relates to the fast groundwater flow through the open fractures, which do not allow for degradation of the various contaminants that may go from the surface into the groundwater systems. However, in spite of these problems, karstic aquifers remain some of the best and more confiable aquifers utilized for urban water supply throughout the world.

3.4.2 Karstic aquifers of Latin America

Although carbonate formations are widespread throughout Latin America, highly productive carbonate aquifers are mostly found towards the Northern hemisphere, next to the Caribbean and Gulf of Mexico regions.

There are important carbonate aquifers in several Caribbean islands (Cuba, Jamaica, Puerto Rico, Barbados, several islands in the Bahamas archipielago, etc.), in the neighboring peninsulas (Yucatan and Florida), in the Mexican hinterland (Nuevo Leon, Tamaulipas, Coahuila) and in the coastal areas of Northern South America.

As a result of the existence of these aquifers, many cities have based their water supply on their utilization. Havana in Cuba, Merida in Mexico, Montego Bay in Jamaica, Bridgetown in Barbados and Miami in Florida, USA*, depend exclusively on groundwater obtained from carbonate aquifers.

Other cities which depend on a considerable measure on carbonate aquifers include Kingston (Jamaica), Nassau in the Bahamas (which also utilizes desalinized sea water), and several of the largest cities in Puerto Rico (San Juan, Ponce, Arecibo).

Carbonate rocks in Latin America are very heterogeneous both in composition and genesis, with varied porosity, fracturation and degree of consolidation, and therefore, their hydrogeological properties are also very varied.

---

* This last city cannot be defined, strictu sensu, as belonging to the Latin American/Caribbean region politically speaking, but it is located in the Caribbean geological area of influence, and is strongly Latin American in many other ways.

There are very compact, non fractured limestones or dolostones with very small porosity, and practically no water resources value for any practical purpose; and on the other hand there are a number of high porosity, densely fractured carbonate formations that can provide huge volumes of water with excellent potential as urban water supply sources.

Examples of highly porous carbonate aquifers can be found in the molassic basins of the Sierra Madre del Sur, in Mexico (i.e. in the Huacapa river basin, near Chilpancingo); in the foothills of the Jamaican Highlands towards the Northern side of the island; in Southern Puerto Rico and along the coastal region of Venezuela.

Examples of typical karstic (with fracture flow) aquifers can be found in the aquifers of Havana South, in Montego Bay (Jamaica), in the Yucatan peninsula and in Nuevo Leon in Mexico and in the Morelos formation of Central Southern Mexico.

Karstic aquifers utilized for urban water supply in Latin America are particularly vulnerable to contamination. **Firstly**, these aquifers are located close to the cities (even underneath the urban areas, in some cases) and therefore domestic and industrial wastes can find easily their way into the groundwater reservoirs. **Secondly**, the areas surrounding the cities are also the areas in which agriculture is more intensive, and hence the use of fertilizers and pesticides is more important. And **thirdly**, fast water circulation within the karstic aquifer systems does not allow for an adequate filtration and depuration of the recharged water.

Examples of these problems are found throughout all karstic regions of the continent (and elsewhere, for that matter). Problems of industrial and domestic wastes contaminating the urban aquifer are found in Merida and Kingston. In Havana, it is suspected that the intensive agricultural practices in the recharge area of Havana South may be negatively affecting the karstic aquifer that is the main source of water supply for the city of Havana and surrounding areas.

It has become clear that carbonate aquifers are very sensitive to anthropogenic interference and careful management is necessary for their rational utilization. Latin American cities are not an exception. In Chapter 6 additional facts and comments on this and related matters are included.

3.5 Pre-tertiary sandstones and conglomerates

In this section we refer to the aquifers contained in the large Pre-Cenozoic sedimentary basins of the continent. Obviously, several other basin rocks may contain groundwater in utilizable volumes (as it is the case with many carbonate rocks and some lavas). Carbonate rocks and lavas were specially discussed in sections 3.2 and 3.3. Excluding the above mentioned petrographic units (and even -to a certain extent- without excluding them) by and large, the main groundwater reservoirs of the large basins are constituted by sandstones and conglomerates.*

The principal characteristics of the older sandstones and conglomerates that make them suitable to contain aquifers of urban use are the following:

1) Sufficient thickness (normally of a couple of hundred meters or more);
2) Sufficient lateral extension (normally of a few thousands or tens of thousands of km2);
3) Not excessively affected by macro-faulting and folding (which may affect their hydraulic continuity);
4) Primary porosity at least in the "medium" range (in general, in excess of 5%). In some cases, the presence of fracture flow may compensate for the reduced primary porosity;
5) Hydraulic conductivities values in the 10-0 to 10-1 m/d range or more;
6) Consequently, high well yields of at least 100 liters per minute (depending on the required investments);
7) Depth not beyond one to two-thousand meters (in which case exploration and exploitation can become too expensive);
8) Relatively shallow static and dynamic water levels (artesianism is desirable but frequently this condition is lost after heavy abstraction);
9) Sustainable rates of renewability (which normally related although not exclusively, to recharge from the ground surface);

10) Low levels of mineralization (i.e. TDS levels of less than .05%).

---

* We are not including in this Section either, the younger Cenozoic sandstones and conglomerates of alluvial origin which are treated separately in Section 3.3.

Most sandstones and conglomerates meeting these conditions are located in large or medium size Pre-Cenozoic sedimentary basins, and are of alluvial, coastal-marine, or aeolian origin.

The main sedimentary basins of the continent, whose hydraulic continuity has been less affected by tectonic events, are located around the cratonic tectonic provinces of South America and in the Central South American plains region.

One example of a large basin of this type is provided by the huge Amazonas sedimentary basin which is composed of a Pre-Cenozoic sedimentary fill in the bottom part and a large Cenozoic sequence overlaying it. Their use is practically nil due to their depth and to the very low density of population and abundant water resources of the Amazonian region.

Another very large sedimentary basin of South America is the Parana basin. This basin which underlies the Parana river and its tributaries is a very deep basin (it goes down to 6,000-7,000 m. in its central axis, next to the course of the river Parana in Argentina) composed by a impressive sequence of Paleozoic to Cenozoic sedimentary rocks.

This basin contains a large number of conglomerates and sandstones that contain regionally or locally utilizable volumes of water.

The Devonian is composed by an older formation of arkoses and coarse sandstones and a younger unit of sandstones. Due to the fact that they are normally found at great depths they are not used for any practical purposes.

The Eo-Gondwana (Permo-Triassic) also possess coarse detritic formations on its base. They are the Conglomerates (tillites) of Itarare - San Gregorio of glacial origin and the sandstones of Rio Bonito - Tres Islas formed in a fluvio-glacial environment. These units contain water but their use is limited due to: 1) in large areas they are too deep; 2) where they are at a reachable depth their water quality is poor due to excess S and F. The upper part of the Eo-Gondwanan sequence is also composed of sandstones (Estrada Nova) which are locally utilized as aquifers in Southern Brazil and Uruguay.

The upper filling of the Parana basin is known as the Neo-Gondwana and is composed mainly (but not exclusively) of aeolian sandstones (paleo-desert of Botucatu/Tacuarembo) and a thick accumulation of basaltic flows. Botucatu is a medium to high porosity sandstone, poorly consolidated and contains one of the largest aquifers of the continent extending from Mato Grosso to Uruguay with a estimated storage volume of 10,000-20,000 Km3. The Botucatu aquifer, in addition, contains good quality potable waters practically throughout the region, provides very high yields (often of about 500 liters per minute) and is artesian in a large part of its extension. In spite of these advantages the aquifer is only used close to its outcropping range due to the difficult access through drilling. In fact, the Botucatu formation is covered, throughout most of its occurrence areas, by a basalt mantle several hundred meters thick (locally more than 1,000 m.) which is not only largely unproductive (hydrogeologically speaking) but also very difficult and expensive to drill through (*). The upper part of the Parana basin sequence is composed by relatively thin deposits of Late Cretaceous and Cenozoic age. Some of these deposits are utilized for groundwater supply purposes, as is the case with the formation Bauru in Brazil and the formations Mercedes-Asencio in Uruguay, but, by and large, the most commonly utilized aquifers are the Plio-Pleistocene alluvial sediments. These aquifers are described in sections 3.3, 4.2, 4.3 and 4.7.

There are several other large sedimentary basins in the region, but not as large as the two previously mentioned basins. A brief description of the main ones is presented in Chapters 2 and 4.

(*) Ref. 18, 52 and 58.

3.6 Coastal aquifers

These aquifers are not defined through their genesis but rather through their location next to the coast. Following this definition, any aquifer located near the coastline is a coastal aquifer.

There are many possible types of coastal aquifers depending on the historical geology of a specific area. From a genetical point of view, and due to their location, a large number of coastal aquifers are the result of the geological interference of continental and littoral -marine formations. In some cases, they are composed exclusively of coarse marine or coastal detritic deposits (such as beach sands, coastal dunar sands, or miscellaneous shallow water sandy deposits).

In some other cases they are composed of marine or littoral carbonate rocks (which in most cases are also genetically marine or littoral: see Section 3.4). A considerable number of coastal aquifers are alluvial with or without intercalation of coastal or marine formations (see Section 3.3), and a smaller number can be volcanic (see Section 3.2), composed of older coarse detritic sedimentary rocks (see Section 3.5) or of crystalline rocks.

In spite of those varieties of genesis and sedimentological characteristics, these aquifers have in common their location next to the sea. This location puts them normally in close contact with the high salinity groundwaters usually contained in the sub-oceanic geological environments and are -therefore- very sensitive to overpumping, particularly beside the sea shore. In addition, these are low elevation hydrogeological units (frequently below sea level or slightly above), located at the mouth of the various (present and ancient) fluvial basins, and in close association with existing waterways (which normally have their maximum annual flows near their mouths into the ocean).

The main problems affecting these aquifers relate -therefore- to salinization of their waters due to various forms of saline encroachment. Due to their smaller density, freshwaters "float" on more saline waters. Because their difference of density is relatively small (only 1/40th when normal seawater (with 3.5% TDS) and freshwater are compared)* the column of freshwater that will normally overlay the saltier contiguous groundwater, can displace the salty water many meters below sea level. However, when careless pumping takes place, for each meter of drawdown of the water levels, there is a related increase of the lower-lying interphase between fresh and salty water of 40 m.

---

* Density of sea water is 1.025.

This "upconing" of the salty water, may occur long time after the drawdown has taken place (sometimes a few years). For this reason, the effects of overpumping may not be felt until it is too late.

This problem is very serious because a large number of Latin American cities are located along the coastal regions (particularly on the Pacific and Atlantic coasts of South America and the Caribbean), and many of them utilize groundwater (obtained from different types of coastal aquifers) for their urban water supply.

There are about 30-40 large coastal cities utilizing groundwater for the above mentioned purpose and some of them have encountered problems analogous to those described in the previous paragraphs. Some examples of this are provided by Lima in Peru (which obtains about 40% of its water supply from a coastal alluvial aquifer), Havana in Cuba (which extracts all its water supply from a karstic aquifer on the coastal plain of the southern Havana region, next to the Caribbean coast line), Mar del Plata in Argentina (also taking its water from an alluvial aquifer next to the Atlantic Ocean Shores), Natal in Brazil and Santa Marta in Colombia.

Many other smaller towns and some larger towns in a lesser degree have similar problems.

Chapter 4 WATER RESOURCES AND SUPPLY IN SELECTED URBAN REGIONS

4.1 The valley of Mexico

4.1.1 Environment and history

There are probably very few cases in the world in which a physical environment has been so completely transfigured by urban development as it is the case in Mexico City. The valley of Mexico is a 9,600 km2 closed basin raised to an altitude above 2,200 m. above sea level, located in the heart of the Mexican Neo-volcanic Belt (see Fig.3).

Before the arrival of the Europeans, in 1521, the valley was a depression in whose bottom several lakes had developed due to volcanic obstruction of the drainage about 700,000 years ago. These lakes occupied a total area of about 2,000 km2 and were partially connected, particularly during periods of highwaters. Three of the lakes contained freshwater (Lakes Mexico, Chalco and Xochimilco) and the other three, brackish water (Lakes Texcoco -the largest with 800 km2-, Zumpango and Ecatepec) (see Fig.4).

The area was (and is -to a certain extent-) sub-humid, rainfall was probably slightly more than present figures (which range from 600 mm. per year in the bottom of the valley to 1,200 mm. in the nearby mountains), with relatively cool average temperatures (for the sub-tropical latitude in which the city is located) ranging from 8 to 15 degrees C depending on the altitude, and highly fertile and easily workable deep soils.

The land was completely covered by thick forests, particularly on the slopes of the mountains and highland areas. The valley plains (which were originally also covered by forests), were very soon dedicated to the agriculture and therefore parts of the forest were eliminated to give way to farming activities.

In addition to the freshwater lakes, there were a large number of springs providing considerable volumes of good quality water, located both around the lakeshores, and on the foothills of the nearby mountains.

Due to these environmental resources, the valley was occupied from very early by a number of indigenous populations, which based their economy on a number of locally domesticated crops and farming animals (corn, tomatoes, chilies, cacao, turkeys, "escuincle" dogs,

---

(*) Ref. 12, 15, 39, 42, 45, 46, 62, 75, 81 and 90.

etc.) and fishing. Because the local civilizations did not have any domesticated working animal and did not use the wheel, most of the commerce had to be carried out by using boats (or on human backs).

Several nations successively inhabited and controlled politically the lacustrine area during the last few centuries before European conquest started. The last nation to control the region were the Aztecs. This group had arrived from the legendary land of Aztlan (probably located to the North in more arid territories) during the 14 century A.C. and due to the general occupation of the lacustrine shores by other groups, they were forced to settle some swampy lands inside the lake.

At that time, the Aztecs probably obtained their livelihood from fishing and commerce with neighboring groups.

Gradually, they managed to build an island in the Southern sector of the lakes (in the center of the Lake of Mexico), in which a town developed: Tenochitlan; which later was to become the main city of the valley.

Through alliances and wars, the Aztecs built an empire, and Tenochitlan grew to become a thriving city of several hundred thousands people. A bridge was built to communicate the island with the mainland, and large boats were used to transport people and merchandises in all directions.

The Aztecs built important pieces of engineering (earth dykes) to control flooding and to separate lakes with saltier water from those of fresher water. In addition, aqueducts were built to bring fresh water from the springs to the city (through the lake and along the dikes).

4.1.2 From Tenochitlan to Mexico City

It is difficult to believe the extent of the changes that took place in the few centuries after the Spanish conquest.

Today, the proud Tenochitlan has disappeared and only scattered archaeological remnants can be found during excavations. In its place stands the highly urbanized downtown area of Mexico City.

The Lake of Mexico is gone. Instead, there are several hundred km2 of urban neighborhoods built on what used to be the lake bottom. The lakes of Chalco and Xochimilco are also gone. Only a few canals and little lakes are left. The rest has also been covered by streets, buildings and other urban structures.

The three Northern lakes have also disappeared. As it also happened with the Southern lakes, they were gradually drained (since 1786) and the former Texcoco lake bottom has become a flat vast plain*, in which vegetation does not grow (or grow with difficulty) due to the high levels of alkalinity (pH in excess of 10), and an intricate maze of wells and pipes pump the brines contained in the lacustrine sediments out of the ground for exploitation of the various chemicals contained in the groundwater (sodium carbonates and sodium chloride).

The old springs that provide water for the riverine populations are also gone, now more than 5,000 wells extract in excess of 50 m3/sec. of water from a depth averaging more than 100 m., gradually pushing down the aquifer levels by as much as 1 m./year.

As a result of this overpumping and due to the compactation of the upper layers of sediments, widespread subsidence phenomena have developed. The sinking has reached more than 6 m. in several places and due to the differential rates, many structures have been weakened and in some cases dangerous deviations from the vertical can be observed (as it happens in the Cathedral, in the older Basilica de Guadalupe church and the Palacio de Bellas Artes).

This type of phenomena has been exacerbated by the frequent seismic activity, of which the most recent destructive example was felt in the earthquake of September 1985.

The forests that used to cover all the adjacent hilly slopes have practically disappeared and widespread soil erosion processes have developed. On the other hand, most former agricultural lands have been covered by pavements, houses and other urban constructions.

Quarries have also been excavated throughout the whole region to obtain construction materials. Some became garbage dumps in which part of the annual 10 million tones of garbage are disposed.

A not negligible portion of the garbage is disposed in the "shores" of the (former) lake Texcoco particularly on its Southern part, Ciudad Netzahuatcoyotl, which is located in that zone of the city, is a 3 million people neighborhood built on the bottom of the lake. This recently created urban area has become a highly degradated environment in which developed areas alternate with garbage dumps and slums.

The drainage of the valley, which used to go to the lake, now is channelled out of the basin, together with the urban wastewaters through a system of canals and tunnels into the Gulf of Mexico hydrographic system.

---

* Lake Texcoco was practically totally drained in the early 900's. However, still today, there are permanently flooded areas which are used for evaporation of the water to obtain high concentration brines.

A number of the pumping wells utilized for urban water supply are located next to the canal evacuating both the wastewaters and the excess stormwaters (the Chalco Canal). Risks of contamination are obvious and, in fact, some wells had to be closed due to the presence of nitrates in the water.

The atmosphere of the valley has also changed its composition; emissions from 4 million vehicles and 25,000 industrial establishments in a poorly oxygenated environment (due to the altitude) have transformed the air of Mexico City into one of the most unhealthy urban environments for human life, particularly near the downtown core.

Twenty-one million people live today in Mexico City, making it the largest urban center of the world. Seven hundred and fifty thousand persons are added every year to its population, both by vegetative increase and immigration from the rest of the country. It is estimated that by the year 2000 the city will have 29 million people (surpassing the whole of Canada!) and by the year 2010, 38,000,000 inhabitants (see Table 3).

All the problems being mentioned previously, are going to be still further exacerbated, and the ancient paradisiac valley may become (and is in fact becoming already) one of the worst environmental nightmares of the XXI century.

4.1.3 The aquifer and the urban water supply

The aquifer of the Valley of Mexico is one of the key natural elements of the Mexico environmental puzzle. It provides the bulk of the water that makes possible the survival of the City as such.

Some water is brought form outside the basin (from the Lerma-Cutzamala basin), but the volumes are less than 1/5 of the total requirements.

On the other hand, any other option to bring outside water to the valley is becoming unpractical or too expensive. The Lerma-Cutzamala water resources are almost exhausted and the utilization of other basins (as the Balsas basin or the Amacuzac sub-basin) may imply pumping up the water about 1,200 to 1,500 m., plus the construction of long pipelines, storage reservoirs and other related expensive engineering works.

It must also be considered that the use of additional out-of-the-basin water will hurt a number of communities that are dependant on that water for irrigation and supply.

In the meantime, the aquifer remains the main option for the survival of the Mexico urban region.

4.1.4 Geology and hydrogeology of the Valley

The Mexico aquifer is contained in a number of Tertiary and Quaternary units with a thickness ranging from a few hundred meters to nearly 2,000 m. These units are formed by a wide range of sedimentary materials, including various pyroclastic and alluvially reworked pyroclastic sediments, breccias, conglomerates and agglomerates, several types of volcanic sandy formations, volcanic ashes, lacustrine lenses and intercalated lava flows (see Figs. 5 and 6).

The whole of these deposits are closely related to the active vulcanism that took place during the construction of the Trans-Mexican Neo-volcanic Belt and synchronic epirogenesis.

The base of the sequence is overlying the Cretaceous limestones of the Morelos formation, a 1,000 m. -thick heavily karstified unit, which in the Mexico area constitutes in some way the "floor" of the volcanic sequence.

The above mentioned "base" is composed of the conglomerates and sandstones of the Balsas group of Eocene-Oligocene age. This group is a molasse, which filled the grabens developed during the post-Laramidic orogenetic period. It includes up to 500 m. of conglomerates covered by poorly sorted finer deposits (sandy, but also silty and clayey) up to 2,000 m. thick.

Overlying the Balsas Group there is a complex volcanic sequence of Early Miocene age, composed of various types of pyroclasts (tuffs, breccias, and agglomerates) and alluvial clastic sediments and lava flows intercalated. Thicknesses encountered in recent boreholes varied from 390 to 1,750 m.

Overlying the Early Miocene volcanics, there is a 300-800 m. thick volcanic sequence which includes andesitic lavas, volcanic breccias and tuffs, which in turn is overlain by andesitic-dacitic volcanic of Early Pliocene age, including lava and several associated unconsolidated pyroclastics (300-600 m. thick).

On top of these extrusive rocks, the pyroclastic flows of the Otomi formation are found, with ash-flow tuffs, ash-fall tuffs, breccias, and associated andesitic lavas.

The Otomi formation is covered by a complex sequence of volcanic units including the formations Las Cruces, Zempoala, Navaja and undifferentiated Pliocene pyroclastics of Pliocene age and the formations Llano Grande, El Pino, Tlaloc, Popocatepetl, Chichihuanitsin and Iztaccihuatl of Quaternary age.

Finally, the plateau depressions are filled with a sequence of alluvial and pyroclastic accumulations with thicknesses of about 500 m. (Formation Tarango in the valley of Mexico) over which a few tens of m. thick lacustrine deposits are found (locally up to 400 m.).

The valley of Mexico, therefore, has been formed as a result of continued volcanic build up, in which the molassic detritic formations of the Early Tertiary were covered by a long and complex succession of volcanic extrusions, which included huge volumes of pyroclastic materials (more or less reworked by fluvial action) and intercalated lava flows. In moments of volcanic paroxysms, tuffs breccias, ashes and lava were formed, while in moments of less activity, alluvial and lacustrine action was more important. From a hydrogeological point of view, the main water-bearing formations are the Tarango Formation and associated alluvia, and the Cenozoic sequence of fractured pyroclastic and lava flows. These formations are overlain by younger lacustrine sediments, giving a confined character to the main aquifer.

This whole sequence can be up to 2,000 m. thick, but the lower 1,500 m. are more consolidated with a smaller effective porosity (associated with fracturation) and -hence- much less production potential. The upper tens of m. of the aquifer are too close to the upper lacustrine clays and continued pumping may produce dewatering and consolidation of these clays, unleashing subsidence processes.

Therefore, the usable portion of the aquifer is normally situated between 100 and 500 m. below ground surface.

Recharge to the aquifer mainly takes place in the mountains area (Chichinautzin in the South, Sierra Las Cruces in the West and Sierra Nevada to the East). The total recharge has been estimated at about 25 to 50% of the precipitations (25% in Sierra Las Cruces, 35% in Sierra Nevada and 50% in Sierra Chichinautzin). Of these volumes, about half flows towards the valley of Mexico and the rest outwards to other basins.

Accurate figures for inflow to the valley aquifer itself are difficult to come by. However, they are certainly below 50 m3/sec. (which is the total abstraction) due to the general lowering of the water levels. Figures of 30-40 m3/sec. are probably not far from reality.

Additional lowering of the water levels will produce a consequent increase of inflow from the "Sierras" (due to increase in gradients). However, this is not enough to compensate the deficit, particularly if pumping is increased (see Fig. 7).

Precise forecasting of aquifer reaction to very prolonged pumping requires accurate modelling for which only recently adequate information on the geometry and hydraulic properties of the reservoir have been available. Modelling of the aquifer has been mainly developed at the Instituto de Geofisica of UNAM by I. Herrera and other Mexican scientists and it is expected that factual adjustments to the existing models and new models to be developed in the future will allow to predict the actual potential of the groundwater resources of the Valley.

4.2 The Sao Paulo metropolitan region (*)

4.2.1 Introduction

In spite of its relatively reduced size for Brazilian standards (247,898 km2), just over 3% of the national territory, the State of Sao Paulo with its 33 million inhabitants possesses about 23% of the total population of the country with a density among the highest in the Latin American region (almost 140 inhabitants per km2).

The State also concentrates in excess of 65% of the industrial output on the country, and is the largest agricultural producer (its plantations of sugarcane, coffee and citric fruit trees are the largest in Brazil and among the largest of the world). It also possesses a very numerous cattle stock of nearly 12 million and is the first producer of milk and dairy products.

The State population is main urban, (more than 80%) with about 29 cities exceeding 100,000 people. The largest of those, and capital of the state is the City of Sao Paulo, with a population of 17,500,00 inhabitants. The 37 municipalities forming the Greater Sao Paulo metropolitan area, are home for 55% of population of the state and 15% of the total population of Brazil. The Sao Paulo urban area alone produces more industrial goods than the rest of the country. By far, more jobs, are created in Sao Paulo than in any other major city of Brazil.

It does not come as a surprise, then, that the city of Sao Paulo has seen its population increase through constant immigration from other areas of the Brazilian territory. If present trends continued unchecked, the Greater Sao Paulo will possess about 26-27 million people by the year 2000 and 35-37 million by the year 2010.

4.2.2 Historical background

Portuguese settlement in the Sao Paulo region started in 1532, when Martin Afonso de Souza founded the city of Sao Vicente in the Atlantic coast about 400 km. South of the Bay of Rio de Janeiro. In that part of the country, the coastal area is a narrow plain at the foot of the scarpment of the Serra do Mar, with little room for agricultural expansion. The next step was to found a city in the interior, beyond the coastal range. This was done by the jesuits, who had already missions in the Upper Tiete basin.

(*) Ref. 3,32,44 and 56.

The city of Sao Paulo de Piratininga (which was to become simply "Sao Paulo" in the future) was finally founded in 1554, on a hill between the rivers Anhangabau and Tamanduatei, tributaries of the Tiete river.

During the XVIIth and XVIIIth centuries, the growth of Sao Paulo was tied to its role as traffic center of indian workers for the sugar cane plantations of the Northeast, and for the mineral exploration in the hinterland (particularly in what was going to become the State of Minas Gerais). At a later stage, in the XIXth century, the city became the center for the production of coffee, which was going to be -with time- the main export item of the region and the country for many decades.

During the XXth century, particularly during the last decades, the city became a very strong industrial center, both for national consumption of industrial products and for export. Some of the most important industrial activities include metallurgy, automobile manufacturing, chemical, mechanical, textile and food industries, etc.

4.2.3 Geology and hydrogeology

The city is located in the heart of the "Planalto Paulistano" which is a 5.000 km2 area of undulating relief, with elevations ranging from 715 and 900 m. above sea level. The region is underlain by crystalline shield rocks including phyllites, micaschists, gneisses, various types of migmatites and isolated granitic intrusions.

In the Sao Paulo site itself, there is a sedimentary basin of tectonic origin, developed during the Pliocene and Pleistocene Epochs of the Cenozoic Era. The sediments of this basin extend for about 1,000 km2, with a maximum thickness of 300 m. and are composed of clays, silts, clayey sandstones, and some sandy and gravelly lenses. The crystalline areas of the Planalto Paulistano are deeply weathered, with weathering mantles locally exceeding 70-80 m. thickness.

The main aquifers of the Sao Paulo region are the coarser sandy lenses of the Sao Paulo formation and the thick mantle of weathering in the crystalline areas. The wells in the Sao Paulo aquifer are normally screened at depths from 100 m. to 200 m. and deliver yields of 50 to 1,700 liters per minute.

4.2.4 The environment

The area possesses a Sub-tropical humid climate, with average annual temperatures of 20 degrees C, varying from a low average of 14 degree C in the winter (July) and a high of 26 degrees C in the summer (January).

The Sao Paulo site is among the most humid areas of Brazil. Average annual rainfall ranges from 1,500 to 2,000 mm. in the Sao Paulo stations, and can reach in excess of 3,000 mm. per year in some neighboring hilly areas. Hydrographically, the city is located very close to the waterdivides between the large Parana basin to the West and the small steep coastal basins of the Serra do Mar scarpment to the East. The city itself, has grown to occupy the valley of the river Tiete and its largest local tributary: the river Pinheiros.

The river Tiete is the hydrographic backbone of the state of Sao Paulo draining an area of 150,000 km2 and flowing Westwards form its sources in the Serra do Mar highlands, to the Upper Parana, about 150 km. North of the river Parapanema confluence.

4.2.5 Problems of water management and supply

Originally, all the Sao Paulo water drained towards the Parana basin. However, in 1920 a reservoir was built in the Upper Pinheiro basin (the "Billings" reservoir) with the purpose of taking advantage of the Serra do Mar fall towards the Atlantic, for hydro-electrical production purposes. The project included building a reservoir, and letting it fall towards the coastal plain for power production.

At that time, the river Pinheiros was not contaminated, because the city growth had not reached it yet. Presently, the river Pinheiros has become an "open sewer", its water is a combination of highly contaminated urban wastewaters and stormwaters and this is what is presently being pumped up into the Billings reservoir.

Instead of writing off the reservoir for water supply purposes, the Billings reservoir has been divided in two parts: one portion which is the one who receives the water from the Pinheiros, and another section which is utilized for water supply purposes by the large suburb of San Andre (with in excess 1 million inhabitants). Both parts of the reservoir were divided by a relatively permeable earth dam which allows flow in both directions; however, the "water supply" water is kept at a higher level than the contaminated water in order to restrict the flow in only one direction. The Billings reservoir, however, receives probably also polluted water from urban encroachment in its basin. Close monitoring of the situation is required in order to prevent the obvious hazards represented by utilizing a water body with those risky characteristics.

The upper course of the river Tiete has also become a highly contaminated river (another virtual "open sewer"). Its waters are partially utilized for irrigation of vegetable farms (for consumption in the city of Sao Paulo) and then continue flowing downstream through the "Paulista" hinterland, where they are utilized for water supply purposes by many communities of the Sao Paulo interior.

The water supply for the city of Sao Paulo and neighboring municipalities is obtained mainly from a complex network of reservoirs utilizing many small tributaries of the Tiete in the upper basin of this river (which includes the previously mentioned Billings reservoir in the upper Pinheiro basin).

The total municipal water consumption of the Greater Sao Paulo is of about 50-55 m3/sec. It is expected that by the year 2000 it will reach 65-70 m3/sec. and 80-85 m3/ in the year 2010. These water volumes do not include private wells and are primarily obtained from surface water sources.

Some groundwater is obtained for municipal purposes utilizing both the aquifer contained in the Sao Paulo formation and in the weathered mantle of the crystalline complex. By far, the main use of groundwater is by the industrial establishments with consumption volumes of 20-25 m3/sec. (slightly more than 1/3 of the total).

4.2.6 In brief

Although the city of Sao Paulo is located in a high rainfall site, the available water volumes are limited due to the proximity to the Serra do Mar waterdivide. All rivers are small, with small catchment basins and many dams had to be built in order to store the water required by this huge megalopolis. In addition, a complicated system of pipelines, tunnels, storage tanks, and various other conduction and storing structures have been constructed (and more are required) to bring the water for Sao Paulo from the surrounding small basins and reservoirs.

Unfortunately, groundwater resources are not very abundant either. Sao Paulo is located on the crystalline Brazilian shield with few hydrogeologically productive areas. The presence of the tectonic basin of Sao Paulo allows some storage underneath the city and some water is available from the weathering mantle of crystalline rocks. However, the volumes available from this source are also limited.

In addition, the city has not controlled properly its wastes during too many years. The rivers are heavily contaminated, some catchment basins are threatened by urban expansion and therefore contamination, and the groundwater reservoirs are not protected.

Sao Paulo will be facing a difficult environmental future if a much more careful management of its water resources is not implemented. Only then, it will be possible to survive in this hydrological environment, which was suitable to satisfy the needs of a small or medium size city, but is by no means adequate to solve the water problems of a megalopolis of nearly 20 million people.

4.3 The Greater Buenos Aires and La Plata

4.3.1 Environment and history

The city of Buenos Aires was founded in 1536 by the Spanish explorer Pedro de Mendoza near the confluence of the Parana and Uruguay rivers on the Southwestern shore of the River Plate estuary. The environmental set-up is very striking. The city is located on one of the largest grassland plains on the planet: the Pampas. The Pampean plains are vast, almost flat area of about 1 million km2, in which slopes are normally of less than one per thousand, drainage is difficult and lands are easily flooded.

Before the Spaniards arrived, the Pampas were domain of a large number of herbivorous mammals and birds (deers, capibaras, armadillos of several species, nandus, etc.) which served to sustain a sparsely distributed nomadic population of hunters and gatherers (of which the most important ethnic group was constituted by the Pampidos nations). The first years of the novel colony were not easy. The city was destroyed by the indigenous population and had to be refounded in 1580 by Juan de Garay.

From a merely environmental point of view, the original site of Buenos Aires could have hardly been better chosen. It possessed moderate sub-humid climate, excellent agricultural lands, very sparsely populated, easy maritime access, good overland communications and practically unlimited volumes of water.

The city enjoyed also the position of being located just at the mouth of one of the largest navigable waterway systems of the continent.

It does not come as a surprise therefore, that the city developed very fast from a small village in the XVI century, to a medium size town in the 1800's and to one of the largest megalopolis of the world in the XXth century.

Presently (1990), the population of the Greater Buenos Aires has exceeded 12 million and although its growth has somewhat slowed down it is expected to reach almost 14 million by the year 2000 and 16 million around 2010.

The city is the capital of the Republic of Argentina and is home to almost 40% of the population of the country. The immediate Buenos Aires hinterland has also become a densely populated area with intensive agricultural and industrial activities, which include one of the most important grain -and cattle- producing areas of the world. In addition, the Buenos Aires region is heavily industrialized with a large number of agricultural related industries (slaughterhouses, tanning and textile factories, mills, various food producing industries, etc.) and a relatively important number of metallurgical, mechanical and other various industrial activities (foundries, automotive industries and many others). The

Province of Buenos Aires, which includes the approximately 300,000 km2 surrounding the Federal Capital, is where most of the above-mentioned activities are carried out and does not depend administratively from the city of Buenos Aires itself. In 1888, a new city was designed from scratch, and built on a site not far from the city of Buenos Aires in order to house the authorities of the province. This provincial capital was called La Plata and rapidly grew to become a 600,000 person urban concentration. Due to the rapid growth of the suburban metropolitan neighborhoods, today La Plata has practically merged with the outer suburbs of Buenos Aires forming a single macro-urban region.

4.3.2 Water supply

This phenomenal growth of Buenos Aires has started to have overwhelming deleterious effects on the environment. Originally, the city utilized the small streams, such as, "El Riachuelo" and a number of shallow wells. With time, these water sources became insufficient and contaminated (presently "El Riachuelo" is an open sewer and all the older wells were abandoned) and the municipal water system was developed utilizing water drawn from the River Plate. In many cases, the outlying suburbs preferred to use groundwater obtained from an underlying alluvial aquifer (as is the case in the large municipality of Quilmes (East of the Federal Capital) and La Plata among others).

Most of the groundwater obtained in Buenos Aires and surrounding areas is drawn from the "Arenas Puelches" (Puelches Sands) which is a permeable sandy alluvial aquifer, about 30-50 m. thick filling a fluvial paleo-valley (the Paleo-Parana valley) covered by a semi-permeable (aquitard) silty aeolian formation (Pampeano) about 40 m. thick. Unfortunately and oddly, there is a narrow strip of Quaternary formations (Querandinense/Platense) along the River Plate coastline, remnants of the Late Pleistocene and Holocene transgressions, containing highly saline groundwater, hydraulically connected with the Puelches Sands. In fact, along the coastal fringe, the whole Quaternary sequence (including the Arenas Puelches) contains high salinity water(1). An additional element is constituted by the fact that the river Plate in Buenos Aires is a freshwater body.

---

(1) The entire geological section in the coastal zone, from the lower Arenas Puelches to the Querandino contains salty water. The Puelches sands have TDS usually **higher** than those of the Querandino or the Pampeano. Whether the original Querandino salty water contaminated the Puelches aquifer or not is not known (although it is very likely)

As a result of overpumping, saline groundwater has reached a large number of coastal wells and they have had to be closed. The unsual feature in this cse is given by the fact that the saline intrusion is not related to the nearby estuary, but probably to a narrow saline remmant of a marine transgression.

All of the water of the Federal Capital, and a considerable volume of the suburban water supply, is obtained from intakes located well into the River Plate. The original intakes were situated a few km. upstream of the Buenos Aires port, not far from the shore. New intakes were built in the fifties much further from the coastline (about 5 km.) near the locality of Bernal, downstream of the Federal Capital.

There are some water quality and treatment problems, associated with the utilization of the River Plate waters for urban water supply, which may affect adversely the potential of the estuary waters for this purpose.

4.3.3 Water quality changes of the River Plate

Firstly, the River Plate receives its water from the Parana and Uruguay rivers, which in turn drain a vast 2 million km2 basin. The composition of the River Plate water is closely associated with the various phenomena taking place throughout this large hydrographic basin. Most of the flow is the result of outflow from the humid highlands of the Brazilian Shield and the Planalto and the sub-humid Chaquean-Mato Grosso regions.

This flow was originally composed of sediment-free water and not very variable throughout the year, with the possible exception of the apport of the floodwater from the irregular tributaries of the Western portion of the basin.

In fact, a considerable volume of water flowed into the Parana as a result of the rainy periods in the semi-arid Chaco and the arid "cordilleran" foothills. One of the main rivers draining this Western part of the basin is the river Bermejo -which during those periods is heavily loaded with reddish suspended solids - (incidentally, Bermejo in Spanish means "red", due to the color of the Bermejo waters). A not so intense sediment supply is found in several other rivers joining the Parana-Paraguay main valley form the right margin, as in the case of the Pilcomayo and Salado rivers.

In spite of the smaller volumes brought by these Western tributaries, their flow was (and is) extremely concentrated in a short period of time, and during those periods the River Plate received a much larger flow with a considerable amount of suspended sediments. However, with the exception of the short west-originated floods periods, for most of the time, the River Plate water was limpid and relatively sediment-free.

The reason for the regularity and relative cleanliness of the Parana and Uruguay waters coming from the North and Northeast was the presence of a dense forest covering their catchment areas. Most of the Planalto and Shield highlands were covered by a quasi-monospecific Araucaria forest and other less extensive forest ecosystems, the Mato Grosso was covered by a tropical rain forest and the Chaco by a relatively dense xerophytic forest vegetation.

During the last 20-50 years most of these forests were eliminated. The old Araucaria forest of the Planalto has been practically completely exterminated, astonishingly in less than 20 years!. The trees were felled for lumber and land converted mainly for cattle-grazing, but also for various agricultural activities (it only survives in isolated pockets and in the steepest slopes). The Mato Grosso forest is disappearing very fast giving place to short-lived rice crops, and finally being dedicated to low-productivity cattle raising, and a large tract of the Chaquean hinterland has also been heavily degraded. As a result of that, the fluvial regimes have been substantially modified and the percentage of suspended materials in the River Plate has increased dramatically.

Secondly, the outflow from the city sewers and stormwater systems has also increased considerably, probably approaching 90-100 m3/sec. This wastewater is -as it can be easily imagined- heavily contaminated and it is thrown untreated into the River Plate.

Thirdly, because the city is a large port, very busy shipping activity takes places in the waters surrounding the port, which by the way, are the same waters that are used for the urban system. Ships are known to be a focus of heavy pollution and this may (and actually does) seriously affect the water quality at the water intake level.

Because of all these problems, treatment procedures for the Buenos Aires municipal water are costly and probably insufficient. In any case, contamination risks are increasing, to a point in which it may become unavoidable to implement wastewater treatment systems, or find alternative sources of uncontaminated water supply.

4.3.4 The groundwater alternative

Groundwater is one of those alternatives. It is presently used to a considerable extent in some municipalities of the Greater Buenos Aires. Metropolitan Buenos Aires consumes 85 m3/sec. of water, of which 65 m3/sec. is utilized for domestic consumption and 20 m3/sec. for industrial use. Of the 65 m3/sec. used for domestic consumption, 24 m3/sec. (37%) are obtained from groundwater sources, and the rest (63%) from the River Plate. A considerable volume of the industrial water consumed (about 20 m3/sec.) is also obtained from groundwater sources (probably as much as 40% or 8 m3/sec.). The total volume of groundwater consumed in the Buenos Aires area is, therefore, in excess of 30 m3/sec., which seems to be -at least locally- more than the available recharge would sustain.

The presence of a protecting aquitard on top of the Puelche aquifer, does not seem to be enough to prevent some contaminants from going into the groundwater reservoir. Many water supply wells are located close to industrial areas in which various hazardous wastes are disposed without adequate control.

In addition, many groundwater-supplied zones are unsewered and multi-sources contamination from domiciliary septic tanks is affecting or might potentially affect the water supply of probably as many as 3 million people through the "Gran Buenos Aires" region. Due to these problems, the utilization of groundwater in Buenos Aires and surrounding areas may become an unsustainable proposition, unless sound environmental controls and groundwater management practices are introduced.

One way or the other, Buenos Aires has cornered itself in a very difficult position due to the irrational utilization of its abundant water resources. In any case, the solution to the water problems of Buenos Aires will not be to keep blindly ignoring the growing degradation of the environment.

4.4 The Valley of Guatemala

4.4.1 Environment and history

The city of Guatemala is by far the most important city of the Republic of Guatemala and its national capital. It is located at an elevation of 1800 m. above sea level in a high valley on the Guatemalan volcanic plateau.

Before the Europeans arrived, the Guatemalan highlands were already densely populated by a civilization based in the cultivation of corn, chili pepper, tomatoes and other locally domesticated crops very similar to the cultures of the Mexican plateau. At the time the Spaniards arrived to Guatemala, the highlands region was inhabited by the Cakchikel nation of the Mayan group, with their capital in Iximche.

Following the example of the Mexican conquest, the Spanish conquerors established the capital in the same site in which the Cakchikel capital was located (in 1523). That site was located at about 100 km. to the West of the present site of Guatemala City, and at a higher elevation (about 2,000 m.).

A few years after the foundation, in 1527, and due to the occurrence of a destructive earthquake, the city was moved to a site about 80 km. to the East at a lower elevation (1530 m.) where the new city of Santiago de los Caballeros was founded (present site of Antigua). This site was (and is) located at the foot of a high volcano (the "Volcan de Agua") whose main crater was occupied by a lake.

In 1533, the "Volcan de Agua" had a strong eruption and a strong flood and "laharic" mudflow developed, destroying and burying large sectors of the city. Several hundred people died and most buildings were annihilated.

In 1543, a new city was founded in the same valley and with the same name. The city was again destroyed by an earthquake in 1773, and, as a result of this catastrophe, it was moved again in 1776, this time to the present location, under the name of Nueva Guatemala de La Asuncion. The new site was situated at about 25 km. from the destroyed site and at a slightly lower altitude (1,500 m.). The old city was gradually rebuilt and today is a medium size city of about 50,000 people (Antigua).

The new city of Guatemala, which remained the capital of the colonial "Capitania General de Guatemala", became the capital of the independent Republic of Guatemala in 1837. Gradually, the city has grown from a few tens of thousand inhabitants, at the beginning of the XXth century to the present population of 1.8 million people, with all the increased requirements and strains on the environment that usually come with this type of accelerated urban growth.

As it can be easily imagined through these episodes of the history of the city of Guatemala, the Guatemalan highlands are a very active volcanic and seismic area. Not less than 20 large volcanic cones with elevations ranging between 2,000 and 4,220 m. and several hundred smaller ones dot the landscape of the Southern mountainous areas of the country. Volcanic eruptions and related seismic activity are very common and the recent historical geology and geomorphological development are closely tied to this dynamics.

The climate of the highlands is sub-humid to humid, with precipitations ranging from about 1,000 mm/yr in the drier North-facing slopes to more than 2,000 mm/yr in the South. In the city of Guatemala itself the annual rainfall averages 1,300 mm. to 1,500 mm., concentrated in the summer period (June to September). As a result of these climatic characteristics the natural vegetation is a deciduous forest up to 2,200 m., and a coniferous forest above this altitude. This forest was partially eliminated (even during pre-hispanic times) in order to make place for agricultural activities. This process has continued, and has intensely accelerated during the last few years. Today, the forests of the highlands have been substantially reduced to small pockets in the steeper areas that are not suitable for farming.

4.4.2 Geology and geomorphology of the Valley

The geology of the valley of Guatemala is relatively complex. Over a base of Cretaceous limestones and plutonic rocks an intense and prolonged vulcanism took place giving raise to large accumulations of varied type of volcanic rocks and associated deposits.

The valley itself is a NNE-SSW oriented elongated depression in which water flows both Northwards and Southwards on both sides of a waterdivide more or less transversal to the main axis of the elongation. This waterdivide is part of the continental waterdivide.

A large lake (lake Amatitlan) has formed on the Southern part of the valley, due to volcanic obstructions with its excess water flowing to the Pacific coast through the river Michatoya. The Northwards flowing rivers (River Las Vacas and its tributaries El Zapote and Tzalja) drain the smaller northern part of the valley towards the Caribbean sea.

Several volcanic cones surround the site of the city, the largest ones being the "Volcan de Agua" (to the SW of the city at about 20 kms of the city boundaries), whose summit exceeds 3,000 m., and the volcano "Pataya" (located to the South of the city at about the same distance) with an elevation slightly above 2,000 m.

The valley itself has been interpreted as a large graben with locally intercalated horsts. Both the elevated and subsident areas are composed of volcanic rocks, although older limestones are found in the river Las Vacas in the North of the valley.

The oldest formation identified in the Valley of Guatemala is a calcareous unit of fractured limestones exclusively circumscribed to the rio Las Vacas basin, with a very limited outcropping extension.

Overlying the Las Vacas limestones, a thick sequence of lava flows and associated deposits of Tertiary age are encountered. These lavas are heavily fractured providing a relatively high secondary porosity for water storage and circulation. The Tertiary lavas are covered by two sequences of Fluvio-lacustrine and volcanic deposits of Quaternary age:

1) a sequence of fluvio-lacustrine deposits; they are composed of volcanic materials alluvially reworked and depositated in river beds/plains or in lakes. Thickness do not exceed 100 m. The alluvial sediments have a relatively high permeability, but the lacustrine deposits can act as aquitards or aquicludes;

2) a sequence of volcanic deposits; they are formed by a large accumulation of pyroclastic products including ash-flow tuffs. The materials possess a wide range of consolidation levels, from loose to well consolidated. The maximum thickness of this formation exceeds 200 m. This unit is moderately and highly porous and contains an excellent aquifer which is heavily utilized for water supply purposes.

4.4.3 Water supply

The city of Guatemala obtains most of its water from groundwater sources (80%), which cannot probably provide much more water than the present abstraction figures. Of its 5 m3/sec. consumption volumes, (requirements are probably somewhat higher, particularly during the peak periods), up to 4 m3/sec. are extracted from 200 wells distributed throughout the valley.

The remaining volumes (1m3/sec.) are obtained from surface sources outside the local valley. To the effect of conducting the water from the above mentioned river to the city, a pipeline was built which is presently underutilized. The capacity of the pipeline is of 2.5 m3/sec. and only 1m3/sec. is transported. There are plans to build a battery of wells in the volcanic aquifer of Antigua in order to utilized the unused potential of the pipeline. In any case, it is expected that Guatemala will continue depending on groundwater for its water needs. Because the recharge to the aquifer(s) takes place in a large measure in urban and suburban areas, strict controls are required to avoid degradation of the groundwater resource. These controls are -presently- practically absent. One of the main tasks of decision-makers in the Guatemala valley will be to protect the aquifers from outside contamination. The population of Guatemala city, located in an area with scarce usable streams cannot afford to loose this key resource for lack of adequate protection on planning.

The only other surface water resource available would be the lake Amatitlan, but this water body is heavily contaminated and its use would be hazardous and the correction of pullution problems, too uneconomical.

Groundwater resources, therefore, still the best alternative to satisfy the needs of the Guatemala city metropolitan area.

4.5 The Managua basin

4.5.1 Introduction

The city of Managua is located in the large volcanic valley of Central Nicaragua. It developed as a small farming and fishing indian village which took advantage of the fertile volcanic soils, the abundance of water and the vicinity of the large lake Xolotlan (which is also sometimes denominated "Lake Managua").

At the time of the arrival of the Europeans in 1522, the territory possessed a moderately high density of population, based in the cultivation of corn, cacao, chili peppers and tomatoes, and the raising of turkeys and dogs. Ethnically the native population of the lands to the South of the lakes was of Nahuatl ("Mexican") origin: the Nicaraos.

At the time, Managua was a prosperous 40,000 people community located along the shores of lake Xolotlan.

When the Spaniards arrived, they selectively settled on the narrow strip of Pacific highlands and shores of the larger Nicaraguan lakes (lake Xolotlan or Managua and lake Cocibolca or Nicaragua). The town of Managua was strongly affected by the Spanish conquest. Its population decreased to a mere few thousand people and it would not be until three centuries later that the city would reach the pre-hispanic population level.

As a consequence of the Spanish conquest and settlement, a relatively large colonial urban center developed to the Northwest of Lake Xolotlan: the city of Leon. This city was destroyed by an earthquake in the XVIIth century, and a new city was founded on the Western shore of lake Cocibolca (Granada). Since then, the colonial (and later the republican) history of Nicaragua is heavily influenced by the rivalries of the old city (Leon) and the new one (Granada).

The Republic of Nicaragua, of which the city of Managua is today the capital, became independent upon the disintegration of the Union of Central America in 1838. After the formation of the newly declared Republic of Nicaragua, there was a period of conflict between the liberal factions based in Leon and the conservative ones based in Granada. In 1852, and as a compromise solution, a new capital was chosen in the location of the small village of Managua, which gradually grew to become the largest city of Nicaragua.

In 1973, the city suffered a major earthquake that destroyed practically the whole downtown area. After the earthquake, the city center was not rebuilt, in spite of the assistance that poured into the country from throughout the world. The new government that took power in 1979, after a long civil war, has decided to leave the zone aside as a green core in which public parks and squares were recently established.

It is also important to note, that during the last 11 years, the state of war has continued practically without interruption. In addition, for the last 9 years Nicaragua is under commercial boycott by the United States, and this has seriously harmed the economy of the country. As a result, the city has suffered enormously from the point of view of availability of basic goods, functioning of public services and necessary investments. The war also meant heavy casualties in the population and a continued flow of war refugees from the countryside to the city. Today, Managua possesses nearly 1 million inhabitants, which is almost 1/3 of the total population of the republic, and extends for an area in excess of 60 km2.

4.5.2 The environment of Managua

The city is located on the Southern shores of lake Xolotlan, on the terrains sloping from the Cordillera del Pacifico (which locally are called "Las Sierras de Managua"). The Cordillera del Pacifico reaches elevations of the order of 900 m. above sea level, while the lake itself is at about 40 m. altitude. The Xolotlan depression extends Southeastwards through the Tipitapa plains to the lake Cocibolca (Nicaragua), which stands some 9 m. below lake Xolotlan at 31 m. above sea level.

The water in excess from the Managua basin flows as surface flow through an emissary canal (river Tipitapa), and as groundwater flow towards the lake Cocibolca. The outflow of the Cocibolca basin exits to the Caribbean through the river San Juan. These two lakes occupy a very large area of 9,000 km2, of which 8,000 correspond to lake Cocibolca and 1,000 to lake Xolotlan.

Several other smaller lakes of volcanic origin complete the lacustrine panorama of the Nicaraguan valley. The largest ones are Laguna Masaya, Laguna de Apoyo, Laguna de Apoyeque and Laguna de Jiloa. In the area of Managua itself, there are a number of smaller crateric lakes (Laguna de Asososca, Laguna de Nejapa and Laguna de Tiscapa).

The climate of Managua is tropical with warm temperatures all year around (lowest monthly average is 23 degrees C. in January and the highest is 31 C. in April), sub-humid with mean annual precipitation of about 1,200 mm. concentrated from May to October, coincidentally with the arrival of the inter-tropical convergence. The dry season takes place between November and April.

The Managua "slopes" do not show practically any permanent stream flow, only sporadic flow can be observed immediately after strong rainfall episodes in the largest drainage channels (as is the case with the Rio Borbollon which flows near the Las Mercedes Airport). The main reasons for this limited stream flow are the high permeability of soils and surface formations, the concentration of rainfall and the poor development of the hydrographic network (which is a common feature in volcanic landscapes due to the frequent accretions of volcanic materials).

Geologically the area is composed of various types of volcanic rocks and deposits. The Western edge of the depression is formed by a volcanic range extending on a NE-SW direction including symmetric volcanic cones, explosive craters and calderas.

All geological formations in the Managua area of Cenozoic age and directly or indirectly of volcanic origin. The oldest stratigraphic unit is a pyroclastic sequence denominated Grupo de Las Sierras. This group is mainly composed of relatively uniform and massive agglomeratic tuffs and breccias, which outcrop in several areas, within and near the city site. The thickness of this unit is of about 680 m. (Kuang, 1971) and the total volume was calculated by David Clifford Bice, 1980, at about 450 km3. Although the age of Las Sierras is not accurately known, existing data tend to donfirm a Quaternary age (or at the least Late Pliocene) for all the Group. The younger deposits have been determined as older than 100,000 years. The relationship between these deposits and the volcanoes surrounding the Masaya caldera has not been proven. Overlying the Las Sierras Group in the Managua region, there is a thin (10-20 m. thick), layered volcanic sequence, including airfall tuffs, ashes and lapilli beds (C. Bice, 1980) which has been named Managua Group. The sources for these deposits seem to be related to recent vulcanism occurred in the Masaya caldera and the Nejapa-Miraflores aligment (see Fig.15).

Above the Managua Group a formation of ashes, lapilli cinders and lipillis is found (Formation Motastepe). The source of this volcanic unit seems to be the volcanic structures of Cerro Motastepe, and the volcanic chimney found in the Caldera of Asososca.

The youngest deposits of the area are of lacustrine origin (related to sedimentation in the bottom of the larger lakes and the smaller "lagunas") and alluvially reworked volcanic materials. The lacustrine layers are relatively thin, not more than a few tens of meters thick (although the maximum thicknesses are not accurately known), and the alluvial-volcanic sediments thicknesses range from 0 to 90 m.

4.5.3 Hydrogeology (*)

The Grupo Las Sierras is -due to its permeability, thickness and horizontal extension- the one which offers the greatest potential for groundwater abstraction. In fact, most water consumption for the Managua area is obtained from this unit.

(*) Ref. 48 and 53.

The geometry of the Las Sierras Aquifer is relatively simple due to its uniformity. The saturated zone is very deep in the Pacific range area (down to 200-300 m. below ground surface), and it is in this location that most of the recharge takes place. The groundwater divide seems to follow approximately the topography, and groundwater flow occurs in two main directions: 1) towards the Pacific ocean, giving raise to several streams in the bottom of the deepest valleys/ravines (the deepest ones possess permanent flow); and 2) towards lake Xolotlan.

Some of the groundwater flowing towards the lake, discharges to the small streams near the Managua plain, in a few places where the water levels intersect the ground surface. A certain volume recharges the Asososca, Tiscapa and Nejapa crateric lakes, and the rest discharges into lake Xolotlan.

The city of Managua has been using directly or indirectly this aquifer for some time. The main sources of supply have been the Laguna de Asososca (since 1914), the well fields "Carlos Fonseca Amador" and lately, the wells drilled within the framework of the "Plan de Emergencia" of the Instituto Nicaraguense de Acueductos y Alcantarillados.

The Laguna de Asososca has been during long time the main source of water supply for the city of Managua. This crateric lake has been regularly pumped by the Instituto Nicarguense de Acueductos y Alcantarillados as the main source of water for the urban population. However, when the city requirements exceeded the groundwater discharge to the lake, other sources of water had to be developed.

Abstraction levels in the Laguna de Asososca grew gradually during the period 1914 to 1975 to a maximum slightly exceeding 80,000 m3/day in the last mentioned date, which made the lake levels drop from 40.57 m. in 1960 to 35.38 m. in 1975. Since then, the pumping rates have been reduced to between 50,000 and 75,000 m3/day, and even less in recent dates (1989), and the water levels have somewhat stabilized around 36 m. above sea level.

The well field "Carlos Fonseca Amador" is located in the zones in which higher transmissivity had been detected when these wells were chilled (near the zone of Sabana Grande and International Airport A.C. Sandino). Presently there are 12 production wells with an average production of about 50,000-60,000 m3/day. Recently, two more production wells were built. The water pumping from all wells in the Managua area is now slightly exceeding the abstraction from the Laguna de Asososca. The total production of INAA in July, 1988 was of 165,000 m3/day. The above mentioned figures do not meet present requirements of the Managua region which are presently in excess of 200,000 m3/day and growing fast, and new alternatives need to be investigated. (1)

4.5.4 Proposed new sources of water supply for the City

The potential new sources of water for the city are the following: 1) Lake Xolotlan; 2) Lake Cocibolca; 3) New wells in the Las Sierras aquifer; 4) the "Lagunas".

1) The Lake Xolotlan

The Lake Xolotlan is a large lake of more than 1,000 km2 (63 km. long and 17-26 km wide) with slightly brackish water located next to the city of Managua.

The excess water of Lake Xolotlan goes to Lake Cocibolca through the river Tipitapa. During the last few years, however, the lake has behaved as a closed basin, and has accumulated gradually the incoming salts as a result of in-basin evaporation. In any case, on a long term basis, there is very limited flow from Xolotlan to Cocibolca, increasing the fragility of the previously mentioned lake.

Because of the heavy agricultural production, with utilization of pesticides, and the continued disposal of Managua wastewaters into the Lake, the quality of its water has been gradually deteriorating, to the point in which the water is not safe for drinking or bathing anymore. Particularly damaging for the Xolotlan environment was the disposal of toxaphene (a pesticide of the DDT family) and other waste substances (including mercury) by the Pennwalt and Hercules chemical plants during the 70's into the lake. According to one United Nations environmental study, 60 tons of mercury have settled in the water. According to other study 17% of all deaths in Managua were related to mercury poisoning and the contamination of the lake (Environment and Development, April 1987).

As it can be seen, there is still a significant amount of corrective environmental work to do in order to recuperate lake Xolotlan from its present situation. If that work is carried out, the lake could become a very practical alternative as a potential source of water supply for the city.

2) The Lake Cocibolca (Lake Nicaragua)

The Lake Cocibolca is a very large body of good quality freshwater (8,000 km2), with only minor contamination sources around the city of Granada and other smaller towns. It has a positive balance between inflow and evaporation (the excess of water flowing into the Caribbean through the river San Juan with an annual average flow of 10,300 MMA).

---

(1) Water cuts in Managua can extend to 15-20 hours per day, and sometimes there are neighbohoods not receiving practically any INAA water for days at a time.

This lake is probably the best option for water supply purposes, no only for Managua, but also for other towns and irrigated farming. However, because of the relatively larger distance to Managua (40 km), and lower elevation, a water supply project based on water extraction from Lake Cocibolca could be beyond the economic possibilities of the country, at this stage.

3) New wells in the Las Sierras aquifer

This is probably the easier alternative, although the available volumes of water can be locally somewhat limited. The aquifer transmissivities are high, and its uniformity facilities well location. There is, however, the need to insure that long term abstraction does not upset the balance of the aquifer. It is important to include in this balance, the water abstracted from the "Lagunas" which act in fact as "open wells" from the hydrogeological point of view.

4) The "Lagunas"

All the "Lagunas" are in effect "outcropping" zones of the local groundwater. Their utilization, therefore, will need to be limited by the same abstraction constraints affecting the long term operation of well fields, plus the need for special protection due to the exposure to potential sources of contamination.

Of the eight largest lagunas located in the neighborhood of the Managua region, one has been and is already used for water supply as previously described: the Laguna de Asososca. Other three "lagunas" are situated in the Managua area (Nejapa, Acahualinca and Tiscapa). The first two do not have sufficient volumes of water, or the water quality is inadequate for urban water supply purposes. Only the Laguna Tiscapa could be considered to this effect. In many ways this "Laguna" compares to Asososca. It has the added advantage of its location in the center of the city and the consequent disadvantage of a higher vulnerability to contamination.

The northern "Lagunas" (Lagunas de Jiloa and Apoyeque) located in the peninsula of Chiltepe near lake Xolotlan are not suitable (chemically) for urban water supply and are therefore excluded.
The remaining two "Lagunas" are located to the East of Managua, outside the city area but close enough to be potentially utilized. The Laguna de Apoyo cannot be used because of the poor quality of the water. The Laguna de Masaya, however, possesses acceptable water, has a water volume 8 times larger than the Laguna de Asososca and could be considered for water supply purposes for Managua. However, in spite of the volumes available, their renewability is less, and the utilization of water in the surrounding areas is already consuming a significant part of the water, making this option less economically feasible.

<u>In brief</u>

As it was described in previous paragraphs, the environment of Managua has experienced a continued degradation -particularly due to the poor utilization of the abundant water resources. Unfortunately, the correction of these problems, that have accumulated during years of degradation and environmental mismanagement will require considerable work and investments (which certainly will not be readily available, given the particularly difficult economical and political circumstances that Nicaragua is suffering).

A first step towards the necessary social awareness and understanding of the problems is being successfully taken at this moment. Much Nicaraguan efforts and international assistance (and not necessarily boycotts and wars) will be required to transform the Xolotlan basin in the harmonic environment of the past.

4.6 The valley of Cochabamba

4.6.1 Environment and history

The city of Cochabamba is one of the largest cities in Bolivia. With nearly half a million inhabitants, it has become the "capital" of the Sierras region, which is a zone of Bolivia located in the dissected mountains of the intermediate zone between the Altiplano to the West, and the "Llanos de Santa Cruz" to the East. The Department (Province) of Cochabamba is one of the most densely populated of the country, including not only the city of Cochabamba but also other cities and villages within the valley and nearby highlands.

The geographical character of Cochabamba is partly a result of its altitude (2,550 m. above sea level) which is intermediate between La Paz (3,700 m above sea level in the downtown area) and Santa Cruz (415 m. above sea level). The climate is also intermediate between the 10 degrees C of La Paz and the 27 degrees C of Santa Cruz. Average rainfall in the city itself, is of about 450 mm. per year, mainly concentrated during the summer months of January and February. From the point of view of its precipitations, the valley can be classified as a semi-arid environment, with a considerable water deficit during the winter and spring months.

As a result of this climate, agricultural activities are based in sub-tropical and mild temperate climate farming, including mainly fruit production, but also several types of grains, vegetables, dairy farming, etc.

The Spanish city of Oropesa (later to be renamed Cochabamba) was founded in 1574 by Sebastian Barba de Padilla. During the few centuries before the arrival of the Europeans, the region of Cochabamba was part of the mighty Tahauntisuyu (Empire of the Incas), which was a very large indian empire extending from Ecuador to Argentina. The capital of the Tahuantisuyu was located in Cuzco (in today's Peru) and the whole Altiplano and Sierras of Bolivia were part of the Inca's domains. The main and dominant ethnic group of the Inca Empire were the Quechuas, which gradually extended their cultural control in a large part of the territory.

Some areas of Bolivia kept their ancient culture and languages (as it happened with the Aymaras from the Altiplano and the La Paz region). By and large, Cochabamba was "Quechuanized" and presently represents one the most important Quechua-speaking regions, South of Cuzco. During the centuries of Spanish and "Criollo" domination there was a strong process of "Hispanization" and Spanish became the dominant language in the city. Quechua, however, has remained the main language in the rural areas, in the urban shantytowns and in the folklore. As a result, Cochabamba can be considered today as the "Quechua capital" of Bolivia.

Due to its climate and agricultural productivity, Cochabamba has recently attracted a number of people displaced from the mining communities of the Oruro and Potosi areas in the Altiplano, due to the tin crisis. The recently arrived migrants are normally Aymaras having added a new element to the cultural diversity of Cochabamba. However, the valley of Cochabamba remains a predominantly agricultural region, representing one of the most productive farming areas of the country. Due to the relative scarcity of precipitations, a significant part of the farming activities are carried out by means of irrigation methods, which add to the water consumption volumes of the valley. As a result of the considerable utilization of water, due both to irrigation practices and high local density of population, management of water resources has been and it is one of the key elements in the development of the valley and the urban region.

Another fact that cannot be overlooked is the transformation of Cochabamba in one of the centers of processing and commercialization of cocaine. The coca leaves are produced in the "El Chapare" and "Chungas" regions and in other isolated areas of the lower slopes of the Sierras. Traditionally, the coca leaves were used by the Andean peoples as a stimulant and a medicine. In fact, they are still widely and legally used today throughout the region. Processing of the coca leaves for cocaine extraction is a relatively new development.

It is believed that at least some amount of cocaine is produced in the Valley of Cochabamba using the recently arrived migrants as cheap labor. Because the processing of the coca leaves require the utilization of kerosene, sulfuric acid and some other environmental damaging substances, there is some concern not only on the social effects of drug production but also on its environmental effects (particularly on the water resources).

4.6.2 Geology and geomorphology

The valley is a relatively narrow valley (5 to 10 km. wide) apparently -at least partially- of tectonic origin, developed over a Paleozoic and Mesozoic basement (Ordovician, Silurian and Cretaceous).

The Ordovician is composed of a lower sequence of siltstones, claystones and sandstones (Formation Cuchu-Punata) and an upper sequence of quartzitic sandstones (Formation San Benito).

The Silurian is formed by a lower formation of quartzites and clay grits (Formation Cancaniri) covered by claystones (Formation Uncia).

Mesozoic sedimentary rocks of the Cretaceous Period are also found overlying the Paleozoic rocks. They are mainly limestones and marls in the bottom (Formation El Molino), underlying a "flysch" type sequence of calcareous sandstones, marls and clays (Formation Santa Lucia).

The Tertiary is represented by the "molassic" deposits of the Formation Morochata, of Paleocene age, composed by conglomerates of reduced areal extension.

The bottom of the valley is filled with a thick sequence of Quaternary deposits starting with Pleistocene lacustrine deposits (clays, sandy and silty clays, etc.) in the lower parts, which develop into fluvio-lacustrine and fluvial sediments towards the top. On the foothills of the lateral slopes there is a development of coarse deposits (agglomerates, gravels, coarse sands) related to the alluvial fans of a number of torrential streams, descending from the nearby highlands.

Only the fluvio-lacustrine, fluvial and fan deposits have demonstrated to have potential for groundwater extraction. Yields in the lower fluvio-lacustrine deposits vary from about 1,800 liters per minute in the edges of the basin to less than 100 liters per minute in the center. The fluvial and fan sediments have a much higher permeability with yields reaching up to 3,600-4,800 liters per minute in the case of the fluvial deposits, and even more in the fans. Water quality is good in the fluvial and fan aquifers (Ref. 86).

4.6.3 Hydrology

The basin of Cochabamba has about 1,150 km2. The main river is the river Rocha, which has a very small flow during the dry periods, but can be responsible for destructive floods during intense rain episodes. This river receives its water from the Cliza-Punata basin, through the river Tamborada, whose flow is controlled by the dam "Mexico" forming the "Angostura" lake (see Figs. 17 and 18).

A number of lakes (some natural, some artificial) are found throughout the basin. The natural lakes are presumably of glacial origin and together with the artificial reservoirs they constitute one of the main sources of water supply for the city.

4.6.4 Water supply

The water consumption of Cochabamba region is served in part by surface water, brought by mean of open aqueducts from the lakes Warawara, Escalerani and Saytokhocha located in the neighbouring highlands (at about 4,000 m. of elevation). The rest is extracted from the alluvial aquifers of the valley. In order to abstract the water, several SEMAPA (Servicio Municipal de Agua Potable y Alcantarillado) batteries of wells are presently in operation (in Cona Cona: 9 wells, in Vinto: 10 wells, in Muyurina: 14 wells and in El Paso: 3 wells). In addition, there is a large number of private wells.

In the edge of the valley the wells were and are all phreatic. In the center of the valley, artesianism was the rule. Presently, intense abstraction has significantly lowered the water levels and therefore many wells have lost their free-flowing characteristics and pumping is required.

Water consumption for the urban region is of the order of 0.65 to 0.75 m3/sec. (about 60-70,000 m3 per day), of which about 60% comes from surface sources and 40% from the aquifers (perhaps as much as 25,000 m3 per day).

In addition, there is a significant amount of groundwater utilized for irrigation and other farming purposes (probably as much as the volumes abstracted for the city).

4.6.5 Environmental problems

Both surface water and groundwater of the valley of Cochabamba have a high degree of vulnerability. Drilling of wells continues at an unabated pace without any available legal tool to control or prevent it. As a result, groundwater extraction may result in excessive lowering of water levels with higher pumping costs, and risks of dewatering some higher parts of the aquifers.

In addition, recharge areas are not protected and waste disposal may take place in a relatively irrestricted way. Presently, the alluvial fans represent the main recharge area, and they have not been strongly touched by urban encroachment, but the threat is increasing with the growth of the urban areas. In the central part of the valley, the aquifers are semi-confined and the risk of contamination is less (although if the waterlevels continue dropping, there is a clear risk of some contaminants making their way into the groundwater reservoir).

Surface waters are also threatened. The river Rocha is heavily contaminated and therefor it cannot be used for any water supply or irrigation purpose. The basins of the water supply lakes are less threatened because of the relatively low density of population, but the risk exists and they need to be strictly protected.

There are also other environmental risks in the city area, which mainly relate to the river Rocha irregular regime and its flood control systems. In order to control the destructive periodic flows of the river Rocha, a diversion scheme was implemented by means of an artificial lake (the "Laguna Alalay"), which provides storage volumes for the excess waters during flood episodes (the water is diverted through a tunnel excavated in some hills outcropping in the center of the valley near the city core). Due to growth of the city around the shores of this lake, this water body has become a dumping ground for various types of wastes and local sewage. As a result, the lake Alalay has become one of the main environmental concerns affecting the Cochabamba urban area.

In addition, Cochabamba suffers periodically, as it is suffering at the time of writing this chapter, acute droughts which prevent practically any utilization of surface water, overloading the demand on groundwater and threatening not only the water quality level but also availability of sufficient volumes.

As it can be seen, in spite of the relatively moderate size, Cochabamba has already many actual and potential problems that need to be solved, if the city is going to continue growing. A considerable amount of studies and investments may be required to prevent further degradation of the beautiful valley of Cochabamba.

4.7 Montevideo and the Southern Uruguayan Region

4.7.1 Environment and history

Uruguay, with approximately 180,000 km2 and 3 million inhabitants is one of the smallest countries of South America, both, in area an population. Most of the country economic activities and people are overly-concentrated in a limited area of not more than 15,000 km2, forming a strip along the Southern part of the territory (see Fig. 18).

In that area, it is situated the national capital: Montevideo, which is home for nearly 1.5 million people, almost half of the population of the country, and probably over 3/4 of the industrial and commercial activities of the republic. In this zone also, there are about 20 smaller cities with populations in excess of 5,000 (including practically all turistic resorts and beaches) and about 1/2 of the total agricultural production of the country (mainly dairy farming, orchards and fruit production, but also poultry farms and pig farms, beef cattle and sheep ranches, etc).

This demographic over-concentration in one city, which is particularly acute in the city of Montevideo itself, is among the largest in Latin America and the result of a singular combination of historical and geographic circumstances.

The city of Montevideo is located in one of the most strategic sites of all the South American Atlantic facade. The Bay of Montevideo was (and still is -to some extent-) the best (and almost only) natural port in the estuary of the River Plate. This water body is the natural entrance and exit of one of the largest waterway networks of the continent (including three of the largest navigable rivers of South America: the Parana, the Paraguay and the Uruguay rivers).

The natural port was very good: an almost closed quasi-circular bay, protected from the winds from the sea, surrounded by undulating terrain composed of low crystalline hills. These crystalline landscape was (is) covered by a discontinuous mantle of predominantly silty deposits of mainly aeolian origin, over which good deep fertile soils were found. The bay was originally deep enough for most commercial vessels, and its entrance was partially blocked by a peninsula providing an excellent configuration for defensive purposes (for the XVIIIth and XIXth warfare technology).

In spite of the excellent conditions of the site, the city of Montevideo was only founded in 1729, mainly as a base to defend the Eastern Province of the River Plate Vice-Royalty (Virreinato del Rio de la Plata) from Portuguese incursions. A few years after its foundation, Montevideo became the main city of the territory North of the River Plate and East of the Uruguay river, competing with Buenos Aires for the predominance in the maritime commerce of the Vice-Royalty.

In addition to its strategic location, the city had the additional advantage of being surrounded by a sedimentary basin (the sedimentary basin of Santa Lucia), in which soils were even more deep and fertile than in the Montevidean surroundings, and by abundant sources of freshwater (some small streams and springs next to the city, and the relatively large Santa Lucia river about 20 km. from the urban site).

The countryside was characterized by practically treeless grasslands (except near the rivers where bush forests were found), in which various types of herbivorous animals used to roam (nandus, deers, armadillos, capibaras, "South American" otters, etc.).

The indigenous population (the Charrua nation) were hunters and gatherers related to the Pampidos nations of Buenos Aires, with a very low density of population (perhaps as low as 1 person every 20 km2) with a nomadic way of life.

When the Spaniards arrived, they introduced cattle into the Montevideo hinterland, which gradually substituted the native herbivorous animals, settled the land and pushed the Charruas and other native groups to the North, to the farthest areas of the province or even outwards to the "Jesuitic" Misiones territories.

Originally, the city obtained its water from the springs of "La Aguada" and from various nearby small streams (Arroyos Miguelete, Pantanoso, Malvin, Pocitos, Seco, etc.). With time, these sources were exhausted or insufficient and by the end of the XIXth century the city was forced to bring the water all the way from the Santa Lucia river. Because the lower course of the Santa Lucia had often relatively brackish waters, the intakes and treatment plant were built some 25 km. upstream of the mouth of the river, about 40 km. from the city itself.

During the second half of the XIXth century, Montevideo experienced a very fast growth from 30,000 inhabitants in 1850 to 300,000 by the end of the century. This growth was due to the development of a very strong migratory current from Europe which has determined the present ethnic make-up of the country. This growth continued largely unabated during the first half of the XX century and the city reached the million people mark in the early fifties. At the time, Montevideo was the fifth largest city of Latin America.

Since then, the growth has considerably slowed down and even stopped during some periods. Today the city population does not exceed yet 1.5 million.

During the 2 1/2 centuries of urban occupation, the Montevideo environment has been seriously disturbed, the various streams within the bay basin have become virtual open sewers, where the wastes of tanning wool-washing establishments, slaughterhouses and textile industries are disposed (cases of the Arroyos Pantanoso and Miguelete) or have been incorporated into the stormwaters system.

To the East of the city, the basin of the Arroyo Carrasco was also seriously disturbed. Originally the stream extended in wide swampy lands (the Bañados de Carrasco) with dense natural vegetation, in which the industrial and domestic wastewaters of the upper basin were naturally depurated. During the last decade -for unexplained reasons- the swamps were reclamated in a very damaging environmental decision and the wastewaters now flow directly into the beaches and resorts of Carrasco, which has become a highly contaminated coastal zone.

During the XXth century, the city grew very dynamically towards the sandy littoral plains of the East. This area is composed of the coastal transgressive sandy deposits of the Formation Chuy, which contained a shallow fresh water aquifer. This aquifer was over-exploited for some time, and as a result, saline encroachment from the brackish River Plate waters developed. This process was further exacerbated by excavations of numerous sand pits, in which phreatic lakes formed, inducing phenomena of evaporation and additional salt concentration in the aquifer.

Today, all the Eastern sector of the Montevidean metropolitan region obtains its water supply from the Santa Lucia river (which is to the West of the city at about 60 to 80 km. from the above mentioned consumption areas).

As a result of this evolution, the whole Greater Montevideo depends almost exclusively from the river Santa Lucia. There are still a few hundred private wells utilized by industries, residences and soft-drink, and mineral water companies, but they don't provide more than 5% of the total consumption.

4.7.2 The Santa Lucia basin

The Santa Lucia river is a medium-size river with an average flow of 10 m3/sec. (check) which would suffice ot satisfy the present needs of the region, if properly managed.

However, because the flow is irregular (the actual flow figures range from practically 0 to several thousands m3/sec.), there is a need to store water in order to respond to the water demand during the periods of drought. Additional problems are created by sediment clogging of the intakes during the flooding episodes and encroachment of saline water from the brackish River Plate, upstream to the "Aguas Corrientes" intakes during the longer droughts.

In order to partially regulate the flow of the river, two dams were built (in the Canelon Grande and in the Santa Lucia Chico tributaries), which help in some degree to prevent floods, but do not allow a comprehensive management of the basin. Still, during drought periods, in which consumption is the highest, the city demands are larger than the available river water volumes.

Presently, during the summer, there is no flow downstream of the Aguas Corrientes, (although there may be still some minor flow downstream of the river San Jose confluence, about 15 km from the River Plate and a few km downstream of the intakes).

One alternative that was proposed to solve this problem, was the utilization of groundwater from the Santa Lucia basin aquifers, in order to satisfy the water demand during the summer peaks and the future growth of the consumption.

4.7.3 The aquifers of Santa Lucia

The Santa Lucia sedimentary basin (see Fig.19), approximately overlaps with the Santa Lucia hydrographic basin (although it is smaller in size). It is contained in a deep graben (2,000 m. deep) almost completely filled with sediments of Early Cretaceous to Quaternary age. The Early Cretaceous sequences (Formation Migues) reach 1,800 m. of thickness in the deepest part of the basin and are composed of consolidated detritic deposits (mainly sandstones). The Formation Migues is covered by the sandstones of the Asencio formation (Late Cretaceous), over which the moderately consolidated and poorly sorted siltstones and sandstones of the Fray Bentos Formation (Miocene) are found. These formations have a combined thickness of up to 150 m. in the area.

On top of the above mentioned geological units, there is a poorly consolidated gravelly and sandy alluvial formation (Formation Raigon) discontinuously overlain by the poorly sorted silts of the Libertad Formation (of probable aeolian origin, stratigraphically related to the Pampeano of Buenos Aires).

Not very much is know on the hydrogeological characteristics of the Formations Migues, Fray Bentos and Asencio. They contain water, but their aquifers have not been yet exploited or investigated. The Raigon aquifer, on the other hand, is relatively well-known and extensively exploited by means of several hundred municipal and farm wells throughout their area of occurrence.

The aquifer Raigon, extends for about 1,000 km2, with an average thickness of about 30-50 m., and effective porosity of about 15% and well yields of up to 15,000 liters per hour.

Most of the recharge to Raigon occurs through the Libertad sediments, which seem to act as an aquitard. Discharge from the Raigon aquifer goes to the river valleys. It is not known, however, whether the river valleys are always discharge zones or they can also serve as recharge sources locally and/or during the highwater periods.

Total potential yields of the aquifer are estimated to be of about 10-15 m3/sec., of which already about 3-5 m3/sec. are used for urban water supply (for the cities of Villa Rodriguez and Libertad) and supply for other smaller communities and farms.

There is a considerable potential for abstraction within the renewability rates of perhaps 2-3 m3/sec. or more during long periods (to contemplate the consumption growth), or up to 5 m3/sec. during short periods (to satisfy the summer peak requirements). These volumes of water could be obtained from a couple of hundred production wells adequately distributed throughout the basin.

The city of Montevideo consumes almost 500,000 m3/day (about 5 m3/sec.) of water. If the aquifers were utilized during the summer peak periods in the next decade, and in a more permanent way during the following decade, the problem of water supply for Montevideo will be solved for some time to come. However, if the city accelerates its growth and its water consumption, other alternatives may also need to be considered, as utilization of water from the River Negro, or from the River Plate at Colonia (with the limitations imposed by the increasing contamination of this last water body, (see Section 4.3).

4.8 The aquifer of Lima

4.8.1 Introduction

The city of Lima, capital of Peru, is located in the coastal foggy desert of the Pacific facade of South America in the latitude of 11° degrees South.

This desert is characterized by the quasi-permanent presence of stratocumuli formed as a result of the cooling of the lower layers of the atmosphere in contact with the cold waters of the Pacific Ocean. This ocean is particularly cool along the Chilean-Peruvian littoral due to the cold oceanic current of Humboldt and the upwelling of deeper, cooler waters.

As a result of those peculiar climatic characteristics, Lima possesses a climate much cooler than any other city located at the same latitude and altitude in any other part of the world. Also, it has one of the lowest precipitation levels of the continent (9 mm. annually). In spite of this lack of precipitations, the city atmosphere is relative humid with frequent fogs and dew formation.

The city has developed near the foothills of the Andean range on the present and ancient alluvial fans of a short and torrential river descending from the neighboring mountains: the river Rimac. Lately, the Northern suburbs of the city have extended into the alluvial fans of another river of analogous characteristics: the river Chillon.

The city was founded by the Spaniards as an exit port, mainly for the Andean exports of precious metals coming from the Alto Peru (Upper Peru: i.e. Cuzco, Potosi, etc.). In fact, the actual port was El Callao and the colonial city of Lima was founded at a prudential distance of 10 km. from the shoreline.

When Peru declared its independence in the early XIXth century, Lima became the country's capital.

The growth of the city was gradual until the 1940's, when the population reached the 300,000 inhabitants mark. Since then, that growth has accelerated, and today it is estimated that the population of the metropolitan area of Lima is very close to reach 7 million people.

4.8.2 Water supply

The water supply for the city of Lima and suburbs comes practically all from the two sources:

1) from the river Rimac (through the treatment plant of La Atarjea and its distribution system and;

2) from wells drilled in the Lima alluvial coastal aquifer (9).

Figures from a report prepared by Binnie and Partners in 1987 for SEDAPAL (Servicio de Agua Potable y Alcantarillado de Lima), which

is the governmental institution in charge of urban water supply, estimated at about 21 m3/sec. the total annual consumption for 1986. Of that amount, a volume of 11.35 m3/sec. was abstracted from the Rimac river and 9.45 m3/sec. from groundwater sources (the Lima aquifer) which amounts to about 45% of the total usage.

It is also estimated that the demand has increased in 1990 to a present figure of 25 m3/sec. and will continue growing at a rate of about 4% per year to reach 33 m3/sec. in the year 2000 and 45 m3/sec. in 2010.

The La Atarjea distribution network, distributes water for about 60% of the population using not only the river water, but also including the water obtained from 42% of the production wells (106 out of 253). The remaining 147 wells are connected to local distribution networks.

In 1985, it was estimated that about seventy percent of the population was legally connected to the main municipal water system. An additional 16% obtained their water illegally (also from the system), and remaining 14% had to get their water from public fawcets or water tanks.

With the recent continued growth of Lima it is very likely that the actual number of people not connected or illegally connected with the main network may be closed to 40%, which amounts to about 2,800,000 people.

Industries, commercial companies and irrigated farms meet most of their water requirements through the operation of a few hundred private wells, increasing total groundwater abstraction quantities to the previously mentioned figures.

The requirement for the year 2000 will be -it is estimated in the same report- of about 13 m3/sec. additional to the present supply volumes.

4.8.3 <u>The aquifer</u>

The areal extension of the Lima aquifer is 390 km2 (including the lower Rimac and Chillon alluvial basins and associated coastal deposits). The water is contained in a coarse-grained formation of sands and agglomerates with a thickness ranging from 0 to probably about 500 m. (accurate figures are not available).

The upper 100 m. are high permeability, relatively clean sands and gravels with very little finer element. It seems that from 100 m.-200 m. to the bottom of the aquifer, there is a reduction of the general permeability of the formation, although very little information is available below 200 m.

Water levels have consistently dropped in most wells for about 1 to 2 m. per year, and a number of wells along the coastal zone had to be closed due to high salinity along the coastal zone and to dewatering (having become dry) within the inland areas.

Subsequently, and to compensate this decrease in production, new wells had to be constructed and pumping rates increased in a number of pre-existent wells.

Water level decreases during the period 1969-1985 have been -at least- of 10 m. in most of the coastal area and reached 30-40 m. in the higher part of the coastal plain next, to the foothills.

The actual exploitation of the aquifer presents a number of operation problems which have been identified by SEDAPAL/ Binnie and Partners. They are:

1) Well yields have been and are dropping, therefore increasing pumping dynamic heads and pumping costs;

2) A number of wells have become and are becoming dry, even when they are drilled into the bedrock;

3) Water levels dropping near the coast have induced phenomena of salinization of the abstracted groundwater;

4) Pumps are (or have become) over-dimensioned for the present pumping rates, increasing costs;

5) Dynamic water levels falling under the upper limit of the screens have produced incrustations in the screens, therefore reducing well yields.

It seems clear that the renewability of the aquifer is considerably less than the total volumes being abstracted. Groundwater recharge from the surface (which provides practically all the renewed water) takes place in several ways:

1) recharge from the bed of the river channels (mainly river Rimac, but also river Chillon);

2) recharge from the swamps and other naturally vegetated areas to the North of the city;

3) recharge from agricultural irrigation return in the nonurbanized surrounding areas of the coastal plain;

4) recharge from garden irrigation in the urban areas;

5) recharge from losses in the water distribution system and;

6) recharge from losses in the sewer systems or unsewered disposal of domestic wastewaters;

It is important to note that practically no direct recharge through rainfall or local run-off takes place in the Lima region, due to the low precipitation level (just 9 mm. per year) and the type of precipitations (drizzles and dews). As a consequence, run-off on the surrounding slopes, as well as infiltration in the foothill colluvia and local fans are extremely rare events.

Of these sources of recharge, the most important are the first four mentioned (river channel recharge, irrigation recharge and losses from the system). According to estimates present recharge from these sources could amount to about 11 m3/sec. If underground water flow from upstream alluvial areas is included, the total input to the aquifer is approximately 13 m3/sec. Of these, about 4 m3/sec correspond to infiltration from the river channel, 3 m3/sec. to infiltration from farms, parks and gardens, and 4 m3/sec. to leakage from the water distribution system.

Several of the above mentioned sources of recharge are presently being threatened by the continued urban growth. Firstly, many irrigated farms and parks surrounding the city were lost to urbanization. If this trend continues, recharge from these sources could be reduced by half in the next twenty years. Secondly, the city is encroaching on the river channels where an important part of the infiltration takes place. For instance a new highway is being built parallel and along the valley of the Rimac river, which will impermeabilize several hundred hectares of the permeable channel surface.

Probably, the recharge to the aquifer will be reduced to 11 m3, or less, is these phenomena continue unchecked. The present balance is negative (at least 1 m3/sec. more is abstracted or lost to the sea through underground flow, than recharged from the various sources previously mentioned). Because abstraction is not being reduced and recharge is decreasing, things do not seem to evolve in the right direction. Water levels declines and saline interference are going to continue, pumping costs are going to increase and many old wells will become dry or saline.

On the positive side, there is presently a project to artificially inject water into the aquifer to push the balance of the aquifer towards positive numbers.

The availability of surface water which provides 55% of the supply (and will probably be used for injection purposes), is also a problem. The present average discharge of the Rimac river is of 32.3 m3/sec. in Chosica, upstream of Lima and the discharge of the Chillon river of 7.5 m3/sec. in Larancocha close to the exit to the coastal plain.

About 10 m3/sec. are lost to the sea during the flood episodes of the Rimac river. During these high flow periods, too much waster, with a very important sediment load finds its way to the sea. The Chillon losses are of about 2 m3/sec.

About 12 m3/sec. of the Rimac flow is utilized for urban water supply and 4 m3/sec. for irrigation. The rest (5 m3/sec.), infiltrates into the aquifer. The Chillon is practically only used for agricultural irrigation purposes (4.4 m3/sec.).

These data show that the city of Lima is using most of the available water from the two rivers and there is only a relatively small volume of water (10 m3/sec. and 2 m3/sec. respectively) lost during the most intense floods. This water is difficult to use because of the materials in suspension, but they could allow a small increase in the available volumes.

One additional problem is the increasing risk of contamination both of the surface water and of the groundwater. The surface water quality is being seriously affected by the many activities taking place in the middle and upper Rimac basin. Firstly, all wastewaters from the communities and cities located upstream of Lima are thrown into the stream. Secondly, mining and industrial wastes (particularly mining) are also disposed into the river (s). As a result of that, water quality has been gradually deteriorating (contents of heavy metals and other toxic substances already constitute a potential hazard for the city water supply). The aquifer of Lima is also at risk. The Lima alluvia is permeable up to the surface, and there is risk that uncontrolled hazardous wastes could also give raise to unwanted phenomena of contamination.

4.8.4 Conclusion

The continuation of the city growth and the lack of financial resources to implement environmental control measures are not going to help check this evolution towards water quality degradation.

The city keeps growing at an accelerated rate and water resources are not only fragile but also limited. If the growth continues the city of Lima is going to have more than 10 million people by the year 2000 and not far from 15 million by the year 2010.

It is very clear that by then, the Rimac and Chillon rivers and the aquifer will not be able to satisfy (not even close) the domestic, industrial and environmental requirements of an urban region of this size. As a result, there is no guarantee, from that point of view, on the actual availability of these basic resources for the developmental needs of the Lima metropolitan area. Alternative sources of water are not easy to come by. The best options are probably situated in the mountain region particularly beyond the continental waterdivide, in the headwaters of the Amazonian tributaries. However, any project attempting to bring water from such distant and not-easily accessible locations will be extremely expensive (almost certainly of the order of some billion dollars).

Peru is a heavily indebted country, with very little credit in the international financial system, and it is not very likely that these types of investments are going to be found in the foreseeable future. Therefore, for the time being, the only solution is better management and protection of the scarce surface and underground water resources of the Rimac and Chillon basins and of the aquifer of Lima, reuse of the wastewaters -at least for irrigation and industrial purposes- and better control of the water distribution losses.

The final solution, will be to reassess the environmental potential for growth of the city of Lima itself. The Lima environment is relatively fragile and there is a limit to the degree of urbanization that can be indefinitely sustained. This limit was certainly exceeded long time ago. The coastal plain of Lima cannot sustain a population of 7 million people (and much less one of more than 10 million as projected in the next decade) without suffering irreparable damage. This issue has become one of the main issues of contemporary Peru.

4.9 Water supply and environment in the "Sabana" of Bogota

4.9.1 Site and history

When one looks at the map of Colombia, it is difficult to understand why the capital of the country is located where it is. In effect, the city of Bogota, which concentrates nearly 1/5 of the population of the Republic of Colombia, has been erected in a site with difficult access by land from all directions, very distant from the sea ports (the closest ports, Santa Marta and Buenaventura are respectively located at about 1,000 and 900 km, through very mountainous terrain) and even from the fluvial ports (the closest fluvial port is in the Magdalena river (Honda) about 150 km from Bogota downslope of a very steep scarpment).

It is also important to remember that the Magdalena river is a fast flowing and rocky river, which makes upstream navigation difficult and slow.

In addition, Bogota is located at about 2,700 m. above sea level, in one of the coolest environments of the country, with average temperatures of 13°C, with a very cloudy and humid climate and very few warm breaks.

However, in spite of these apparent inconveniences, Bogota was preferred systematically to other warmer and more easily accessible places, as might be the ports on the Caribbean coast or Cali in a pleasant, warmer and productive valley not far from the Pacific coast.

We believe there are a number of reasons that have made the early founders and subsequent country leaders to establish and keep the city and later the capital where it is. Some of them may be the following:

1) The Cundi-boyacense plateau, where the city is situated, was the center of the most technologically developed culture in prehispanic Colombia: the Chibcha culture. It is estimated, that at the time of the arrival of the Spaniards, the Chibcha nation had a population of nearly 1 million people dedicated to various farming, mining and metal crafting activities. This nation was politically organized in several mini-states and it became much easier for the colonizers to organize the work of the local population taking advantage of the pre-existing socio-economic structures.

2) The Cundi-boyacence highlands were also the main gold and precious stones (emeralds) producing centers of the newly colonized American territories. It is believed that the famous legend of El Dorado was based in the gold offrends offered by the Chibchas in the meteoric crater of Guatavita, not far from Bogota.

3) The "Sabana de Bogota" possessed excellent agricultural lands

both for native (of indigenous crops) and european farming (as for instance wheat, barley, raising of cattle and other Old World farm animals, etc.).

4) The climate of the "Sabana" was similar to the cool climates of the Castillan-Leonese plateau in Spain (to which the "conquistadores" were used to).

5) The environment of the "Sabana" was also among the healthiest of the region. Most tropical illnesses that were common in neighboring lowlands were rare in Bogota (as it is the case to day with yellow fever, cholera and malaria). To that it must be added, that in pre-antibiotic times, in which plagues could kill tens of thousands of people in a short period of time, the cool climate of the highlands helped to slowdown the spread of those plagues and to reduce their effect.

Whatever the reason, the first group of Spaniards, who arrived to the "Sabana de Bogota" in 1538 leadered by Gonzalo Jimenez de Quesada found a prosperous society in which several states commanded by their "Zipa" kings shared the green highlands of the present departments of Cundinamarca and Boyaca. One of the most powerful kings of the Chibcha nations was the Zipa of Bacata, who was based in the village of Bacata located not far from the present location of downtown Bogota.

The Spaniards decided to settle at that place next to the Chibcha village and founded in 1539, the city of Santa Fe of Bacata or Bogota, as it came to be known the future capital of Colombia, in later times.

The Spaniards gradually took control of the region, exploiting the mineral and agricultural resources using indian work, and during long time Bogota remained only a remote city of the colonial domains of Spain in the Northwestern region of South America.

At that time, the port cities of the Caribbean were more important both in size and commercial activity (i.e. Cartagena and Santa Marta), although also more vulnerable to attacks by pirates and foreign powers. This was probably the reason why Santa Fe de Bogota was made the capital of the Vice-Royalty of Nueva Granada, when this Spanish administrative and politic entity was created in 1716 (and 1739) (1).

During the Bolivarian period, in 1819, Cucuta was made the capital of the Gran Colombia, but was from Bogota that Simon Bolivar governed the first and last attempt to build a Latin American Federation.

---

(1) This Vice-Royalty was created in 1716, suspended in 1723 and reestablished in 1739.

After Bolivar's death in Santa Marta (1830), and after the failure the grandiose Gran Colombia project, the present Republica de la Nueva Granada was formed, with its capital in Santa Fe de Bogota. The name Republica de Colombia, was finally adopted in 1884.

During colonial and republican times, until well in the XXth century, the city of Bogota remained a relatively small and neatly planned city, thriving in a fertile and highly productive area of the Eastern Range plateau.

The population of Bogota, by the end of the XXth century did not exceed 100,000 people, and it was not until 1955 that the city surpassed the 1 million mark. Today, the city is nearing 6 million inhabitants and it is expected that it will grow to more than 8 million by the end of the century and 11 million by the year 2010.

4.9.2 The environment

The city of Bogota is located, as previously described, in the "Sabana de Bogota", a high flat-bottom valley, surrounded by mountains, which together form the Cundi-Boyacence plateau. This plateau is a narrow and elongated (300 km-long), flat to hilly region situated along the highlands of the Andean Eastern Range of Colombia at altitudes ranging from 2,500 m. to 3,700 m. above sea level. Near Bogota, the valley flat bottom widens considerably to about 25 km., and it is this area that is called the "Sabana".

The original vegetation of the "Sabana" was probably forest, but after a couple of millennia of agriculture (both pre and post hispanic conquest, the forests were eliminated and croplands and grasslands took their place.

During the last few decades, the expanding urbanization has encroached in nearly half of the total area of the "Sabana".

4.9.3 Geology and hydrogeology (*)

Geologically, the "Sabana" is a Tertiary-filled graben which includes a lower unit of claystones and shales (Formation Villeta), a middle unit of sandstones, with a thickness of about 300 m. (Guadalupe Group), and a overlying clayey formation (Formation Guaduas). On the top of these deposits, there is a Quaternary lacustrine and alluvial sedimentary sequence comprised of clays and intercalated sandy lenses (Formation La Sabana) on top of which thin younger alluvial lenses can also be found.

(*) Ref. 73, 74 and 76.

The main water-bearing formations of these sequences are the upper units of the Guadalupe Group (particularly the "Areniscas de Labor" and the "Areniscas Tiernas" with a total thickness of about 160 m., and the sandy lenses of the Formation La Sabana.

Presently, all groundwater abstracted is obtained from the shallow sandy lenses and very little water if any is extracted from the deeper sandstones.

4.9.4 The river Bogota

The river Bogota is one of the most important tributaries of the river Magdalena. It drains a basin of about 6,000 km2, which provides most of the water for the city of Bogota and neighboring municipalities and serves as a draining channel for the wastewaters of the city.

The upper basin, of about 1,800 km2, and a population of slightly less than 100,000 is the main source of water for Bogota from the various reservoirs built to that effect. The elevation varies between 2,590 m. and 3,700 m. above sea level, and the average precipitations are of about 850 mm/year.

The middle basin, has an area of 2,470 km2 and a population in excess of 5 million. It is a mainly flat area, situated at about 2,500 m. above sea level, with a mean annual precipitation of 900 mm., and where the main water consuming activities take place.

The lower basin, extends for about 1,800 km2 and it is composed of very steeply sloping terranes. The actual fall of the river in this stretch is of about 2,000 m. in a 35 km distance. In the "Salto del Tequendama" the river Bogota falls about 180 m. The average rainfall for the lower basin is of 1,200 mm. annually.

In addition to the Bogota basin water, some additional water is imported into the basin from the Eastern slopes of the Eastern Mountains Range (Macizo de Chingaza; embalse de Chuza) through a tunnel.

4.9.5 Water supply

The population of Bogota consumes about 200 liters per person per day, and it is estimated that it will grow to 300 liters by the end of the century.

Present total consumption is of about 17 m3/sec., of which 85% (or 14.5 m3/sec.) returns to the river Bogota to be evacuated downstream as used waters.

The remaining municipalities of the basin consume about 1 additional m3/sec. giving a general figure for the whole basin of 18 m3/sec. This amount will increase to 23-25 m3/sec. by the year

2,000 and to 27-32 m3/sec. by the year 2010.

There are approximately 700,000 persons without water service in the Bogota metropolitan area. Another 75,000 people do not have water service in other municipalities of the basin, giving a total of nearly 800,000.

4.9.6 Wastewaters

The wastewaters of the city go untreated into the Bogota river at the lower exit of the Sabana and a few km. upstream of the Tequendama falls. The river Bogota flow, in this stretch of its course, is made mainly of the city wastewaters and stormwaters and, as it can be imagined, it is heavily contaminated. Presently, during its whole course downstream of Bogota, the Bogota river has become an open sewer, and the "Salto del Tequendama" falls are the largest "wastewater" falls of the world.

4.9.7 Irrigation

Because of the relatively high levels of precipitations, irrigation farming is not very important in the Bogota region. It is estimated that about 6 to 7 m3/sec. of water is used for various irrigations purposes, in which the watering of flowers in many Bogota greenhouses is probably the most important (Colombia is the one of the largest exporters of flowers of the world).

4.9.8 Electrical generation

Due to the large differences in elevations and steep slopes, the water strategy for the Bogota region was largely dominated by the need to produce energy. A complex system of hydro-power generating systems has been built taking advantage of natural water falls, or channelling/piping the water to the steeper slopes for electricity generation purposes. About 670 MW are presently produced in the Bogota region alone. Some additional 600 MW are expected to be produced by the project Chingaza.

4.9.9 In brief

It is clear, that in a urban region as complex as the Bogota valley, a very careful strategy of water management is required. Until now, this was oriented towards utilizing all surface water resources available and dispose the used water in the rivers, expecting that the large fluvial volumes would somehow disperse and purify (with time and distance) the contaminated waters.

In fact, now it appears that the resources of the Bogota basin are barely sufficient to satisfy the requirements of the city. It becomes still more serious, if it is thought that the cost of providing water supply for some neighborhoods in the South and East of the metropolitan area is too high, if the northern distant water resources are utilized.

In opinion of some Colombian hydrogeologists, the solution would be to go into groundwater supply. According to C. Rodriguez (1988) the volume of groundwater available is of 26,000 M. m3 (in the aquifer "Guadalupe"), which is 30 times more than all the water stored in the reservoirs (950 M. m3). Presently the groundwater lies unutilized, there is not recharge because the aquifer is saturated and no outflow seems to exist towards the lower terranes surrounding the Bogota plateau. The utilization of the aquifer would allow to take advantage of the recharge from the river Bogota during the period of highwaters (storing the waters and controlling the floods at the same time).

However, the problems of contamination of the river Bogota need to be solved. Presently, the river Magdalena is starting to be affected by these contaminated Bogota waters. Although the Magdalena flow is much larger than the Bogota (about 25 to 50 times more), during some periods the river Bogota may supply up to 10% of the river Magdalena at their confluence. The degree of contamination of river Bogota is such, that even this 10% is too much, and if not checked in the very near future this may significantly affect (and it is in fact affecting) the quality of the Magdalena waters. Because there are so many cities and people depending of the Magdalena river (for water supply, for fishing) the risk needs to be eliminated.

The once pristine "Sabana de Bogota" has become a surrealistic nightmare. While many tens of thousands of people continue immigrating to the city from throughout Colombia, the environment is being deteriorated and soon it may be too late to prevent the total destruction of the hydrological systems of the Magdalena basin and the "Sabana".

Of course, if these problems are going to be solved, there will be a need for investments for treatment of wastewaters, for construction of wells, for comprehensive water network distributions systems. There is no way out. The cost of not doing it may result too high.

Chapter 5 MANAGEMENT OF WATER RESOURCES IN DENSELY POPULATED AREAS

5.1. Complexity of water management in urban areas

Management of water resources is a very complex issue. From the moment precipitations hit the ground, there are a number of problems arise about the future utilization (or not utilization) of the water, and in particular about who has the authority to control its use and/ or disposal, as well as to decide about conflicts that may develop on that matter.

Without human intervention, the fallen water would infiltrate, flow on the surface or evaporate following naturally induced patterns.

In forest areas, most of the water infiltrates, or is evapo-transpirated (mainly or almost solely by the vegetation) with very little run off on the ground surface. The infiltrated water recharges the aquifers, which in turn discharge in nearby streams.

In steppe or desert areas, run off predominates, with infiltration (recharge) dominating over discharge in the flood plains.
On the other hand, evaporation (rather than evapo-transpiration) may become important in the lowest topographic areas of closed or semi-closed basins.

In sub-humid grasslands the hydrological behavior of the landscape is somewhat intermediate.

Once man introduced changes of any kind on the ground surface, the natural hydrological dynamics is affected. When the forest cover is substituted by a herbaceous cover, the proportion of run off in the total water budget is normally significantly increased. When trees are planted on a former grassland area, the opposite frequently happens.

Agriculture has a -still- stronger effect on the water balance. In order to grow most types of crops, it is normally required to strip the land clear from any pre-existing vegetation cover (to eliminate competition for the future crop). During a certain period before the growth of the crop, the land remains bare producing -obviously- a drastic change in relation to the previous ground surface conditions.

Once the crop has grown, the hydrological behavior of the land changes again. All crops pass through various stages of soil cover and height, going from small herbaceous size, with reduced soil cover to shrub, bush or tree size, with partial or almost total cover of the ground surface.

In all agricultural landscapes, the hydrological balance is strongly controlled by the characteristics of the farming activities taking place.

Urbanization still affects in a much stronger way the water dynamics.

Firstly, a considerable portion of the ground is covered with relatively impermeable layers of various paving materials (asphalt, cement, tiles, etc.), in which infiltration and evaporation are practically nil, and all precipitations flow as run off.

Secondly, another portion of the ground is excavated, removed or buried under fill materials brought from somewhere else, producing significant hydrological changes.

Thirdly, all kinds of structures of varied nature are inserted in and/or laid on top of the ground surface with important effects on the water dynamics. These structures can sometimes collect the precipitations (as for instance the roofs), in other cases they may obstruct the surface and/ or the groundwater flow, and a number of other water regime modifications.

In addition, urban design includes (well planned or not) comprehensive water management schemes. Stormwaters running off from pavements, roofs, etc, is collected in culverts, canals and pipes and conducted out of the city through a network of water conduction systems.

Cities must also "import" water to satisfy the water needs of the urban population. As a result, water is abstracted from nearby streams, lakes or wells, treated, stored, conducted to the users, utilized for various purposes and disposed as used waters. This disposal is carried out by means of another water conduction system, in some cases this wastewater is treated and at a later stage (treated or untreated) is thrown back into the "natural" (often not so natural) hydrological system, in a much different state than it was when it was originally abstracted.

Stormwaters and wastewaters may remain isolated from each other within the urban area, or be jointly disposes.

In any case, all this abstraction, conduction, use and disposal of water implies dramatic changes to the environment in the urban region. Rivers are channelled or piped, and their flow volumes and regimes substantially modified, their waters are loaded with many types of artificially produced and "relocated" natural substances, groundwater levels and therefore groundwater flow are also changed (generally they are drawn down, although in some cases they may be raised).

Changes may happen at the abstraction sites (i.e. flow reduction of a river at the water intake site, drawdown of water levels in wells, etc); they may take place during conduction and storage (due to leakage from water supply pipes, from tanks, from canals, from sewers, etc); and they may occur at the disposal end of the system (outlets of sewers of run off canals).
All these phenomena are closely interconnected. The natural and

anthropogenic systems are, in fact, one single unit and must be dealt with, in a coherent way.

Forests in catchment areas control the flow towards the reservoir, from which the water treatment plan is fed, which in turn provides the water for the homes and industries, which is going to become sewage, which will be treated and/ or disposed at a later stage in a stream or other natural water body.

If the forest is eliminated, the water regime in the reservoir will change. If water is withdrawn from a river, and disposed somewhere else, the river regime downstream will change. If groundwater is pumped form an aquifer, discharges and recharges to and from hydraulically connected streams will be modified and the stream regime will also change. If surface water is used, somehow, the related groundwater will be affected. If the vegetation is eliminated, both surface and groundwater in the downstream basins will be affected.

All parts of the water system are closely linked, and the effects of any action can be much more complex than a mere first sight observation could superficially imply.

Therefore, it is very important to define who has the right and authority to modify what, that will produce changes that may affect in various measures other people living in the same hydrological region.

5.2 Legal set-up

Due to the complexity of the problem, in most Latin American countries, there is not a comprehensive definition of the water rights of individuals and institutions, and of the jurisdiction of the various public and private organisms that can make water management decisions or arbitrate or judge in the water conflicts.

In some countries there is a Water Code or Codigo de Aguas (i.e. in Chile), but by and large, most countries do not have it (i.e. Venezuela, Uruguay, Bolivia and many others). In those cases, the water juridic body is the result of a number of casuistic decisions and rules, defined for very specific purposes by the several levels of governments (local, municipal, provincial, federal or national), and the various branches of power (legislative, executive, judicial). As a result, in most cases, the body of laws and reglaments that rule the water subject is a complex set, in which there is as much confusion on rights as on jurisdictions. By and large the Latin American farmer has the right to use the water falling on its farm. He or she has also the right to channel the drainage water out of his farm, through the normal drainage waterways. He or she has also the right to change the hydrological regime of his land decreasing or increasing infiltration, evaporation or run off according to his or her wishes and possibilities. This normally applies also to any private or public institutions owing land. Normally, although the landowner does not own the underground resources, including the groundwater, they can drill wells and operate them without any special requirement.

In some countries, there is complete freedom to abstract groundwater from privately owned lands by their owners with very little control if any (i.e. Venezuela, Colombia, Bolivia, Uruguay, etc). In some others, special authorizations are required and strict controls are applied (as in the case of Mexico).

Once the water is flowing in a larger stream, the rights to use these waters may vary from place to place. The traditional Spanish law, gave the property of the stream and its shores to the Crown, and in general terms this law has been followed in the post-hispanic laws of the Hispano-American countries.

However, in practice, riverine owners can withdraw water from streams to the point in which conflicts with other users may arise. Decisions on that, are often made on a case by case basis and often following political criteria.

In those circumstances, it is obviously necessary to have a water management or any other authority with jurisdiction on this matter, in order to interpret and apply the existing laws and rules, and in general decide on who has the right when conflicting interests arise.

The rights over the use of groundwater are still more fuzzy. This is because, the origin of groundwater has been for so long time a mystery for many people. In some ways it still is.

Although in many Latin American countries no special authorizations are required to utilize underground water by any landowner that wishes to do so, the development of various types of problems related to overpumping has forced many governments to reconsider this situation. Presently, water laws are being written (when they are not already), or modified (when they are not suited for newly developing water and specifically, groundwater problems).

Normally, when overpumping occurs, it may become too costly to keep pumping groundwater under low yields and high pumping costs, and therefore pumping may decrease on its own, causing often irreparable financial damage to farmers, municipalities or industries using those -now unproductive- wells and related water structures.

In coastal areas, overpumping may bring saline degradation of the aquifer, which may be permanently damaged (at least on a short or medium term perspective).

In any case, groundwater use controls are very limited, both in farming areas and in cities, because of the lack of adequate legislation, reglamentation or implementation of existing rules or due to insufficient and/ or ineffective monitoring and control.

5.3 Administrative set-up

In most Latin American cities/ countries, water management activities are under the responsibility of public institutions. The same applies for most urban water services, which are almost always under the authority of a public water company.

Although, normally, this responsibility falls on public institutions, there may be several of them dealing with different aspects of the water problem, frequently with overlapping jurisdictions.

In few cases, the water matters (including water supply and sanitation) are centralized in one single institution or Ministry. This is the case in Cuba, where the main authority on this subject-area is in the "Instituto de Hidroeconomía", Venezuela, where the responsibility lies with the "Ministerio de Recursos Naturales Renovables" (MRNR), which is a Ministry with national jurisdiction, and Chile, where the Dirección General de Aguas (DGA), depending from the Ministerio de Obras Públicas is the principal authority in the matter.

In the cases in which the jurisdiction on water activities is divided between several institutions or government levels, there is often a "water service" institution, or several, dealing with institutions dealing with other aspects of water management (as for instance, hydrography, groundwater, irrigation, etc).

Very often water companies are under the jurisdiction of a National or Federal Ministry. This is the case of Mexico City, in which case the urban water supply institution for the Federal District (and surrounding areas) depends from the "Secretaría de Agricultura y Recursos Hidráulicos" (SARH) which is a federal institution. The water supply company for the valley of Mexico is called the "Gerencia de Aguas del Valle de Mexico" (formerly the Comision de Aguas del Valle de Mexico), which is a dependency from the SARH.

In Argentina, the federal district (Capital Federal) is served by a Federal Institution, Obras Sanitarias de la Nacion, depending from a Federal Ministry.

In Lima, Peru, water supply is in the hands of SEDAPAL (Servicio de Agua Potable y Alcantarillado de Lima), which in turns depends from the Ministerio de Vivienda y Construccion, at the national level. A similar situation is observed in Nicaragua, where all water supply and sanitation is taken care by the "Instituto Nicaragüense de Aguas y Alcantarillado", which is an institution with quasi-ministerial rank.

In many countries/ cases the responsibility for water supply lies with the provincial (or state or departmental) governments. This is the case in most Mexican states in which the States governments run their own water supply institutions (i.e. the Water Supply company in Saltillo and other cities of Coahuila which is called

Servicio de Agua Potable y Alcantarillado de Coahuila depends from the government of the State of Cohauila).

A similar set-up can be observed in Bolivia, in which the water companies depend from the provincial (departmental) authorities. The main water supply and sanitation institutions in Bolivia are SEMAPA in Cochabamba, SAGUAPA in Santa Cruz, SELA in Oruro, SAMAPA in La Paz and COSAALT in Tarija 1. All these institutions depend from the respective provincial governments, often through provincial "development" corporations" (i.e. CORDECO in Cochabamba, CORDEOR in Oruro, etc).

In the Province of Buenos Aires, in Argentina, the water supply and sanitation company is called Obras Sanitarias de la Provincia de Buenos Aires and it provides water and sanitation for most of the largest cities of the Province of Buenos Aires.

In some other countries the water supply is responsibility of the municipalities. In Colombia, for instance, the larger cities have their own water companies (i.e. Empresa de Aguas y Alcantarillado de Bogota; Empresa de Aguas y Alcantirallado de Cali; Empresa de Aguas y Alcantarillado de Medellin; among others). In the smaller Cities/ Departments there used to be a water company for the whole department (i.e. Emposucre for the Department of Sucre; of Empomarta for the Department of Atlantico), but presently the whole system of water supply and sanitation for all but the larger cities is under revision.

In some cases, the water supply services are in the hands of a private or semi-private company. This will be the case in a number of cities of Colombia in which the old Departmental water supply institutions are being phased out and new semi-private companies are being instituted.

In the case of Brazil, water activities are mainly managed at the State level. In the Greater Sao Paul, there are two institutions dealing with water supply and sanitation problems. They are the Departamento de Aguas e Energia Eletrica (DAEE) and the Companhia de Saneamento Basico do Estado de Sao Paulo (SABESP). The first mentioned institution depends from the government of the State of Sao Paulo and the last one possesses a mixed economy status (part of its capital comes from the private sector (35%).

In some countries there is a mixture of all the previous systems. For example, in the Greater Buenos Aires, there are a large number of water authorities and companies. The Federal Capital itself and a number of municipalities outside the Federal Capital are under the authority of the federal "Obras Sanitarias de la Nacion", the city of La Plata and several other municipalities of the Greater Buenos Aires are under the authority of the provincial "Obras Sanitarias de la Provincia de Buenos Aires", the Municipalities of Quilmes and Berazategui (among others) are under the authority of their own (municipal) water companies, and finally, several other municipalities and urban or sub-urban development are being administered by local cooperatives under the authority of the local municipalities.

In the case of Brazil, the water supply and sanitation role normally is in the hands of the States. The federal "Departamento Nacional de Aguas e Energia Eletrica" intervenes only in the regulation and policy aspects of the problem, as well as in the cases of national basins (as is the case in the Amazonas or Parana basins).

There are still a certain number of Brazilian municipalities that remain in charge of the water services (as it was the responsibility of the municipalities). One example of a municipality that kept its control on the local water supply company is Santo Andre, which is a large city of approximately 1 million people, part of the Greater Sao Paulo region. The Santo Andre municipality preferred to keep the water company as municipal (probably due to its profitability) and is still in charge of the service. There are still a certain number of municipalities in the State of Sao Paulo and in the rest of Brazil in the same situation.

5.4 Political issues

As any other institutions that are part of political societies, water institutions are normally strongly influenced by the political systems. This is particularly true in the case of most Latin American countries in which politics percolates heavily into most socio-economic activities, even in those in which it would be expected a more "neutral" or exclusively technical approach.

This applies at all levels of the institutions. At the higher level, upper management appointments are seldom non-politically inspired. At the medium and lower levels, appointments and promotions are also frequently based on political criteria.

The same applies to decisions taken both at the short and long term level. Very frequently, political pressures not only have a decissory influence on general policies, but also on what it is done or not done, on what technical solution is applied, or whether the purchases are made with this company or that one.

In practically all Latin American countries, the maximum authorities of the water institutions are appointed by the executive government (i.e. the President or his or her ministers) and normally technical experience on the matter is not the key qualification for the position. Frequently, these appointments rewards political friends or allow agreements with political opponents.

In any case, form a political point of view, the Presidency or Vice-Presidency or a position in the Board of Directors of the water institutions give access to a pool of jobs that are often used to strengthen the political power of the appointed person.

On the other hand, water institutions and companies, very often possesses a strong financial power, and that makes them a tempting target for politicians. This financial power is the result of the handling of large sums of money, both as a result of their self-financing characteristics and/ or of the fact that they are frequently recipient of external loans, mostly for infrastructural development purposes.

Therefore, any analysis or interpretation of the water institutions (particularly the water supply and sanitation companies) needs to take into consideration the political elements that determine both their policies and everyday decisions.

The type of decisions that are more likely to be affected by political influences are the following:

1) selection of a system of water supply (surface water or groundwater);

2) location of a reservoir;

3) location of wells;

4) location of a sewer canal or outlets of wastewaters;

5) areas of expansion of water supply and sewerage systems;

6) granting of construction and operation contracts;

7) purchases (particularly large purchases);

8) utilization of funds for other purposes (not directly related with the objectives of the organization);

9) location of water cuts (when cuts are required);

10) decisions on human resources;

11) decisions on administrative matters;

12) decisions of the legal, political and administrative status and organization of the water institutions.

The political or quasi-political organizations that influence on these decisions include: the various levels of government authorities, the political parties, neighborhood associations, miscellaneous associations or lobbying groups of industry or commerce owners, trade unions, the army, etc.

There are so many decisions with potential political implications and so many groups with interest in orienting this or that decision that they often become determinant for the development of the water situation in the urban regions.

In the following Chapter we will attempt to relate these issues to the actual environmental problems affecting the urban regions and their potential solutions.

Chapter 6 PROBLEMS IN WATER RESOURCES AND URBAN WATER SUPPLY IN LATIN AMERICA

6.1 Introduction

During the last few decades, urban water supply problems in Latin America have become increasingly critical in many of the larger cities of the continent. The reasons for these problems are numerous: insufficient knowledge and lack of properly trained professionals, utilization of political criteria in technical decisions, bureaucratization of water management and supply institutions, corruption, etc. In Table 6.1 we attempt a summarized classification of the causes of the problems affecting water resources management and utilization in Latin America, as well as of their direct and indirect consequences. In the next few pages a brief description of the causes of some of these problems is presented.

6.2 Main causes of the water problems in urban areas

A) Less Financial Resources

One of the roots of the environmental, health and social problems that have developed in Latin American cities during the last few decades has been the lack of financial resources. Particularly, the problem has worsened and the situation has deteriorated since 1982, when the Latin American debt crisis surfaced.

Until 1982, although financial resources were scarce already, there had been an open flow of credits from funding agencies, transnational banks and financial centers towards practically all Latin American countries.

This flow of dollars that occurred mainly during the seventies, had been mainly the result of sudden availability of petrodollars ("eurodollars") which had to be recirculated and invested somehow, somewhere in order to produce interest.

At that time, many Latin American countries had fallen, due to internal developments and external pressures, prey of a wave of right wing military governments with very little accountability to any electoral constituency (given the fact that political parties had been outlawed or emmasculated, and elections were not carried out or were more or less fraudulent ...).

Argentina (which had had only short periods of democratically elected governments) had been run, on and off, by military or authoritarian governments since the fifties (or even earlier if we include the populist Peronist period). In 1975, a particularly bloody and authoritarian "junta" took power and remained in power until 1983. During that period most of the Argentinian debt was contracted.

In Brazil, the military took power in 1964, and remained in charge during all the period of the "Brazilian miracle", in which Brazil experienced one of the most sustained (and wildest) growths of the world. In the early eithties, when the economical situation worsened, the military withdrew from the government, mainly because the growing popular resentment and the weaker economy made more difficult, risky and less profitable to stay in power. The bulk of the Brazilian debt was also contracted during that period.

In Uruguay and Chile, the most traditionally civilist countries of South America, two "coup d'etats", mainly organized with outside help, took place in 1973. Oddly, they occurred simultaneously, after almost a century of democracy in both of them. These military dictatorships, lasted until the early and late eighties respectively in both countries. Most of the Uruguayan and Chilean foreign debts were also borrowed by these military governments.

Other countries affected by this political infection on a larger or lesser degree were Bolivia, Peru (whose military government had a more nationalistic orientation) and Paraguay (which had suffered long-lasting military dictatorships during much of its history). These countries also developed large foreign debts during the late seventies.

In Mexico, which has not had a military government for quite a long time, the unaccountability is provided by the particular style of the PRI (Partido Revolucionario Institucional) which developed "number joggling" mechanisms to win all elections, even in the states in which the votes were not there.

In Venezuela, the main problem mentioned by observers of the situation in this country, was the widespread corruption that had spilled through the system during the years of easy money as a result of petroleum price increases. Probably some of the money borrowed by the Venezuelians was Venezuelian money ...

As a result of these two facts: 1) availability of huge amounts of eurodollars in the financial markets; and 2) corruption and unaccountability, most Latin American countries went on a borrowing spree. And the banks on a lending spree.

In a few years, Brazil increased its debt from less than 10 billion dollars to more than 100 billion; Mexico manged to borrow 100 billion at the same time when its petroleum income had multiplied tenfold; Argentina borrowed more than 40 billion; Venezuela, which enjoyed a superb credit rating due to its oil resources, borrowed 30 billion. Chile, Colombia and Peru borrowed about 15 billion each, and even the smaller countries as Uruguay and Costa Rica managed to contract sizable debts of 5 and 4 billions respectively. The list is still much longer.

The money was "invested" in odd ways: some never left the banks coffers (what could be called "fiction lending"), some was transferred accrobatically to various secret (and not so secret) accounts of the local rulers and their political appointees or representatives; some (probably the largest part) went to pay for weapons for the military, for unneeded luxury items or just dumb imports; some (certainly a non-negligible portion) went to keep afloat for a few weeks more, some rapidly sinking local currencies (to the happiness of insiders and associated speculators); and finally some (not too much) went to pay for infrastructure investments. A small fraction went for professional training.

Even the more productive investments that were carried out with this borrowed money, were often, in some ways, counterproductive. Many mammooth-size projects were environmentally damaging (as some ones which were , in some way, suffered directly or indirectly by the whole planet (including by the bankers who lent the money), or to put it bluntly, purely genocidal as a number of cases throughout the continent in which entire tribal nations were decimated (indirectly) by the developmental investments.

Of those "productive" investments, a few hundred of millions went to modernize water supply systems in a number of cities; in some cases, to install treatment plants, storage structures, water distribution and sewerage systems, and in a number of other cases to build reservoirs and conduction lines to the urban centers (see Sections 7.5. and 7.6.)

These investments solved only partially an already difficult situation.

However, the cities kept growing and the new investments almost completely dried out by the early eighties.

During the last few years of the eighties, there has been very little money invested in development of water resources, water supply and sanitation systems in the urban areas. It is not expected that during the nineties this type of investments will re-start.

The lack of financial resources is such now, that not only the development of new water resources has been curtailed, throughout the continent, but the replacement of obsolete system has been postponed and even maintenance has been reduced to a bare minimum.

The main consequences of this lack of financial resources are the following:

1) less investment on maintenance of existing water supply networks;

2) less investment in water and sewage treatment, particularly problematic since contamination sources and risks are increasing constantly;

3) less investment in replacement of obsolete systems;

4) less investment in expansion of networks;

5) less investments in substitution of old reservoirs that have become obsolete for various reasons (i.e. silting, etc).

6) less investments in new reservoirs;

7) increased costs of water services for users due to elimination of subsidies and other reasons;

8) as a cosequence of the previous facts, there is a much smaller investment per capita.

These above mentioned elements, affect seriously the confiability of the urban water supply systems.

In brief: the consequences for the cities are: less water per person, of lesser quality and at a higher price.

B) Structural Adjustments; Requirements for Self-Financing.

As a result of the increasing debt volumes, the Latin American governments have been forced to reach agreements with the financing agencies and banks in order to postpone and re-schedule payments of interests and/ or principal of their debts.

The International Monetary Fund, which is the main financial agency coordinating these types of financial re-schedulings, has traditonally promoted "structural adjustments" in order to deal with the excessive foreign currency requirements which are mainly the result of the large foreign debt (but also of the export of profits by foreign companies, payment of royalties and various types of analogous transfers).

The IMF conditions for re-scheduling, normally include also "strong recommendations" for radical decrease of the fiscal deficit, as well as promotion of bulky superavits in the trade balance.

The IMF recipee for reducing the fiscal deficit includes the decrease of the size of the public service, self-financing of public services, elimination of subsidies, and taxes and prices increases.

The trade balance superavits are obtained through increased exports and reduced imports. One way of reaching this objective is to devaluate the local currency, which automatically reduces the workers' salaries and other production costs making the nationals goods more competitive in the international markets. Increased exports can be attained either through increase of production of some export items or -more often, unfortunately- through decrease of consumption, which, by the way, is easily obtained by means of decreasing the purchasing power of the population.

The decreasing earnings of the workers, also translate in less imports due to the unaffordability by the people of many imported items. As it can be seen, the costs to obtain the needed foreign currency to meet the debt obligations, are paid by the populations at large (particularly by the social sectors depending on a fixed salary).

Water management, water supply and sanitation institutions are normally strongly affected by these types of "structural adjustments".

Firstly, their expenditures budgets are cut. This translates into: 1) laying-off of personnel; 2) reduction of various operational expenses, including maintenance; 3) postponement of new projects (for replacement or expansion of old systems or for building of new ones); and 4) limiting purchases of required parts, etc.

Secondly, the requirement for self-financing and the elimination of subsidies has forced many water companies and institutions throughout the continent to increase their revenues through higher billings to users. As a result, prices of water services were increased considerably, when calculated as a proportion of actual incomes.

These increases normally affected (and are still affecting) both the utilization of the water (measured in volumes), and the connection of the service for the new users.

Frequently, the poorer sector of the population cannot afford to pay these prices. As a consequence, many homes in Latin American cities do not have municipal water due to the excessive price of the connection, and many others have seen their services cut due to lack of payment.

Obviously, these policies result in very different standards of service quality for different neighbourhoods, depending on their economic possibilities. Rich neighbourhoods have normally much better municipal water supply service, than poor neighbourhoods.

The poorest sectors of the Latin American cities, do not have any water connection at home and are forced to obtain their water from nearby public fawcets, tank-trucks or from "aguateros" (water-carriers).

Finally, the need to reduce imports has made more difficult for many water companies to renew or substitute machinery or even to import spare parts, fuels or lubricants required for normal operation of the system(s).

The combined results of the "structural adjustments" have been to increase costs of the water services for the population (measured in working time required to pay for them), and at the same time to decrease the quality of the service (both from the administrative and engineering points of view).

In brief: less water of a lesser quality at a higher price.

C) Strong Population Growth

The population growth of the continent has been strong during practically the whole XXth century, as a result of decreasing death rates, which in turn were produced by the advances of the medical science since the turn of the century (vaccines that controlled pests, and antibiotics which controlled some of the most deadly infectious diseases, as tuberculosis and thyphus).

At the same time, there was not a comparable decrease of the birth rate, and for this reason vegetative growth increased severalfold generally throughout the Third World and specifically in the Latin American continent.

The increase of the birth rate has not been homogeneous. In fact, there has been, during the last few decades, a significant decline of birth rates in the urban environment, due partly to the fact that additional children mean additional responsibilities and expenses, difficult to afford in the strongly money and time consuming urban environment. Obviously, there are other causes for this phenomenon, as for instance the availability of contraception information, drugs and devices; access to abortion, etc.

All these elements are not present to the same extent in rural areas, where, in addition, children are productive from an early age, keeping the birth rates practically unabated for much longer.

However, when urban and rural areas are added, the final balance has been of sustained vegetative growth.

A paradoxic development was, that while strictly vegetative growth was much higher in rural areas, actual population growth was greater in urban areas. This difference is the result of strong migration from the countryside to the cities during the whole XXth century. Latin American cities, therefore, grew at an accelerated pace, mainly as a consequence of rural emigration.

This phenomenon has continued taking place in most Latin American countries at variable rates. In some countries it is less accentuated (i.e. Argentina, Uruguay and Chile), in other it remains very intense (Brazil, Mexico, Colombia) (see Table 1).

On the other hand, during the last 20 years, birth rates have been gradually decreasing, not only in urban areas, but also among the rural population (although this decrease has been much less important there). As a combined result of these two factors, it seems that urban growth is experiencing a general slowdown throughout the continent.

However, the sheer numbers of the cities populations in most Latin American countries are still considerable. In the year 2,000, there will be two cities with more than 25 million people, 10 with more than 5 million, about 50 with more than 1 million and in excess 350 with a population above 100,000 inhabitants.

The annual growth of some cities is staggering, Mexico City and Sao Paulo add about 700,000 - 800,000 residents every year, Bogota, Caracas, Lima, Salvador, Belo Horizonte. Recife, Rio de Janeiro, Guadalajara and Monterrey increase their numbers in excess of 300,000 people annually (*).

Obviously, these new residents require the normal array of urban services, and for that purpose considerable additional investments are necessary.

Unfortunately, this situation happens in times in which financial resources are scarce, and therefore most new poor neighbourhoods remain inadequately served by the urban authorities.

As with other service requirements, water needs also increase when the population grows. However, in many cases, the additional water is not readily available, and even when it is, there is a need to build new distribution networks in order to conduct the water to these new urban residents.

In both cases. the allocable scarce financial resources are (and will continue to be, for the time being) certainly insufficient to satisfy the population needs. As a consequence, Latin American cities possess extensive urban and sub-urban sectors in which urban water supply is unavailable. In other areas of the cities, lack of pressure in the pipes (due to insufficient water for the consumption) determines supply interruptions in the topographically higher or more remote sectors of the serviced city (again poor and newly developed neighbourhoods in most cases).

In brief: the consequences of the population growth have been little water for the new migrants, less water per capita, and increased strain on the systems.

(*) Relevant references, although somewhat outdated are the working papers on urbanization of the International Urbanization Survey, which includes documents on Urbanization in Jamaica, Brazil, Colombia, Venezuela, Pery and Chile (Ford Fundation, New York, 1970- 1972).

D) Lack of Protection of Water Resources

In many Latin American cities, water resources utilized for water supply are poorly protected. In the largest cities of the continent there is very little control on the disposal of wastes, and very often there are many pollution sources, upstream of the surface water intakes, or in the recharge areas of the aquifers utilized for water supply purposes.

One typical example is Buenos Aires, which takes its water from the river Plate, downstream and not very far from the urban sewerage outlets (of untreated wastewaters).

In Mexico City, there is probably leakage taking place from the main sewer into the aquifer and the nearby pumping wells utilized for the supply of the city.

In Sao Paulo, waste disposal sites are next to one of the main local rivers (the river Pinheiros) which is almost an open sewer, and is pumped up into the Billings reservoir. This reservoir is used for water supply for the 1 million inhabitants city of Santo Andre, and in order to protect the water supply an earth dam was built to separate the contaminated waters from the rest. However, in addition to the ever present risk of leakage through the dam, there are a number of pollution sources in the catchment area of the reservoir that are probably affecting the quality of the consumed water (see Section 4.2).

In many others cases, recharge areas of water supply aquifers are not protected at all (as in the cases of Lima, Guatemala, Cochabamba, among others).

Due to the lack of protection of catchment and recharge areas, unwanted changes in their hydrological systems can be produced by the activities of farms, industries and urban developments.

In some cases, forests are eliminated increasing run-off and soil erosion, whcih in turn are the causes of silting of reservoirs. When reservoirs are silted, the actual storage capacity decreases, less water can be stored during the rainy periods, to be used during the dryer season, and their flood control role is also diminished.

This silting may continue until colmatation of the lake, and a new reservoir may need to be built, where and if geographical conditions allow it.

In addition, these changed surface processes result in increased suspended materials (and therefore increased water treatment costs) and what can be even worse, in changes in the hydrological regime of the rivers.

In this last cse, particularly during the dry periods, when consumption is higher, flow decreases considerably and water becomes insufficient. This limited flow reduces the dilution of the various wastes disposed upstream of the intakes (which with normal flow may not serously affect the quality of the water), and as a result, there may be a hazardous increase of the concentration of some substances or germs.

There are many sources of contamination of surface water. They include farming wastes, fertilizers and pesticides, urban domestic wastes and industrial wastes, etc. These types of wastes are produced in large volumes, particularly in or near urban areas.

The results on the unprotected reservoirs or streams may the eutrophication of the water bodies (which is the result of exhaustion of dissolved oxygen) with extensive algae development and -obviously- radical changes in the ecosystems or at a later stage, the death of the water bodies, with elimination of their biological systems.

However, toxic effects on humans may happen much before these extreme developments take place. Although very careful and sophisticated controls and analysis are required to monitor the quality of the urban supply water, in most Latin American cities, only routine (often insufficient) controls and anlyses are normally carried out.

When these phenomena take place in recharge areas, there are strong risks of contamination of underlying aquifers, due to infiltration of wastewaters or water having percolated through wastes, into the groundwater reservoir.

Also the hydrological changes on the ground surface may affect the actual recharged volumes (through increased run-off and reduced infiltration).

The above water degradation risks are high, due to the lack of adequate legislation protecting the water resources and in the cases in which this legislation exists, due to the lack of control and monitoring of what is really taking place in the field.

In brief: inadequate protection of catchment and recharge areas, results in less water of a lesser quality (and frequently at a higher price).

E) Lack of Adequate Knowledge of Existing Resources (Actual and Potential)

In order to make long- term decisions on urban water supply strategies it is necessary to accurately know:

1) the types of water resources that are or could be potentially available;

2) the available volumes (expressed in numbers as accurate as

possible);

3) the present and future renewability of the resource;

4) the vulnerability of the resource to degradation; and

5) the type of measures required to develop, manage and protect the resource.

Acquiring adequate knowledge on these topics, requires the availability of qualified professionals and the financial resources to carry out the needed studies.

In practice, most Latin American cities do not have complete studies of the potentially usable (or even, of those in use) water resources. This is partly due to the lack of properly trained professionals in one or more aspects of the hydrological sciences, partly a result of lack of funds and, partly due to the lack of proper knowledge on the matter by the water mangement authorities themselves.

Still, many cities have updated investigations on the hydrology of some or all the surface basins that are or could be of use for urban water supply purposes. Less common are the studies on contamination problems affecting those waters.

Groundwater reservoirs, on the other hand, are frequently poorly known. In many cases the geometry of the aquifer is unknown or partially known or has been recently incompletely defined (as in the cases of Lima and Mexico City).

In most cases, the water budgets of the aquifers are known only very approximately, or in other cases not at all.

With this type of knowledge, it is very difficult to make appropriate decisions on these matters. As a result, the investments are often applied on the less affective resource, using -sometimes- unnecessarily expensive systems or solutions.

Some examples: 1) a new reservoir is built at a cost 5 times higher than the 20 wells that could provide the same volumes of water of better quality; 2) new wells are built in the cosatal sectors of an aquifer subjected to increasing saline intrusion, the wells will be closed before long; 3) new wells are drilled next to a sewage canal or waste dump, after leakage from these sources is confirmed, the wells need to be shut; and 4) a surface reservoir is constructed in a permeable formation (i.e. limestones, conglomerates, fractured bedrock). Water does not stay for long in the reservoir, which frustates the storage purpose for which it was built.

These examples show just a few of the mistakes that can be made, when technical knowledge is insufficient or decisions are not made according to sound technical criteria.

In brief: the results of not-knowledgeable decisions are less water of lesser quality at a higher price.

F) Inadequate Management of Water Resources

One of the consequences of poor knowledge of the resources and the lack of qualified technical personal, at least at the water management level, is the inadequate management of the water resources.

Very often, the hydrological basin systems are poorly designed (normally with the purpose of saving money but having frequently the opposite effect).

In many cases, there is lack of coordination between the people responsible for making some crucial decisions (as opening or closing reservoir gates, or increasing or decreasing pumping rates) and the technical people with the real time (or extrapolated) information which would allow a quick and sound decision when hydrological events take place (as for instance: floods, spills of contaminants, etc).

In other cases, short and medium term management decisions are taken without insufficient background information. An example is provided by the case in which pumping is increased or suspended in a given well, without concern on the effect of this decision on [illegible] arby streams. In some cases, when water levels drop down, there may be changes at the streams beds (streams that were groundwater discharge areas may become groundwater recharge zones and viceversa).

Therefore, management decisions require a comprehensive analysis of all the aspects of the water situation, and this is frequently not done. The results of poor management decisions, affect both the quantity and quality of the water, as well as the costs of the operations.

In brief: less water of lesser quality at a higher price.

G) Inefficiency, politization and Bureaucratization of Water Institutions

Managing the water resources of an urban region and providing water for its population is a very difficult task, requiring the existence of one or more large institutions, involving many people.

Normally, there is a need for a large number of technical personnel of many different professions, as well as administrative and manual workers. Water companies, in particular, are very complex set-ups.

In any urban water supply company there is a need for a relatively large number of people to take care of the reservoirs, wells and treatment plants at the intake end. In the distribution section of the system, numerous personnel is required to deal with the very complex distribution systems (storage and pumping systems, distribution networks, installation of new lines, maintenance of old ones, connections and disconnections to the system, etc).

Most water companies also deal with the sanitation aspects, and are responsible for the tending, maintenance and management of sewers and -often- also stormwaters systems (these functions also require a considerable number of employees).

However, in most water companies in Latin America, the majority of the workers are employed in the administrative departments of the water institutions and not in the technical sector (*). One of the functions of those departments is to deal with the internal administrative management (as for instance, taking care of the personnel files, paying salaries, etc). However, the most work and time consuming function is frequently the collection of water services fees from the users. A large number of employees are dedicated to this task.

Due to the large number of users, the amounts collected by the water companies put them among the strongest (financially) public institutions. As a result, governments often utilize the water companies for purposes not necessarily related with the principal objectives for which these companies are supposed to be dedicated for.

In some countries, when water companies have superavits (and sometimes, even if they don't have them), the central government may feel tempted to channel the financial resources of these companies for other goals.

Practically throughout the whole continent, water institutions have been utilized to provide employment for the political clientele of the politicians in charge. By and large, these political appointments have been carried out in the administrative sectors, rather than for technical positions.

As a result, there has been a constant increase in size of the administrative personnel, which conspires against the solvency of the institutions. In many cases, the lack of financial resources of a water institution is related to the large volumes of money unnecessarily spent in unneeded administrative personnel.

(*) Ratios of personnel per 1000 connections is of about 2-3 in developed countries companies, and 10-20 in most Latin American water supply companies (see Section 7.6.1.).

Once the person is hired, even if it is difficult to find something to do (or even a desk to work), very commonly new administrative procedures or steps are imagined in order to keep him or her busy. Once there is a new person in charge of one procedure (or a step in that procedure) he or she may feel tempted to emphasize its significance, making it still more complicated, adding new steps which in order to be implemented may require the hiring of new people, which in turn may propose and implement new procedures with more steps, and so on. The irrational logics of the bureaucracy takes over ...

But the problem does not end there. Once there is a strong bureaucratic lobby in the institution (with -by the way- a lot of free time) it feeds itself with whatever available financial resources there are, reducing the money that could be used for technical purposes.

The growth of the administrative departments is often paralleled by the shrinking of the technical sectors. Because of the lack of money in these last sectors, professional salaries decrease, to a point, in which the most experienced people prefer to leave the company for more rewarding employment opportunities.

On the other hand, because the appointments in the water institutions are made following political criteria, very often, the politically appointed managers don't have the adequate professional background and experience as to be able to make the right decisions in a complex field which they don't know very well.

Therefore, many crucial decisions are made without enough or appropriate technical knowledge or input, and as a result, many strategic decisions are wrong and costly. Often, they result in less water of lesser quality at a higher price (*).

(*) A more detailed description of some aspects of these problems is presented in the discussion paper of the World Bank "Management and Operational Practices of Municipal and Regional Water and Sewerage Compaanies in Latin American and the Caribbean", Guillermo Yepes, January 1990. (Ref. 91).

H) Corruption

Problems of corruption in water institutions are not very different from these problems in any other public institutions. In the case of the water companies, sometimes there are better "opportunities" for corrupted practices, due to the fact that these institutions collect large amounts of money and purchase and utilize expensive materials. Theft of materials and charging purchasing "commisions" to the suppliers are common ways of obtaining profit from the positions in some public water companies.

In addition, the many tedious administrative procedures required for connection or maintenance of the water service may promote the "charging" of bribe money ("mordidas" o "coimas") in order to speed up the procedure.

At a higher level, contract "commisions" may be charged, under the table, to companies contracting with the water institutions. These bribes may be relatively frequent in some countries and -obviously- add to the total cost of the service. In addition, because the contracts are not awarded (in those cases) according to technical merits, the quality of the service or of the materials utilized may be affected. These "practices" are difficult to prove, and still more difficult to accurately evaluate, but their existence is "vox populi" in some bureaucratic environments of the continent.

In brief: a less efficient service of a poorer quality and at a higher price.

I) Lack of Properly Trained Professionals

As a result of what was described in the sub-section G), many experienced professionals prefer to leave the water institutions for outside positions offering better salaries and/ or professional opportunities.

This adds to the basic problems of technical knowhow in the water field Latin American countries, which is frequently insufficient in quantities and in quality.

One problem found in some Latin American countries is the skewed proportion between the people studying liberal arts professions (as law, public notary and arts) and the people studying disciplines more directly related to production (as engineering or agronomy). In fact, in some countries the sum of the former is 10 to 50-fold higher than the sum of the later.

The result in many countries is the lack of sufficient professionals in some key fields to contemplate the actual and potential needs.

Another problem, is the lack of proper training in a number of subjects in some Latin American universities. This takes place often due to the lack of incentives (mainly low salaries) for University professors to remain in their Universities. Other reasons that affect the quality of professional training are the lack of equipments, the unavailability of updated technical literature and the obsolence of the study plans and programs.

The water professional fields are seriously affected by these problems. Only a few engineers specialized in sanitary engineering or hydraulics graduate from all Latin American Universities (probably not more that a few hundred per year from the 500 plus Latin American high education institutions to attend the needs of 600 million people).

There are even less hydrologists or hydrogeologists, mainly because there are very few undergraduate or graduate programs in those fields.

In fact, most people dealing with water resources have studied something else, and have been channelled towards the water resources field by the pressing needs of the countries in which they work.

Therefore, there is a widespread lack of proper training which does not help for proper management of the resources. Technical advices to the managers may be given without enough scientific knowledge of the problems and potential solutions to these problems.

However, it must be noted that in spite of the lack of formal training, there are a large number of highly experienced and knowledgeable professionals throughout the continent that are doing a very good job in their respective areas of expertise. As it was mentioned in the opening statement, some of these people have chosen to leave the water public institutions, in order to work in the private sector, and in some cases even to emigrate due to low salaries or inadequate professional opportunities. This brain drainage is another negative factor affecting the future of the water management in urban Latin America.

In brief: less efficient services of lesser quality.

TABLE 3: PROBLEMS IN WATER RESOURCES AND URBAN WATER SUPPLY IN LATIN AMERICA

A. Less financial resources	1) Less investment in maintenance of existing water supply networks	a) Increased leakage
B. Structural "adjustments", requirements for self-financing	2) Less investment in expansion of networks	b) Decreased pressure in pipes
C. Strong population growth	3) Less investment in new reservoirs to attend new needs or substitute old obsolete reservoirs (silted reservoirs, etc.)	c) Increased water supply interruptions
D. Lack of protection of water resources (lack of adequate legislation, controls)	4) Increased cost of water services for users	d) Local contamination of water during and/ or after cuts
E. Lack of adequate knowledge of existing resources (actual and potential)	5) Less investment per capita	e) Increased consumption in relation to water input
F. Inadequate management of water resources	6) Development of neighborhoods requiring large amounts of water	f) Many people cannot hook to the water supply system due to costs
G. Politization and bureaucratization of water companies	7) Urbanization processes encroaching in basins upstream of intakes	g) Many people are cut from the system due to lack of payment
H. Corruption at various levels of the WC and related institutions	8) Deforestation of basins	h) Large poor neighborhoods receive very little water through insufficient systems or tank-trucks, etc.
I. Lack of properly trained professionals	9) Widespread contamination of water resources	i) Rich or political influential neighborhoods have much lesser problems
	10) Utilization of political criteria for technical decisions	j) Available exploited water resources are insufficient for municipal requirements
	11) Inadequate utilization of available funds	k) Increased irregularity in surficial flows in the streams
	12) Decisions are made without proper technical knowledge	l) Accelerated silting of reservoirs
		m) Increased materials in suspension
		n) Increased costs of treatment
		o) Decrease of water quality

II. SOLUTIONS:

1) Increased financial resources and fair distribution of investments.
2) Reduced population growth.
3) Better protection and management of water resources.
4) Increased utilization of groundwater with improved management
5) Depolitization and debureaucratization of water coanies.
6) Increased efficiency of water companies.
7) Promote training in water resources, water supply, sanitation ard related subjects.
8) Increased research in the water sciences and particularly in the water management aspects.

6.3 Environmental problems and actual and potential costs

6.3.1 General

As a result of all the previously mentioned facts, the environmental situation in the larger cities of Latin America has become very serious, both at the regional, city and neighbourhood level.

Environmental problems are widespread and complex, affecting not only the water (which is the main subject of this document) but also the land and the air. Of course, because land, air and water are closely interrelated, any modification of one will bring also changes in the other.

When the urban atmosphere is contaminated, there are unavoidably changes in solar radiation, both in quantities and wavelengths received at the ground level, as well as changes in the volumes, regime and quality of the precipitations. These changes affect both the land and the water.

When the land is degradated (through excavations, disposal of earth or debris, constructions, miscellaneous farming activities and deforestation), the water is affected (as described in Chapter 5), and because of the variation in albedo, evapo-transpiration rates and dust generation, the city atmosphere is also modified.

And when the water is degradated, the air is also affected (due to changes in evaporation levels and emitted radiations), as well as the land (i.e. due to increased erosion and sedimentation, flooding or drying up of rivers or lakes, waterclogging and salinization on soils and unwanted rising of shallow watertables). However, in order not to exceed the purposes of the present document, we will only summarize the main problems affecting the water resources and leave other environmental problems for another occasion.

6.3.2 The problems

Some of the main water-related environmental problems that are caused by city development include the following:

1) Changes in overall flow in streams

These are related to various types of human actions in urban regions, and normally translate into a decrease of the total flow, and therefore of the total availability of stream water for various uses. They include the following:

a) changes in land use in the catchment basins;
b) withdrawal of water for irrigation purposes (and subsequent evaporation, infiltration or diversion to other basin or to a location downstream);
c) withdrawal of water for water supply purposes;

d) withdrawal of water for groundwater recharge (planned or unplanned);

e) building of dams (and evaporation or infiltration associated with these structures);

2) Changes in the hydrological regime of the streams

These phenomena are often related to changes in the land use (i.e. deforestation and agricultural activities), but can be also caused by withdrawal of water for different purposes, building of dams and changes in the discharge/ recharge relationships between groundwaters and stream waters;

3) Changes in the suspended sediments

Increased suspended sediments are often the result of increased erosion in the catchment areas, they may translate downstream in sedimentation in flood plains and reservoirs;

4) Sedimentation and silting of reservoirs

This is normally a natural consequence of normal fluvial evolution. Flood plains are natural sedimentation areas and reservoirs become also sedimentation environments as soon as they are built. However, anthropogenic degradation in the watersheds normally gives place to an increase in the sedimentation rates which in some cases can lead to a very rapid colmatation of reservoirs and subsequent decrease of useful storage capacity (silting). Some reservoirs have seen reduced their predicted useful operation life by one order of magnitude.

5) Contamination of surface waters

It occurs as a result of disposal of wastewaters and other wastes into streams and lakes. The main sources of contamination are: 1) domestic and municipal wastewaters; 2) industrial wastewaters; 3) farm wastewaters; 4) mining wastes and wastewaters; 5) fertilizers and pesticides; 6) acid rain.

The main contaminants found in the water include the following:(*)

1) Detergents (soaps, miscellaneous washing compounds and solvent cleaners);

2) Synthetic organic pesticides (chlorinated hydrocarbons (DDT's, PCB's, etc), chlorophenoxyl acids, organophosphates, carbamates, etc.).

(*) "Environmental Chemistry: Air and Water Pollution", H. Stephen Stoker and Spencer Seager; Scott, Foreman and Company, U.S., U.K., 1976.

3) Petroleum and derivatives;
4) Toxic metals (leads, mercury, etc.);
5) Fertilizers and other plant nutrients (either contained in raw domestic or farming sewage, or in phosphates, nitrates, potassium compounds and other fertilizers of use in agriculture);
6) Oxygen demanding wastes: it includes wastes from many industrial activities as canneries, meat processing plants and slaughterhouses, wool washing establishments, tanning industries, paper and pulp processing plants, and many others, as well as wastes from domestic animals and raw municipal or farming sewage;
7) Disease-causing agents, which are various pathogenic-microorganisms, mainly responsible for infections of the intestinal tract (typhoid fevers, dysentery and cholera), hepatitis, etc.
8) Radioactive substances (as a result of disposal of wastes from mines extracting Uranium and other radiactive substances, or disposal of various radiactive materials used in power generation plants, industries, hospitals and research institutions).

Contaminated wastewaters are frequently used for irrigation purposes. For instance, in the valley of Tula about 90,000 has of agricultural lands are irrigated with the wastewaters of Mexico City the beginning of the century. In Lima, 2,000 has of vegetable crops are irrigated with urban wastewaters. In Sao Paulo, the contaminated waters of the Tiete river are used for irrigation of vegetable gardens downstream of the urban core. In Santiago, approximately 62,000 has of vegetables are produced for raw consumption in the city and surrounding areas, using water from three water courses which are located downstream of the Santiago's sewage flow (9 m3 per second). As it can be seen, the risks for the health and well-being of the populations are not negligible. However,in spite of that, one must recognize, that there is great potential for reuse of urban wastewaters, if appropriate treatment procedures are implemented. Recently, the World Health Organization has published health guidelines for the use of wastewater in agriculture (1989) and it is expected that future controlled (and safe) reuse of urban sewage and stormwaters will increase in the future.

6) Contamination of groundwater (*)

It occurs when wastewaters, other liquid wastes and water percolating through wastes, find their way into groundwater reservoirs. The sources of pollution and the main contaminants are the same as described for surface water. There is a difference, though, because the underground environment contains much less oxygen than surface waters, oxygenation of the wastewaters does not take place to the same extent that in the ground surface. On the other hand, many contaminants are filtered in the geological formations through which the polluted waters are flowing. That occurs at a particularly fast rate with disease-causing agents. However, the filtering capacity of the different formations varies considerably, some are very effective (as silty sandstones) and some allow a very fast movement of contaminants through the underground water conducts (as is the case with karstic aquifers).

Contamination to groundwaters may occur also from natural sources (as for instance from contiguous aquifers or surface water bodies with high contents of unwanted substances, as chlorides, or sulphates among others).

7) Excessive drawdown of groundwater levels

This phenomenon takes place mainly due to overpumping (pumping plus surface discharges, exceeds recharge plus groundwater inflow into the aquifer), but also due to excavations (as tunnels, quarries, etc.), which in some extreme cases, may lead to dewatering of the aquifers.

8) Flooding

This may occur due to excessive run-off or rise of the groundwater levels near or above the ground surface. The causes of run-off floods were already mentioned in 2). Elevation of groundwater levels may be related to artificial obstructions to the discharge (both underground, or on the surface) or increased recharge. All these environmental problems are found throughout the Latin American continent, in one way or the other.

Many cities of the continent have seen reduced their water supply due to the decrease in the overall stream flow or changes in the hydrological regime. In most peri-Amazonian areas, the rivers have changed their regimes, with very low levels during the dry season and flooding during the wet period. One case of a city having this type of problems is Cuiaba, capital of Mato Grosso in Brazil, which getting its water from the river Cuiaba which lately do not bring enough water to satisfy the needs of the city, during the dry period. Similar problems have been taking place in many cities of the Brazilian shield and in Mexico.

(*) Relevant bibliography: "Determinacion del Riesgo de Contaminacion de Aguas Subterraneas"; OMS- PAHO, S.Foster and R. Hirata, Lima, 1988. (Ref. 28. Also 6, 30, 49, 67, 68, 80).

Suspended sediments are creating serious problems at the intake level in many Latin American cities. Some extreme cases are found in some cities of the Colombian mountains (in Ibague, at the foot of the Central Range, in Popayan in the South and in other cities depending on torrential rivers for their supply and hydroelectric power generation), which are being filled at a growing rate (as it is also the case in the Upper Papagayo reservoir upstream of Acapulco, Mexico).

Water contamination is widespread in the whole continent. Practically there is not a single stream, lake or groundwater reservoir that has remained untouched by anthropogenic pollution.

The largest cities are the ones producing the worst effects. There are extreme cases of contamination in all the rivers draining the urban wastewaters of the major cities; the Tiete and Pinheiros in Sao Paulo, the river Bogota in Bogota, the river Mapocho in Santiago, the river Guaire in Caracas, the "arroyos" Miguelete and Pantanoso in Montevideo, the Riachuelo in Buenos Aires, the river Almendaris in Havanna and many others.

This contamination is not very selective, in fact, practically all the above mentioned contaminants can be found, in a larger or a lesser degree, in these urban streams (perhaps with the only exception, but not always, of the radiactive wastes, which are not very common in Latin American cities).

Groundwater reservoirs are somewhat better protected from contamination. However, there are indications that the Mexico City aquifer, as well as the Buenos Aires and Sao Paulo aquifers among many others are starting to suffer the consequences of uncontrolled disposal of a large number of contaminant wastes. Excessive drawdown of water levels is taking place in many cities where pumping is intensive (i.e. as it happens in Lima, Mexico City, some Buenos Aires suburbs, etc). In some case, this overpumping has lead to saline encroachment (cases of Lima in Peru, Mar del Plata in Argentina, Coro and Maracaibo in Venezuela, Havana in Cuba, Nassau in the Bahamas and Santa Marta in Colombia).

Flooding has become very common in cities located downstream of deforested areas (as for instance in the Northern Colombian cities of Sincelejo and Monteria, affected by the increasingly threatening floods of the Sinu river, or even Lima which suffers the periodically destructive floods of the river Rimac).

Obviously, the economic and social cost of all these environmental problems is huge and difficult to calculate. Although the above mentioned problems affect the population at large, by far, the most vulnerable sectors of the population are the urban poor communities.

The better-off social groups can always buy bottled water (although even this one is not always so safe...but this is another problem), or drill their own wells, or install a helping pump with their own generator, and their own treatment systems in order to solve the water problems. They can move to the suburbs, out of the crowded and unhealthy parts of the city.

The urban poor, however, do not have a choice. They can only live in the flood plains, or in the unstable slopes, or next to the garbage dumps. They can only get water from water carriers or tank-trucks, or public fawcets, or from a frequently unreliable municipal system (more unreliable for them than for other sectors of the population). If the water is contaminated, they are the ones to get sick the first. And they are the ones with less access to medical service and less money to pay for it. Paradoxically, in spite of the inadequate services, the poor people of the cities, have to pay higher prices for each liter of their insufficient, poor quality water, than the price that are charged in much more affluent neighbourhoods (*).

In brief: less water of a lesser quality at a higher price.

(*) A relevant paper on the matter was published by the Overseas Development Council; U.S.- Third World Policy Perspectives No 11; "Environment and the Poor".

6.3.3 Water supply issues

Due to the problems affecting the water supply companies/ institutions, the municipal water supply systems of most cities of Latin America are becoming increasingly obsolete and unefficient throughout the continent.

The waterlines bringing water into the city are becoming older and keep breaking and leaking (i.e. practically the whole city of Bogota had the supply cut for 48 hours twice in a period of six months to fix an old pipeline bringing the water from the Northern reservoirs; similar examples can be found in many other cities). The distribution pipes also leak (although it is difficult to calculate how much is leakage and how much in legal or illegal consumption)(*). In any case, losses from the distribution systems may amount to 30-40% of the total input into the system.

Due to these losses, increased consumption and insufficient input, the pressure in the pipes suffers frequent falls, which in many cases forces to the interruption of the service. Another factor of decreased efficiency is produced by the clogging of the pipes due to various types of deposits (carbonates, hydroxides, even sponges (*),etc).

When water is interrupted, pressure in the pipes may become negative, sucking contaminated water from the soils surrounding the lines, adding another source of contamination hazard to the system (which is not recorded in the control analyses at the exit of the treatment plants).

And of course, between 10 and 60 % of the urban population do not get any municipal water al all. They must rely on water carriers, public fawcets, tank-trucks (frequently unwashed, and therefore polluted), nearby contaminated streams or lakes, etc.

All these elements add to the list of more general environmental problems mentioned in the first part of this section. As a result, life for the poor in many Latin American cities has become a very risky endeavour: breathing contaminated air, drinking contaminated water, eating contaminated food, roaming in the garbage, being subjected to catastrophes as earthquakes, mudslides and floods from the early chilhood, with limited access to health and education services, without money or fixed employment. The situation is reaching a point of no return. In Chapter 8, we will try to ellaborate a little more no this not very optimistic view of the situation.

(*) As it happens in the treatment plant in Aguas Corrientes in Montevideo, in which large sponges have grown in the canals and pipes feeding the treatment plant, taking advantage of the nutrients existing in the water. The author doesn't know if this phenomenon occurs in other similar situations.

Chapter 7 WATER RESOURCES: KNOWLEDGE AND RESEARCH

7.1. Water institutions

7.1.1 General

One of the elements for sound management of water resources is to possess an adequate and comprehensive knowledge of their existence, their characteristics, their complex dynamics and their intricate relationships with the rest of the natural (and\or artificial) world.

In order for the investigators to acquire this knowledge, it is necessary that they be able to observe,describe, measure, sample, analyze, interpret and in general carry out the practical and intellectual operations that are required for a better understanding of nature and societies, as well as of their complex relationships.

Generally speaking, a proper scientific evaluation as described, requires experienced and qualified personnel, field infra-structures and equipments of various types, properly equipped laboratories, adequate administrative, research and communications support, enough funding to carry out the needed studies and investigations, political and social support and an appropriate legal and administrative framework.

As it can be seen, the effectiveness of the water institutions in the field of water research, can be severely curtailed, if one or more of the previously mentioned conditions are missing.

In many Latin American countries, practically none of the above-mentioned conditions are met. Knowhow is limited, due to the lack of trained and/or experienced professionals, infrastructures and equipments are inadequate, laboratories are insufficiently equipped and/or staffed, research support is often less than satisfactory, with outdated libraries, communications are poor, funding is systematically below requirements, salaries are low, the legal framework does not provide the authority to carry out some essential tasks, the administrative framework is inappropriate and the actual social and political support is questionable.

Under these conditions research becomes a very difficult task.

However, in spite of all these limitations, the need for knowledge is so pressing, that in fact, relevant research activities of great importance are still carried out, utilizing existing resources, local or external support, and a large amount of goodwill and enthusiasm.

The actual location where these research activities take place is frequently related to the presence of interested and hardworking personnel, with sufficient management support (or professional freedom), or to the presence or absence or knowledgeable and/or environmentally-aware managers and political authorities.

The purchase or obtainment of specialized equipment may help to carry out some research activities, but it is observed frequently that these equipments may be insufficient, inadequate or even in some odd cases "excessive" (in cases of understaffed institutions or lacking appropriate maintenance).

In other cases, expensive and sophisticated equipments that were purchased or simply "received" from donor agencies without proper assessment of the actual research situation or needs, may end actually setting the research agenda on their own, instead of being the other way around.

In each country, province or city, hydrological and hydrogeological research may be (and frequently is) carried out in different institutions, depending on the above-mentioned factors, and on the history and development of the former and present political-administrative and technical set-ups.

Generally speaking, the institutions that may be involved in this types of research are the following:

1) National Ministries or Departments within Ministries;

2) Provincial Ministries or Departments;

3) Autonomous Institutions within the Governments;

4) Water and Sanitation Public Companies;

5) Municipalities;

6) Universities and other Institutes of Higher Learning;

7) Private Companies, Professional Associations and NGO's.

An overview of the actual situation throughout the continent shows that:

1) Private companies, professional associations and NGO's conduct very little research in this field (they are more frequently involved in development and assistance projects);

2) Only the largest municipalities have means to consider this type of activity.In fact, practically no research actually takes place at this level;

3) Although water and sanitation companies have extremely pressing requirements for an adequate knowledge of their surrounding environment, the urgency of their function keeps them normally too busy providing the actual water service, not allowing the

"release" of the needed resources for research activities;
4) National and Provincial Ministries, Provincial Ministries, Departments and Institutions are mainly dedicated to baseline studies and activities (surveys, mapping, monitoring and control) and in a lesser degree involved in research. However, in many cases they are the only institutions carrying out some types of water research;

5) Universities and analogous institutions are more specifically focussed on research, but in most cases, due to the lack of means, only theoretical studies, not always related to the actual needs, are performed.

As a result of what was expressed previously, the two main types of institutions executing some kind of research are Governmental institutions and Universities.

The main differences between both are the following:

1) Governmental institutions are more oriented toward baseline studies, monitoring and surveys, normally only research on specific topics is conducted to solve specific problems;

2) Universities are more "subject" oriented. The selection of the research agenda is based on a more academic, neutral approach;

3) Government institutions have more resources and authority to carry out their studies; they normally have more and better infrastructural resources, field allowances for the personnel,vehicles, equipment maintenance, fuel, laboratories, administrative support, etc;

4) Universities possess more limited resources, both from the infrastructural and financial points of view. That does not apply necessarily to human resources, which in many cases are better than in the Government;

5) University researchers have much more freedom to define the research agenda,than researchers from government institutions.

Cooperation and communication between governmental institutions (including water companies) and Universities, is -at the best- poor. In a large measure, it is generally believed, and we fully agree, that increased cooperation and communications may provide the means to improve the inadequate situation described in previous chapters.

7.1.2 <u>Water research in universities</u>

Not all Universities of Latin America carry out research in the field of water sciences. In fact, we can safely state that only a few do (particularly in the larger countries and those with more serious water problems).

The main University centers of research in water sciences are located in the larger Universities of the continent. Some Universities dealing with water research of some kind include the following:

1) Universidad Nacional Autonoma de Mexico, Mexico City, Mexico;
2) Universidad de Sao Paulo, Brazil;
3) Universidad de Buenos Aires,Buenos Aires, Argentina;
4) Universidad de La Plata, La Plata, Argentina;
5) Universidad Nacional de Chile, Santiago de Chile, Chile;
6) Pontificial Universidad Catolica de Chile, Santiago de Chile, Chile;
7) Escuela Politecnica, Guayaquil, Ecuador;
8) Universidad Los Andes, Bogota, Colombia;
9) Universidad Nacional, Bogota, Colombia;
10) Universidad de La Habana, La Habana, Cuba;
11) Universidad San Carlos, Guatemala City, Guatemala;
12) Universidad Mayor de San Andres, La Paz, Bolivia;
13) Universidad Nacional de Venezuela, Caracas, Venezuela;
14) Universidad de la Republica, Montevideo, Uruguay;
15) Some of the larger provincial/state Universities in the larger countries (Mexico, Brazil, Colombia, Argentina, Venezuela and Chile);
16) In a lesser degree in the main Universities of the smaller countries, however, there are a few countries in which hydrological/ hydrogeological research is not carried out in the University (ies).

Normally, in Latin American Universities, hydrology and hydrogeology are taught (and researched) in different Faculties/ Institutes.

Hydrology and hydraulic are normally key subjects in Engineering Schools, and in some cases autonomous Institutes or Departments of Hydrology are found (as for instance in the Universidad Mayor de San Andres of La Paz, Bolivia).

Hydrogeology is studied more frequently in Geology and Earth Sciences Schools and Institutes (as in the cases of the Universidad Nacional of Colombia, Universidade de Sao Paulo, Universidad Autonoma de Mexico (Instituto de Geofisica), Universidad Autonoma de Chihuahua, etc).

As a result of this separation, there is normally, very limited contact between hydrologists and hydrogeologists, which -in some way- helps to explain the "unilateral" approaches to water research frequently found throughout the continent.

7.1.3 Research in government institutions

A large volume of all water research carried out in Latin America takes place in government institutions (probably the largest part). Normally, the National or Federal institutions are larger and stronger than the provincial institutions, have more financial, infrastructural and human resources, and therefore can deal with more sophisticated research aspects in the hydrological/ hydrogeological field. In some of the larger countries, there are some provinces/ states of larger population or economic power in which provincial resources can be considerably large. These are the cases of the States of Sao Paulo, Rio de Janeiro, Parana, Minas Gerais (*) and Rio Grande do Sul in Brazil, the Provinces of Buenos Aires, Cordoba and Santa Fe in Argentina, the States of Mexico, Jalisco, Veracruz and Nuevo Leon (*) in Mexico, and the Departments of Valle del Cauca (*) and Antioquia (*) in Colombia.

A list of some governmental institutions in which hydrological/ hydrogeological research is carried out include:

1) Ministerio de Recursos Naturales Renovables- National- Hydrology and Hydrogeology, Venezuela;

2) Instituto de Hidro-Economia- National- Hydrology and hydrogeology, Cuba;

3) Secretaria de Agricultura y Recursos Hidraulicos- National- Hydrology and hydrogeology, Mexico;

4) Instituto Mexicano de Tecnologia del Agua- National - Hydrology/ hydrogeology, Cuernavaca, Mexico;

5) Departamento Nacional de Aguas e Energia Electrica- National- Hydrology and hydrogeology, Brazil;

6) Instituto Nicaraguense de Estudios Territoriales (INETER)- National- Hydrology and hydrogeology, Nicaragua;

7) Instituto de Sismologia, Vulcanologia, Meteorologia e Hidrologia (INSIVUMEH)- National- Hydrology and hydrogeology, Guatemala;

(*)Note: the water companies from the (*) above mentioned cities/ provinces have been considered the best administered of the Latin America and Caribbean region in a recent study of the World Bank(#).

(#) "Management and Operational Practices of Municipal and Regional Water and Sewerage Companies in Latin America and the Caribbean"; Discussion Paper, The World Bank, Report INU, 61, G.Yepes, Jan.1990.

8) Direccion Nacional de Mineria de Mineria y Geologia- National- Hydrogeology, Uruguay;

9) Direccion Nacional de Minas y Geologia- National- Hydrogeology, Argentina;

10) Servicio Nacional Meteorologico e Hidrologico (SENAMHI); Peru;

11) Geobol- National- Hydrogeology, Bolivia;

12) Departamento de Aguas e Energia Eletrica- Provincial (State)- Hydrology and hydrogeology, Sao Paulo, Brazil.

In addition to the above mentioned institutions, there are many other institutions dealing with the water field in the rest of the continent, which are included in Annex A.

7.2. The status of water research

The fact that there are such a large number of institutions formally dealing with water research, does not imply necessarily that this type of research is sufficient and accurate, and water knowledge is well developed. Unfortunately, in most Latin American countries, this is not the case. The problems that were mentioned in Chapter 6, are widespread and affect both Universities and Government institutions: lack of funding, low salaries, poor training, inadequate legal and administrative set- ups, lack of political support, etc.

As a result, a great deal needs to be done in order to significantly improve the research conditions and production in these institutions. In the meantime, the lack of accurate knowledge is going to continue affecting the decision-making processes for defining water management strategies and procedures. In the following sections, we will try to define and propose some steps that may assist in the solution of these problems that are making the water situation in urban Latin America and the Caribbean, unbearable for the vast majority of the population.

7.3. Training of water scientists

Training of water scientists in Latin America takes place in Universities and Technological Institutes. Training in the fields of hydrology and hydraulics is normally carried out as a part of the Engineering curriculum as is the case in the two main Universities of Chile (Universidad de Chile and Pontificia Universidad Catolica de Chile) or the School of Engineering of UNAM, Mexico. There is also some training in hydrology in the

Departments and Institutes of Geography, and in some few cases in specialized Institutes of Hydrology (as in UMSA, La Paz, Bolivia) or the Instituto de Hidrologia de Llanuras in Azul, Province of Buenos Aires, Argentina.

Hydrogeology, on the other hand, is taught in the Geology and Earth Sciences Departments and Faculties. In some cases, hydrogeology training is provided by the Faculties of Engineering or exceptionally in other types of Earth Sciences Institutes (as it is the case in the Institute of Geophysics in UNAM, in Mexico).

In some other cases, hydrogeology is part (together with other geological disciplines) of more general Faculties, as it is the case of the Universidad de Buenos Aires, where hydrogeology training takes place in the "Facultad de Ciencias Exactas y Naturales" or in the Universidad de la Republica of Montevideo, Uruguay, which provides training (among other areas) in geology (including hydrogeology as a subject of the curriculum).

However, in spite of the fact that, formally, water sciences are widely taught throughout the continent, in most cases, they are simple theoretical courses, of short duration (one semester or at the most, one year), which only provide very basic notions, and clearly they are not enough for the growingly sophisticated needs of many Latin American environmentally threatened and heavily urbanized areas.

In a few cases, systematic training in the water fields is offered. One example of a training center in which hydrogeological training takes place is the Instituto de Geociencias of the University of Sao Paulo, with its associated research center Centro de Estudos e Pesquisas de Aguas Subterraneas. This institution is probably the most prestigious center in this discipline, provides training for Brazilian (and also non-Brazilian) hydrogeologists and conducts research on groundwater subjects.

In Mexico, there are two centers offering formal training in hydrogeology: one is the Instituto de Geofisica of UNAM, Mexico, which possesses a post-graduate program in this field, and the second is the University of Chihuahua, in the State of Chihuahua, Northern Mexico, which offers a Master Program in Semi-Arid areas.

In other Latin American countries, hydrogeologists must develop their expertise and experience by actually working in the hydrogeological field in local institutions or by following specialized training in developed countries (as it is the case with a considerable number of Latin American professionals studying in the University of Waterloo, Hydrogeology Program, in Canada, or in similar institutions in the United States and Europe.

As it can be seen, a great deal needs to be done in order to improve training capabilities in the Latin American continent. One example of an useful step in the right direction is provided by the IDRC-funded network of projects in hydrogeology, which is based in the Latin American regional office of AGID (Association of Geoscientists for International Development) in Cochabamba, Bolivia, and whose training activities take place in the two main centers of the region (in the Instituto de Geofisica of UNAM in Mexico and in the Instituto de Geociencias of the University of Sao Paulo and CEPAS of this same University in Sao Paulo, Brazil.

A very important source of training assistance has been provided by the World Bank through its Economic Development Institute, which has supplied with the bulk of funding assigned to training in water and sanitation during the last decade. This training has taken place through scholarships in training institutes (within and outside the region) and through courses, workshops and conferences organized in various parts of the continent, and in some cases in programs outside the Americas (as is the case of the well-known training programs developed in Spain by the Prof. E. Custodio and R. Llamas).

The Center (IDRC) through its Fellowships and Awards Division has also played an important role in this aspect in relation to the existing research projects in the above mentioned field. This support has been provided by means of its Earth Sciences training program which includes several training activities and fellowships in Hydrogeology.

A similar role has been played by CIDA as a corollary of some of its water supply projects in the region.

Additional information on this matter is provided in other sections of this same chapter.

7.4. Other avenues of research

7.4.1. General

The main "upstream" research subjects relate to the volume and characteristics of water resources available for sustainable utilization. However, once these resources have been proven and evaluated, a number of other (mainly, but not only) "downstream" research topics, as important as the previously mentioned, may arise.

In first place, there is always concern about the economic viability of water companies and water institutions. In some cases, these companies/ institutions are totally or partially self-financed by mean of their own water and sanitation billing systems or through taxes (municipal, provincial or national). In other cases, in order to break even, they need to be subsidized by the government; as a result of those financial resources they may even obtain budgetary surpluses, which are not always used for renovation or expansion of the systems or for the organizational improvement of the institution.

Because most institutions dealing with water supply require (or have required) large (initial) investments for their new or expanded systems, many companies (or the government from which they depend) are heavily indebted and an important proportion of their income may go to pay for interests and principals on their debt load. Obviously, the new credits that are necessary for future projects are frequently tied to the servicing of the debt, and therefore these aspects can be critical for future investments.

All these matters are researchable, and a clear picture of the issues is required, in order to understand and strategically plan the future development of the water operations in the cities.

Another problem that needs in-depth research relates to the theme of human resources, particularly, the proportion of administrative and technical personnel which gives a measure of the "bureaucratization" of the services. Closely linked with this aspect are the criteria utilized to define and fill the new positions in the water services, the relative budgetary weight of the administrative and technical sections (in relation to the actual needs) and characteristics and effectiveness of the existing administrative structures.

Obviously, the general policies in the water field are defined often (sometimes unnecessarily, but in other cases reasonably) in the political field. This is also a researchable topic.

Another key element for proper water management is given by the existing (or absent) legislation on the matter. Its lack or inadequacy can lead to continuous problems and conflicts between people and institutions and to exhaustion and degradation of the water resources themselves. In-depth research on this subject can help to straighten up regular conflicting situations and reduce misuse of the resources.

Finally, research can frequently be useful in the area of localization of service development and improvement (socio-economic, political, administrative criteria). This type of investigations can answer the question on who is getting the benefits of the investments and why.

In the following list a brief description of potential avenues of research in the field of urban water supply is presented:

1) Research on surface water resources;

2) Research on groundwater resources;

3) Research on various urban environmental problems;

4) Research on ways of improving information flow in the above fields of research.

5) Research in the field of sanitary engineering applied to water supply and sanitation;

6) Research on economic viability of water institutions;

7) Research on debts and future sources of funding;

8) Research on human resources (administrative vs. technical, training of personnel, etc.)

9) Research on administrative structures and practices;

10) Research on political structures as they relate to the water field;

11) Research on the legal framework (water laws and legislation, rights and jurisdictions);

12) Criteria for water and sanitation services development.

Most of those, subjects could be addressed through several of the existing IDRC programs (*). 1 to 3 through the ESP of EESD, 4 through ISD, 5 through HSD, and 6 to 12 through SSD.
In addition, in order to carry out the above mentioned research activities in an appropriate manner it is necessary to ensure an adequate flow of information between the research, and implementation institutions, and users both at the national and regional level. The ISD and the CD of the Center could provide support in selected aspects of these activities.

As it can be expected, not all the above avenues of research possess the same degree of importance or urgency. In the following paragraphs, a more qualified analysis of the research potential in these areas is presented.

(*) Note on IDRC Divisions acronyms: EESD=Earth and Engineering Sciences Division; SSD= Social Sciences Division; HSD= Health Sciences Division; ISD= Information Sciences Division; CD= Communications Division; AFNS= Agriculture, Food and Nutrition Sciences Division; FAD= Fellowships and Awards Division; ESP= Earth Sciences Program.

7.4.2 Upstream research

As a result of all the previously described limitants, very little research has been carried out in the hydrogeological field throughout the continent.

A number of studies have been performed in some cities (i.e. the aquifers of Lima, the aquifer of Guatemala, and some others) often with the help of foreign consulting companies, and participation of national institutions. Those studies have served mostly to produce recommendations that have been only partially followed, mainly due to insufficient funding, but also due to some uncertainty on the accuracy in the forecasts and due to political, administrative problems or other reasons.

At the same time, the urban population keeps growing and the water services do not follow. Less water flows from the taps and more people do not have their own domiciliary water distribution connections.

The reasons why this is so, are several. A non negligible one is that, the studies that have been carried out in the Third World cities, are normally of a general nature. Therefore, often, they do not address some key specific research problems whose solution cannot be obtained just by general aquifer or basin studies.

On the other hand, there are a large number of specific hydrogeological research problems that have been addressed in developed countries and those results can be applied in analogous situations in less developed areas of the world.

However, in addition to the above mentioned aspects there are two types of limitants that need to be considered.

Firstly, many specific research problems that are normal in LDC cities do not exist, or exist in a very limited degree in DC and therefore no specific research has been carried out yet on those topics (in those more developed nations). This type of research needs to be done in LDC because it is not going to be carried out anywhere else (i.e. contamination of groundwater in unsewered densely populated areas).

Secondly, those research subjects (or methods) that have been, or are, being studied in DC require often adaptations for their application in LDC urban environments.

As a result, what is available is mainly some (insufficient) general (baseline) research, and very little specific (completely innovative or adaptive) research.

There have been -recently- some efforts to solve this lack of basic scientific investigations, in which several IDRC-supported urban hydrogeological projects have played a significant part.

Several research projects are under way throughout the continent, of which two have finished their first phases and have started their second phases (one in the Valley of Mexico and the second in the Sao Paulo basin).

Given the magnitude of the problem and the extent of the research effort, these research projects have only opened the door to define the main processes that determine the hydrogeological dynamics of both aquifers. At the same time they have allowed the strengthening of two research teams in the field of hydrogeology in both cities.

Similar results are being obtained in several other cities in which IDRC-funded projects are being executed (Cochabamba, Montevideo, Buenos Aires/ La Plata and in a lesser degree due to political upheaval, Managua, Nicaragua).

In addition, in all the above cities the relationship between research institutions/ individuals and water companies has substantially improved.

Still, this remain a critical issue. There are few contacts between hydrogeological researchers and water engineers, and therefore there are some problems to "transfer" the result of the research to the people that are going to use them.

In some cases, there is not enough practical credibility about actual applicability of the research results among water engineers, and in many cases they are based on substantive facts. Results are often too academic, in some other cases too vague to be used in practice by people pressed by the growing needs of the city.

In other cases (probably in most cases) it is just the lack of dialogue and the sole initiation of these contacts may result in breaking the inertia, becoming a key element in the development of the required cooperation.

In addition, as explained in other section of this document, water companies do not have strong research departments in the hydrogeological field (often they do not have any researcher at all) and they depend from other institutions (frequently from Universities, but also other governmental institutions).

This means that there may be in some cases a lack of adequate "translation" of the research results from the geological "jargon" into the engineering "jargon".

However, in spite of all these problems it is the opinion of the author of this document that the (starting) problem remains the lack of accurate, adequate and often relevant research.

In addition, and probably in a lesser degree, there are problems of communications, and even when the results have been finally satisfactorily received at the users' end, there may be also problems at the decision-making level (political, administrative). Finally (and obviously) there are the ever-present funding constraints. In Table 4 a brief summary of the main problems for the application of the research results is presented.

7.5 Application of research results

As a result of all these constraints, which are partly a result of the way in which the research was conceived or carried out, and partly of the existing political, administrative and financial frameworks, in which the research results are expected to be applied., investigation efforts may remain unapplied in libraries or bureaux.

In fact, one report with its maps, or even a fancy groundwater computer model, no matter how well done they are, do not suffice to insure that the research recommendations are followed.

Of course, in many cases (too many, unfortunately) this research is lacking. Very little information is available of the water (particularly groundwater) resources available for urban use. This lack of knowledge, is often without relation with the size or importance of the city. For instance, it was only very recently that a (relatively) accurate information has become available on the aquifer of Mexico, after some recent deep drilling was carried out by PEMEX (as an indirect result of the tragic earthquake of 1986). The fact that there was an UNAM-University of Waterloo research team working in the subject at the time in which the drilling took place, helped to allow an in-depth analysis of the deep stratigraphy of the basin, which was previously poorly known. As a result, a more realistic conceptual model was developed. and more appropriate recommendations can be proposed to the water management authorities. In many other cities, the information is insufficient (as it was in Mexico City) or almost completely absent. This is one of the reasons why the decision-makers tend to choose surface water supply alternatives (surface water is visible, although sometimes also poorly known) in spite of the advantages offered by some groundwater reservoirs (which are described throughout the text in this document).

However, even when the research results are available, in many cases, the authorities still hesitate to apply the recommendations, and often prefer the surface water option, even though groundwater can represent a more convenient solution to the problem.

The reasons for that are complex. Perhaps one of the most important causes resides in the lack of public awareness on the potential of groundwater for long-term water supply projects, and even on the lack of knowledge on what groundwater is and how do the groundwater natural systems work. The author believes there is a need for basic education on these subjects. In some countries, groundwater utilization has been and/or is a well-known activity, and people always keep in mind the potential or actual existence of the groundwater resource. In other countries, though, this is not so. Very little groundwater is used and even in sites in which its use would be the best alternative, large and expensive surface water schemes may be implemented.

There are also political reasons. Dams and aqueducts are obvious features of the artificial landscape and can be shown and photographed. They can be presented in TV during the political campaigns. Wells are much less conspicuous, because they are underground structures, they don't show well on television or posters.

Another reason that works in favour of surface water projects, is the size of the investments. They are frequently accompanied by heavy lobbying by construction companies, and in the less ethical cases, there may be even room for corrupted practices (as "under the table" commissions). In groundwater projects, because of their smaller size, the above practices are less likely to occur.

Of course, even when the decision to go ahead with a groundwater project is taken, there may be financial constraints that may delay the execution of the project or stop it altogether. This is becoming particularly frequent in some (probably most) LAC countries due to their lack of financial resources and their low credit rating.

In some cases, the projects may be carried out, but the actual results may be poor, due to a number of reasons. Some water companies are very inefficient and the groundwater supply systems may be also utilized in an inefficient way. In other cases, there is a lack of technically qualified personnel (i.e. hydrogeologists, groundwater engineers) and therefore some technical decisions may be inadequate.

Whatever the reason, the application of the research results in hydrogeology is a complex and not always successful task. In Table 4 a general out look of steps and problems on implementation of research results is presented and in the following sections these issues will be analyzed in a more detailed manner.

Table 4

STEPS IN IMPLEMENTATION OF RESEARCH RESULTS	PROBLEMS
1) Research activities	Not sufficient/ not on target/ insufficient flow of information between researchers
2) Presentation of research results	Inadequate "jargon"/ other problems of presentation
3) Communication of research	Not sufficient/ not on target/ wrong "jargon"
4) Decision-making (prior to request or obtainment of funding)	Administrative constraints/ political constraints/ financialconstraints
5) Funding	Insufficient or lack of national funding Insufficient of lack of international funding (due to insufficient credit, etc.)

7.6 Limitants for implementation

As it has been described in Table 4 the main limitants are:

1) Insufficient research (including insufficient flow of information between different research centers);

2) Insufficient communication to water managers of research results;

3) Political-administrative constraints (which may become also financial);

4) Insufficient or lack of funding (national or international)

The first problem, which is addressed by the ULH network*, requires extensive research on specific topics both through completely innovative research or through adaptation of DC research results (or when available from other LDC research results).
It is important to note that this insufficient research is mainly due to scarcity of qualified technical personnel (in hydrogeology), and also to insufficient financial support from the funding institutions.

Although there are other factors, the above mentioned ones are normally the most important causes of this insufficient research activities, which in turn are responsible for the lack of accurate knowledge to make adequate decision on the water resources issues. The basic solution is increased training in the water subjects which will result directly in additional research activities of better quality and indirectly - almost certainly- in additional support from the institutions (due to the growth of the "scientific research lobbying group").

Once the "seeds" of the research teams have been developed, there is a need to develop information/ communication relationships between them (and with other centers outside the region) in order to allow the mutual "feeding" of the researchers activities with each other work. This allows a systematic strengthening of their knowledge and capabilities.

The second problem requires a particular scope in the planning and execution of the research project WITH AS MUCH PARTICIPATION OF WATER COMPANIES AS POSSIBLE, and a particular care to use the right language to convey the research message.

The third problem requires research, both in the political and administrative field as it has been carried out in several occasions by the Water Divisions of the World Bank and Inter-american Development Bank. The author thinks that the above information (from these studies) is not sufficiently known, and that there is strong need to continue this type of studies in order to clarify this complex and important problem.

The fourth issue relates not only to the credit rating of the Water Company (or the country) but also to the priority criteria defined by the governments (even when loans or grants are available, the governments may decide to use them in different types of investments).

---

* Urban Latin American Hydrogeological network supported by IDRC.

7.7 IDRC potential avenues of research

IDRC can tackle some of the above mentioned issues through some of its different programs:

1)	Hydrogeological problems	EESD
2)	Flow of Information between Research Centers	ISD
3)	Training	FAD (EESD)
4)	Political-Administrative constraints	SSD
5)	Dissemination of research results and implementation aspects	CD

As a conclusion of the above, the author believes that the next steps for the Center to take will be the following:

1) To continue developing research projects on specific aspects of water resources applied to urban water supply (and urban environment);
2) To continue supporting the networking efforts (UHLN), through increased investment in the aspects of exchange of information and data banking;
3) To develop a training program in this field of expertise.
4) To develop projects (complementarily of the existing and proposed EESD's) in the fields of political and administrative constraints to urban water supply.

5) To define areas in which the Center (perhaps through CD) could assist for better communication between researchers and users (managers/ engineers) and in the better knowledge of potential avenues of funding that could allow more effective implementation of the research results.

Note: UHLN= Urban Hydrogeological Latin American Network.

7.8. Divisional future scope

7.8.1. Research topics

The Earth and Engineering Sciences Division can provide a very important and key assistance to support useful research that can provide elements of knowledge for the solution of groundwater-related water supply problems of the LAC cities.

The technical hydrogeological subjects that are more important for solving urban groundwater supply problems are the following:

1) Evaluation of available groundwater volumes;

a) stratigraphic and aquifer geometry studies;
b) studies of permeability, transmissivity, storativity;

2) Evaluation of groundwater quality;

a) natural groundwater quality studies;
b) problems of contamination;
c) saline intrusion and saline upconing in coastal areas.

3) Evaluation of groundwater renewability;

a) studies on natural recharge;
b) studies on artificial recharge;
c) hydrological budget investigations;

4) Groundwater management

a) utilization of computer models for groundwater management;
b) basin studies

5) Related geotechnical Investigations

a) subsidence studies in overpumped areas;

6) Well construction

a) studies on construction and maintenance of large yield wells;

7.8.2. Previous and active research projects

Of the above subjects, the Earth and Engineering Sciences Division has dealt with the first five through a number of projects in Mexico City, Mexico, Sao Paulo, Brazil, Cochabamba, Bolivia, Montevideo, Uruguay, La Plata, Argentina, Managua, Nicaragua in LAC; Sfax, Tunisia, Dakar, Senegal, Dar-es-Salaam, Tanzania in Africa; and Bangkok and Manila in Asia.

In Latin America, a network structure based in the continental office of AGID in Cochabamba, Bolivia, is being supported to facilitate contacts and communications between researchers.

A number of meetings, symposia and conferences were organized in order to define the main needs in all participant countries. These meetings took place in Cochabamba, in Lima (twice), in Mexico city, and in Buenos Aires.

7.8.3 Research priorities and project development criteria

As a result of these meetings, the main priorities of the LAC region in this field were better defined:

a) groundwater protection from contamination, saline intrusion and overpumping;

b) devising optimum methods of groundwater management for each type of urban aquifer;

c) developing integrated methods of surface and ground- water (basin) management;

d) evaluating when groundwater is the most economical feasible solution for urban water supply (includes not only hydrogeological investigations but also cost-analysis studies, etc);

e) legal issues in groundwater use and protection;

f) enforcement of existing legislation.

g) development of human resources in the groundwater field.

Of those priorities, the first three (a through c) have been contemplated already in the existing EESD-supported projects, and although the last four fall partially or totally outside the jurisdiction of EESD, they require some input from the Division.

As a result of the above stated facts it is the belief of the author of this document that new projects in the field of urban hydrogeology will need to meet the following requirements:

1) projects must address pressing problems affecting actually or potentially the well-being of the urban population, particularly the urban poor;

2) projects must address problems affecting several cities in the LAC region and/or elsewhere in LDC countries;

3) projects must produce results (as much as possible) at the pre-feasibility level;

4) results should be of the type that could be replicated in other similar situations;

5) projects must include a strong training component, even exclusively training projects would be of interest;

6) water companies must support and when possible participate, not only during the execution of the project but also during the proposal development stages;

7) projects can deal with problems already "solved" in developed countries when the adapting of these solutions to LAC cities is not

a straightforward exercise;
8) projects must be linked with the networking efforts already under way in the region (not only EESD's, but also IS (Repidisca), etc;

9) projects must have an "implementation" built-in component (i.e. participation of other funding agencies in the development of the project, particularly those that can be instrumental in funding follow-ups);

The author considers that those projects meeting all the above requirements will have a much better chance of success at the implementation stage.

In addition, the EESD may develop joint projects with other Divisions in areas not quite inside its jurisdiction as explained in sections 7.4. and 7.7. The urban groundwater field is very complex and requires the participation of many specialists from a wide array of disciplines. Multidisciplinary, laterally-linked and follow-up projects with participation of other programs of the center can provide a excellent tool for increased efficiency of the research efforts and optimization of results implementation.

At this stage, the author believes that it is difficult to be more specific. More results from the active projects are required in order to have a better idea on how the above mentioned strategies can be actually applied in the different urban environments of the continent.

7.9 Funding constraints for implementation of research results

7.9.1 General

As explained in several sections of this documents, one of the main problems of applied research in the urban environmental field in general, and more particularly in the urban water supply field, is the implementation of the research results. Because we are dealing with large volumes of water, complex systems and costly structures, the implementation of any decision that can be based on research results can be very expensive.

Even when research results might recommend "cheaper" solutions, the size of the investments involved may still make very difficult to implement any technically - based alternative.

In addition, any work to be carried out in the cities, must take into account the myriad of local and personal interests interweaving in the urban setting.

When water structures are built on private lands, the costs of acquiring them could -in some urban locations- be staggering.

When these same structures are built on public land, jurisdiction problems may arise (municipalities vs. provinces vs. national government, etc.)

In other cases, research recommendations may touch or affect in some way the political or administrative structures of the country/city and generate unexpected (or expected) opposition from some lobbying quarters, which may perceive the proposed actions as prejudicial to their interests.

In all cases, implementation of any wide -ranging measures- in the urban water field may face a number of obstacles of which the financial and environmental constraints are -by no means- necessarily the only or most important.

However, although financial constraints are not the unique stumbling block to implementation of many research studies in the water field, they can effectively stop the application of the results and recommendations.

7.9.2 <u>Sources of funding</u>

Funding for urban water projects is provided from several sources: 1) water institutions themselves; 2) municipalities; 3) provincial or national governments; 4) other national sources; 5) international agencies; 6) foreign governments; 7) other foreign sources.

Of those, funds from 5 to 7, normally (but not necessarily) comes in the form of loans and 2 to 3 in the form of subsidies or grants.

In the next section a brief description of some funding agencies and types of projects supported is presented.

7.10 Funding agencies

7.10.1 <u>The water and sanitation agenda of the World Bank</u>

In the LAC region the World Bank has committed in the field of supply and sanitation (since 1963 through 1989) 2.9 billion dollars to assist in the financing of 61 projects in 18 countries, averaging 34 M. per project.

The share of the WSS sector has systematically decreased from 7.2% in 1976-80 to 6.1% in 1981-85 and 3.9% in 1986-89.

These figures reflect the reduction in infrastructural investments in LAC countries due to "adjustment" efforts.

The World Bank investments in this sector were conceived with cost-recovery targets, which were seldom met.

Therefore, recently, the Bank has directed its emphasis more towards "policy framework, ... linkages with the rest of the economy, and at long-term financial and training needs of sector agencies"(*).

The Bank has also decreased its involvement in the training aspects, which is mainly carried out through the Economic Development Institute. This decline has been both on a regional and sectorial basis.

It is estimated that the annual financial needs of the WS sector in LAC is of the order of 6,000 M. dollars (in 1985 US$ dollars). At the most, it is foreseen that the bank could lend only 5% (or 300 M. per year) of those needs. The rest must come from other agencies and/ or national funding.

As a result of these limited resources, the Bank is targeting its efforts in the following directions **:

1) development of strong, autonomous institutions at all levels, fostering management stability, staff productivity and training and efficiency of operations;
2) encouragement of financial flows to the sector under coordinated policies;
3) promotion of cost-recovery policies, financial self-sufficiency and accountability (includes elimination of subsidies not justificable for poverty, and environmental protection);

(*) "Water Supply and Sanitation Sector in LAC:" "The challenge of the nineties" and "Water Resources: an agenda for Bank Consideration". (World Bank Internal Documents, 1989).

4) encouragement of a more active participation of the private sector (however, not enough knowledge on that is available to the bank staff as to assist efficiently in this area);
5) extension of WSS in urban areas to avoid rapid deterioration of the living conditions (using low-cost technologies in low income areas, as required);
6) improvement of maintenance, rehabilitation and better use of existing systems; reduction of water losses;
7) assessment of pollution and other environmental problems to start helping in their solution.

7.10.2 Future development of water resources in LAC: the World Bank approach

Another recent paper of the Bank (Water Resources: an Agenda for Bank Consideration; 1989, Draft/MG/8/21/89) stresses on the Water resources aspects, complementing the previously described document.

This paper describes the problems of urban water supply succinctly (increased demand, deterioration and overuse of the less costly water sources, etc.).

Reaction to these pressures could be through:
1) development of new, often more distant, sources;
2) costly additional treatment of water resources under use and wastes;
3) rationing of water;
4) reallocation of water through legal/ regulatory channels or pricing;
5) changing water use practices to reduce pollution.

The recommendations of the paper include increased research on:

1) evolution of usage levels by type of user and supply costs in major metropolitan areas;
2) alternative methods for coping with the multiple demands and costs under different water resources availability and quality conditions.

The objective of the work could be to "ANALYZE THE COST-EFFECTIVENESS of different approaches".

For that, the first step recommended includes the execution of several (8) case studies representative of the water supply and water resource situation.

** Summarized from the paper "Water supply and sanitation; the challenge of the nineties" R. Yepes. (World Bank document, 1989) (Ref. 91).

These studies would be conceived in a coordinated manner, starting with the resources aspect, and then integrating other elements which will allow an informed decision-making process by the water authorities.

It is expected that the Bank will orient its resources towards the countries:

1) with more acute water problems;
2) with less financial resources.

However, a general reading of these and other World Bank papers shows that the problem is far from being defined by the Bank and there is room for a flexible consideration of specific cases.

On this regard, the research efforts supported by IDRC in the framework of the Urban Hydrogeology Network are a first step, which seems to combine very well with the bank agenda in the field of water and sanitation.

Additional support to these efforts may also come from the internal resources of the Bank, which is highly interested in supporting regional research work tending to provide basic information on water resources and management without which all the rest of the projects will be worthless.

NO SELF-FINANCED, WELL-ADMINISTERED institutions can provide water that has not been defined as a resource or that is being wrongly managed due to poor hydrological or hydrogeological knowledge.

In brief: first, the resource and its (technical) management, second, the distribution of the resource among the users and the administration practices of the responsible institution.

In spite of these apparently overwhelming problems, there are a number of companies in the LAC region that have shown relatively successful management practices (#).

(#) "Management and Operational Practices of Municipal and Regional Water and Sewerage Companies in Latin America and the Caribbean" Discussion Paper, The World Bank, Report INU, 61, G.Yepes, Jan.1990.

The list of companies considered as "well managed" include the following:

1. Acuavalle of Valle del Cauca, Colombia;
2. E.P.M. of Medellín, Colombia;
3. EMOS of Santiago, Chile;
4. CAD of Monterrey, Mexico; and
5. COPASA of Minas Gerais, Brazil.

This same author compares the characteristics of these LAC well - run companies with other equally successful companies in Spain and France, (S.G.A.B. of Barcelona; A.M. of Alicante; Gestoras Agbar and Compagnie des Eaux de la Banlieu of Paris, France).

The main differences between the LAC and European companies relate to the area of jurisdiction (rapidly growing urban environments in all LAC companies and in two cases large servicing area at the provincial level, which is not the case in the European companies) and the role of private capital (important in the European companies, not important in the LAC ones).

In other aspects of their functioning no significant differences were appreciated.

The main management practices to emulate, identified in this study, include:

1) development of distinct organizational cultures (managers held in high esteem which translates into a mandate for company excellence);
2) high job stability in mid-management and professional positions (therefore, long-lasting institutional memory and long-term objectives kept in focus);
3) rates cover -at least- operational and maintenance requirements;
4) relations with customers are a priority (therefore feedback and community trust);
5) some companies use private contractors, promote (d) private capital participation and/ or have developed effective cost accounting systems.
6) the ratio of employees per 1,000 water connections is 4.7 in the selected LAC companies, which is much less than the normal ratio in the region of 10 to 20.
   However, this is still lower to ratios in the previously mentioned European companies (2.2 / 1,000), in USA companies (2.9 / 1,000) or in Canadian companies (2.0 / 1,000).
7) ratio of salary cost to the total salary costs is normally above 50% in most LAC water companies and less than 40% in the 5 LAC selected for the study. In the European companies, the ratio is under 30%.
8) the unaccounted water (unmetered, not charged) is of 40 to 60% in most LAC companies, while is only of 34% for the selected LAC companies. Unaccounted water is much less in the 4 selected European companies (22%) and even less in USA (13%) and in Canada (12%).

7.10.3 <u>The Inter-American Development Bank</u>

The IDB is the main inter-american financial institution providing funding support for water supply and sanitation for cities in Latin America.

In general, this support as in the case of the World Bank is provided under the form of loans, with variable repaying terms, according to the countries and types of loans.

The loans have been historically dedicated to development of energy projects (i.e. 30 billion dollars for the period 1961 to 1981). A second traditionally prioritary field has been the industrial and mining sector (21 billion dollars for the same period). Health, environment and urban development have been a much less prioritary sector with a total of about 6 billion dollars (300 million per year).

In addition to the development loans, the Bank also provides technical assistance (normally as grants), and funds small projects for private persons and institutions with difficult access to the conventional sources of credits.

Most of the water supply and sanitation loans(which represent only a small part of the bank investments have been dedicated to meet the needs of the population from rural areas and small towns.

In some cases, IDB loans have been directed to larger towns and metropolis (i.e. Project of Integrated Development of Bogota, Colombia, Urban Development of Buenaventura in this same country, Sewerage of Bridgetown in Barbados, Urban Infrastructure of Quito, Ecuador, Water Supply and Sewerage in several cities of Guatemala, Stormwaters drainage in Port-au-Prince, Haiti, Groundwater Supply for Montego Bay, Jamaica, Water Supply for Mexico City, Water Supply and Sewerage for Monterrey in Mexico, Systems of Stormwater drainage for Asuncion, Paraguay, Disposal of Urban Effluents in Montevideo, Uruguay, etc).

Most of the criteria mentioned in the previous section (World Bank) apply in the case of IDB.

In addition to the previously mentioned loans and grants, there are also grants for regional projects which may include studies in different countries (including aspects of research (original or adaptative) and of training).

During the last few years the IDB has included protection of the environment as an overriding criterium for development of its programs, making much easier to obtain funding for research or training projects in the field of urban hydrogeology, hydrology and sanitation.

The Water and Sanitation Department of the Bank which also deal with groundwater studies and their application, is the section having the technical jurisdiction on all loans, grants and in-house programs dealing with this subject.

During the 31st. annual meeting of the Bank in Montreal (April, 1990) a very rigorous agenda was approved (*): 1) at least 50% of the resources must be dedicated to the "poorest of the poor"; 2) the bank will intensify the programs destinated to incorporate women to developmental efforts; 3) great importance must be attached to deal with demographic problems; 4) and as stated in previous paragraphs, environmental impacts of projects must be carefully considered before their approval. Simultaneously, sectorial "adjustment" loans will be approved in an expeditiously manner in order to facilitate structural reforms (tending to reduce fiscal deficit, increase trade balances superavit, reduce foreign debt, etc). Total loans for 1990 are estimated in 3,500 million dollars increasing to 7,000 million in 1993.

Priorities will be given to seven large countries: Argentina, Brasil, Mexico, Venezuela, Colombia, Chile and Peru, which will receive during the next four years up to 15,000 million dollars (65% of the total).

According to Mr. Joe Clark, newly appointed president of the Board of Governors of the Bank, it is expected that the IDB will help to initiate a new era of progress and pragmatism for Latin America and the Caribbean, after the lost decade of the eighties.

In brief, it is expected that the new scope recently incorporated in the IDB strategy, will greatly facilitate the obtainment of funding for Hydrogeological Projects in the cities tending to solve water supply and environmental problems. The Bank, then, remains one of the main options for financing implementation phases of successful IDRC research projects in the field of water and sanitation.

(*) Information obtained in various newspapers from Latin American countries: La Republica from Montevideo, Uruguay (6/4/1990) and Hoy from La Paz, Bolivia (5/4/1990).

7.10.4 UNDP Programs

UNDP has also programs aiming to solve water supply and sanitation problems in cities, although the first priority is rural water supply. The approach is to develop innovative implementation strategies for extending service coverage to low income groups that can be replicated on a national scale, normally using low-cost technologies and involving local communities and especially women. In the city of La Paz and other Bolivian cities several water and sanitation projects were carried out in the squatters periphery of the urban areas. These efforts were based on neighborhood associations (UNDP-World Bank; Water and Sanitation Program; Annual Report, 1988).

The Water and Sanitation Program includes applied research and individual country programs (ICP) with a wide range of activities. The ICP's support training and demonstration projects, foster cooperation between governments and support agencies and assist in the design and implementation of large scale investments (which may include urban water supply schemes). In Latin America, considerable work is being carried out in 4 cities of Bolivia including a low-cost sanitation component.

For 1989, the WSP has placed more emphasis on environmental and broader waste management issues, sharpening "its focus on urban issues as it expands its activities in Latin America ..." (op.cit).

Other Latin American countries with active WSP projects are Brazil, Peru and Mexico.

Sources of funding for UNDP projects comes from several agencies, of which the World Bank is one. Other sources of funding include the World Health Organization through PAHO, UNICEF, national funding agencies, etc.

7.10.5 PAHO - CEPIS

The Panamerican Health Organization depending from WHO and OAS, is also involved in the field of urban water supply and sanitation, through its program in "Salud Ambiental" and the same as UNDP depends on external funding for its programs.

The main PAHO center dealing with the matter in LAC is the CEPIS (Centro Panamericano de Ingeniería Sanitaria) which is located in Lima, Peru.

CEPIS has developed a large information network and data bank (REPIDISCA*) with partial funding from the Center located also in the Lima office.

CEPIS is mainly a coordinating and informative institution, depending on outside funding for the center projects. The Urban Hydrogeology Network of IDRC has worked in close coordination with CEPIS in the organization of its various meetings and projects development.

* Repidisca: Red Panamericana de Informacion y Documentacion en Ingenieria Sanitaria y Ciencias del Ambiente.

7.10.6 Other sources of funding for urban water supply and sanitation

Other sources of funding for urban water and sanitation programs include the IBRD (International Bank for Reconstruction and Development) and several national cooperation agencies: BMZ (German Ministry for Economic Cooperation), GTZ (German Agency for Technical Cooperation), USAID, United States Agency for International Development, JICA, Japan International Cooperation Agency, CIDA - Canadian International Development Agency, DANIDA (Danish International Development Agency), NORAD (Norwegian Agency for International Development), DDC (Department for Development Cooperation, Italy), FINNIDA (Finnish International Development Agency), SIDA (Swedish International Development Authority), ODA (Overseas Development Administration, United Kingdom) and SDC (Swiss Development Cooperation) which also provide loans and grants for the execution of water supply and sanitation projects.

In the next section we will only briefly describe the role of CIDA which is the more relevant agency for the purpose of this paper.

7.10.7 CIDA - (Canadian International Development Agency)

The water sector in CIDA is divided in two main areas: a) the Water Supply and Sanitation Services including provision of ground- and surface drinking water both in rural and urban areas and b) the Water Resources Management unit which conducts inventories and assessments of surface and groundwater resources, deals with flood hazards and control projects, develops comprehensive water resources projects and aims to the protection and conservation of the quantity and quality of the water resources, including the environmental aspects (Water and Sanitation, CIDA Development Issues Paper, Prof. Services Branch, May 1988).

CIDA bilateral programs deal mainly with the poorest countries of the world and only in a lesser degree with the not-so-poor Third World countries. Only a few Latin American countries have qualified for this type of support in the field of water supply and sanitation, and priority was given to the English- speaking countries of the Caribbean (Belize, Barbados, Sta Lucia, St. Kitts-Nevis, Grenada, Dominica, Jamaica, St Vincent, Guyana, Montserrat, Anguilla, Leeward/Windward, Antigua/Barbuda). Several other countries of the region have also received support in these aspects: i.e. Nicaragua, Guatemala, El Salvador, Haiti, Honduras, and Peru. The total disbursed budget for the period 1968-87 was 116: CAD (16.6% of the world total).

In addition to the bilateral programs there have been contributions to the water and sanitation sector through the Multilateral Programs Branch (about 20 million per year), the Special Programs Branch (approximately 6 million per year) and still and in a lesser degree through the Industrial Cooperation Branch (about 1-2 million per year).

In the field of water supply and sanitation, CIDA efforts have been mainly directed towards the rural water supply field; and only in a few occasions towards urban water supply (and that only for smaller cities). Some examples of urban water supply and sanitation projects include the following: Proj. 00106, 10159 and 11097, Water Supply and Sewerage for Belize (total of approximately 34 million CAD)(1971 to 1988); Proj. 01656, 00081, 00308, 12996, 13319, Water Supply and Treatment for Roseau, Dominica, (total of approximately 7 million CAD) (1971 to 1988); Proj. 00103, 00139, 01101, 01102, 00101, 00116, Jamaica: several projects in water supply (some rural, for small cities, one for a Kingston suburb), (total of approximately 4 million dollars), (1965 to 1977). In addition, other Caribbean islands received support for several water supply projects (Grenada: about 5 M. CAD; Barbados: 12 M.CAD ; Montserrat: 2.5 M. CAD; St Kitts and Nevis: 4.5 M.; and St Vincent: 3.5 M..

In South America and Central America there was some support for Peru (project "pueblos jovenes" of Lima, through WUSC), and recently emphasis has been put in Bolivia and Nicaragua where new projects may be developed soon.

In recent conversations of the author with the Water and Sanitation Officers at CIDA, it appears that gradually CIDA will be increasing its participation in the urban water and sanitation field in the urban poverty belts and slums. This new scope would take into account the growing needs of the Third World cities due to the urban demographic boom that many of them are experiencing.
Therefore, CIDA contribution could be a key factor in the implementation of many of the recommendations presented in this document.

CHAPTER 8 CONCLUSION

The water supply and environmental situation of large cities in the final result of a complex array of circunstances which include not only the availability of water resources and the characteristics and vulnerability of the environment, but also demographic, legal, administrative and political aspects.

Therefore, although at first sight, it may be considered that when water resources are available the problems are solved, in fact, in many cases, it is not so.

The first element to take into consideration when assessing the water situation is the availability of safe surface water resources. In some cases, surface water resources are very close to the city, but at a lower altitude (cases of cities located at high altitude), in other urban areas, they are at a higher elevation, but further away (i.e. Lima). In both cases, the costs of conducting water to the consumption sources can be very high and -perhaps- unaffordable. Of course, when water sources are remote and at a lower altitude, then, costs can become prohibitive.

In some cities, there is a large, regular, nearby river and in others there are only irregular streams in the proximity of the city site. In the first case, the problem of water supply can be solved -in principle- by means of an intake and adequate treatment, storage and distribution structures. In the second case, there may be a need for upstream dams or reservoirs to stabilize the flow and/ or to store water for the dry periods. These structures, obviously, affect the cost of the water.

The quality of the water also varies, sometimes it possesses a large concentration of suspended sediments (as clays, silts and sands), sometimes organic matter or organisms, and in other clases various types of contaminant substances. In some water bodies, all these problems are present. As a result, treatment costs can become very high. Of course depending on the requirement treatments, the costs may vary substantially from place to place.

As these examples show, the utilization of water for public consumption is not a straightforward exercise, available volumes may vary, and treatments can be complicated and expensive.

Because available water supply and consumption vary considerably both through the year and the day, it is necessary to build storage structures as reservoirs, pools or tanks. These structures are normally very costly, adding to the other expenditures that are required to provide the necessary water supply for the cities.

Distance to the surface water sources is another element that can increase substantially the cost of water, due to the high cost of conduction, pumping and storage structures.

When the consumption area is at a higher elevation than the water sources, new costs are added (for pumping up the water and conducting the needed water volumes).

When a city grows, at a certain point, it may "outgrow" the original water sources; new larger reservoirs, located further away, and longer and more complicated conduction systems are required and as a logical result water costs multiply.

A key limitant is the need for increased treatment due to contamination problems and presence of suspended sediments with the obvious and consequent augmentation of costs.

The above mentioned costs can be of two types:

1) Investments (construction of dams, pipelines, pumping stations, treatment plants, etc); and

2) Operational and maintenance expenditures.

In addition, the water companies have many other costs that do not relate directly to construction and operation (administrative costs of various types, including salaries and benefits, interests of loans, rental costs of lands/buildings not affected to specific water supply and sanitation purposes, taxes, and even transfers of funds to other governmental institutions).

Normally, the operational and maintenance expenditures are "continuous", and although they are relatively "minor" on the short term, they can amount to large sums of money, when considered on a long term basis. On the other hand, the construction investments are normally very considerable, and are often measured in the hundreds of millions of dollars.

When the financial problems of the Latin American and Caribbean countries are taken into account, it can be easily perceived that these investments can only be made if new outside credits or grants are obtained. Otherwise, they are practically impossible to finance.

Underground water provides a second possible option. When the aquifer is close to the city, conduction costs are low. If this is not the case, costs can increase considerably.

Drilling and well construction costs must be added in order to properly assess the feasibility of a groundwater supply project. As in the case of surface water, in any groundwater supply scheme, there are two types of costs:

1) investments (exploration and studies, drilling, well construction, pumps, conduction systems, water treatment); and

2) operation and maintenance.

Initial investments in groundwater projects are normally much less than in surface water projects, and not always heavy borrowing is required. Often, the water companies, or geological institutes have idle drilling rigs and crews that can be used at a relatively low additional cost AND AFFORDABLE. In most cases, it is -still- much cheaper to drill and build several wells, than to build an equivalent dam or reservoir. In addition, groundwater requires less treatment than surface water (further reducing costs).

Other elements of the water supply systems are similar in both cases (ground and surface water) and no significant economic differences can be found.

Another advantage of groundwater use, is its modular characteristics: surface structures require a large initial volume of investments, while groundwater investments can be spaced in time (a few wells each yar with NO NEED to obtain large credits).

One added benefit of groundwater is provided by its much lesser vulnerability to contamination.

In brief: when urban or suburban surface water resources are insufficient, have been exhausted or are polluted, groundwater in very often the best option; surface water can still offer the best alternative in cities next to large rivers or lakes or downstream of high rainfall, uncontaminated catchment basins. However, even in this second case, some neighbourhoods may be better off by using local groundwater and therefore avoiding investments in conduction systems and eliminating their dependance from the -sometimes unreliable- and often expensive municipal systems.

In spite of the previous statements, it must be said that groundwater reservoirs do no possess unlimited volumes of water and are not invulnerable to degradation.

The potential of each aquifer must be properly assessed (both on a short and long term basis) for optimum planning of effective technical and economical strategies.

In order to properly assess both the groundwater and surface water resources, a thorough knowledge of the natural and artificial systems in the urban region and surrounding areas must be acquired. This implies a network of observation stations and wells, accurate and updated thematic maps, accurate water balances, and, of course, a capable and well trained and experienced research team to carry out the processing and interpretation of the information.

But this is not enough, a very well documented assessment of the long term feasibility of the water projects must be carried out. This includes, not only the technical and economical aspects but also the environmental, social, political and administrative aspects, as well.

The following are some of the questions that must be answered in order to properly evaluate these projects:

1) Is the project technically feasible?

2) How much will it cost?

3) Who is going to pay it?

4) How is it going to be paid?

5) What will be the overall effect (short and long term) ons the environment?

6) Who is going to build, operate, maintain and administer the proposed systems?

7) What effect is the project going to have on the communities living next to the reservoirs, structures and plants?

8) Who is more likely to benefit from the project?

9) Will new jobs be created, or will existing jobs disappear?

10) Who is more likely to be service by the water obtained from the project?

11) Is it likely that all or a substantial part of the water will only be utilized for well-to-do neighbourhoods? or will also serve the poor sections of the city?

12) How is the project going to affect (or be affected by) the legal, administrative and political set-ups?

Once all these questions are answered, then, there will be elements to choose between the various options, if in fact, there are various options. In many cases, unfortunately, the options are very limited by the differences in costs of the various potential projects, and more often -still- the answers are not black and white but in several shades of grey.

Many typical "surface water" cities, utiliza groundwater for their industries or communities located further away (as it is the case of Asuncion, in Paraguay, Santa Fe in Argentina and Ciudad Guayana in Venezuela).

All these cities could continue to expand the use of their aquifers or obtain all their water from the nearby water bodies.

Some cities which depend almost exclusively from groundwater, could completely switch to surface water if decided (i.e. Managua in Nicaragua). Some others, do not have so many options, Havana depends almost exclusively on groundwater and it is not likely that the new volumes required could be obtained from the short, contaminated rivers located in the vicinity (i.e. the river Almendaris and tributaries); in Rio de Janeiro, where groundwater is brackish, surface water reservoirs are the only alternative.

As it can be understood from the above thoughts and examples, the solutions are varied, and depend on the specific conditions of each city.

Before an appropriate water supply alternative is selected it is necessary to have a thorough knowledge of the existing water resources of the urban region and of the possibilities of the cities to develop them and utilize them in an efficient manner.

In order to solve the problem, therefore, it is necessary to carry out intelligent research that will allow an informed decision. This is very important, because the consequences of inadequate decisions in this matter may translate in very harmful and expensive situations in the future. For this reason the importance of water research cannot be overestimated. As it was explained in Section 7.4. the avenues of research are many, and all converge, in a greater or lesser degree in providing the best ways to solve the urgent water problems of the cities of the continent.

However, in order to be realistic, we must assume the actual situation of the LAC cities, with limited water resources, even more limited financial means, and -still- unabated demographic growth.

In fact, in many cases, water works will not be carried out for some time to come and important and growing sectors of the urban populations will lack of this vital element. Presently, in excess of 15% of the Latin American and Caribbean urban population do not possess home water distribution services (which is more than 30 million people), and probably another 40-50 million are using water of doubtful potability. In addition, throughout the continent, not less that 60% suffer frequent water cuts, depending on very unreliable systems which in some cases do not operate more than a few hours a day. These numbers are not likely to decrease in the near future.

In addition, the quality of the service (continuity, water pressure, maintenance) as well as the quality of the water itself is being negatively affected everywhere in the continent.

At the same time, the "structural adjustments" are pushing water prices up making less affordable the service for the poor communities of the city.

On the other hand (and -in part- as a result of the above mentioned facts), whenever there is a choice between various neighbourhoods needing new distribution connections, the more politically influential or better-off people are likely going to get the service or the improvement.

Therefore, water supply is also a social issue, and probably, when we return to the basics, the bottom line is there. Social inequalities are expressed in the political, administrative, and socio- economic systems; water as a basic resource, becomes another commodity (which -unfortunately or not- is what it is in our societies). As another material element of social life, water also expresses the inequalities of the social systems. When it becomes available to everyone, one important cause of these inequalities disappears.

During their whole history, the Latin American and Caribbean region has been a continent of social disparities, and the scarcity of water, mainly affects those with lesser means to pay for alternative solutions. Those unemployed, living in precarious and environmentally hazardous neighbourhoods, with lower incomes, and larger families, are the ones that are mainly hurt by the wrong decisions in the choice of the various possible water supply and sanitation alternatives.

Solving the water problems, which involves RESEARCHING THE WATER PROBLEMS, therefore, not only solves a critical general issue involving the health and well- being of all the population at large, but also allows to give a giant step towards solving -perhaps- the most important material need of the poor population of the cities in Latin America and the Caribbean.

REFERENCES AND RELEVANT LITERATURE

Ref.#	TITULO/TRABAJO	AUTOR	CONGRESO O PUBLICACION SI CORRESPONDE	CIUDAD/PAIS	ANO
86	Los acuiferos de la Cuenca de Cochabamba	F. VON BORRIES G.	La contaminacion de aguas subterraneas en areas urbanas en America Latina	Ottawa/Cochabamba	1987-1988
19	Normas basicas para la proteccion de acuiferos en Chile y la aplicacion de algunas de ellas	DALANNAIS L./GIGLIO M.M.	La contaminacion de aguas subterraneas en areas urbanas en America Latina	Ottawa/Cochabamba	1987-1988
11	El abastecimiento de agua potable de Iquique y efecto sobre los recursos subterraneos de la Pampa del Tamagural	CABRERA G./ PEREZ F.O.	La contaminacion de aguas subterraneas en areas urbanas en America Latina	Ottawa/Cochabamba	1987-1988
73	Estudio de control de inundaciones y generacion de hidroelectricidad mediante el aprovechamiento de aguas subterraneas en la zona urbana de Bogota	RODRIGUEZ C.O.	La contaminacion de aguas subterraneas en areas urbanas en America Latina	Ottawa/Cochabamba	1987-1988
74	Contaminacion agua superficial subterranea en un acuifero libre en el area urbana de Bogota	RODRIGUEZ C.O.	La contaminacion de aguas subterraneas en areas urbanas de America Latina	Ottawa/Cochabamba	1987-1988
55	Acuifero de Quito	MALDONADO S.	La contaminacion de aguas subterraneas en areas urbanas de America Latina	Ottawa/Cochabamba	1987-1988
5	Estudio hidrogeologico del Valle de la ciudad de Guatemala	BALDISON R.	La contaminacion de aguas subterraneas en areas urbanas de America Latina	Ottawa/Cochabamba	1987-1988
64	Efectos de la sobreexplotacion del acuifero de Coro, Estado Falcon, Venezuela	PEREZ ROAS J.A.	La contaminacion de aguas subterraneas en areas urbanas de America Latina	Ottawa/Cochabamba	1987-1988
52	Isotopic study of the Botucatu aquifer system in the Brazilian portion of the Parana basin	KIMMELMAN E SILVA A.A/ REBOUCAS A.C./ SANTIAGO M.M.F./ GOUVEA DA SILVA R.B./	Proceedings Regional Seminar on the use of isotope techniques in hydrology	Mexico	1989
77	Estudio de aguas subterraneas en la zona semi-arida de Atlantico-Bolivar (Colombia)	SANCHEZ L./ OBANDO E./ JIMENEZ G./ TORRES E./ ALAYON E./ HUGET A./ MOSQUERA F./ VARGAS M.C./ STICHLER W.	Proceedings regional seminar on the use of isotope techniques in hydrology	Mexico	1989
32	Evaluacion del acuifero de la Sabana de Bogota utilizando tecnicas isotopicas	TORRES E./ JIMENEZ G./ OBANDO E./ ALAYON E./ SANCHEZ L.	Proceedings regional seminar in the use of isotope techniques in hydrology	Mexico	1989
20	Investigation of a volcanic aquifer system in Costa Rica using environmental isotopes	DARLING W.G./ PARKER J.M./ RODRIGUEZ H.V./ LARDNER A.	Proceedings regional seminar on the use of isotope techniques in hydrology	Mexico	1989
38	Estudio mediante isotopos ambientales del origen de las aguas subterraneas y de la intrusion salina en la parte central de la cuenca sur de Matanzas, Cuba	GONZALEZ BAEZ A./ SEILER K.P./ STICHLER W./ RAUERT W.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989

26	Estudios isotopicos e hidrogeologicos en la region suroeste de la Republica Dominicana	FEBRILLET J.F./ BUENO E./ SEILER K.P./ STICHLER W.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989
2	Cubeta de Quito: Comportamiento general y problematica de la recarga natural del acuifero	ARANYOSSY J.F./ POURRUT P./ MALDONADO A.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989
36	Etude isotopique des eaux souterraines de la plaine du Cul-de-Sac, Republique d'Haiti	GONFIANTINI R./ SIMONOT M.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989
14	Isotope studies of precipitation and groundwater in the Sierra de las Cruces, Mexico	CORTES A./ FARVOLDEN R.N.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989
84	Estudio de isotopos ambientales en las aguas subterraneas de las subcuencas de Yautepec y Cuautla, Estado de Morelos, Mexico	VAZQUEZ S.E./ CORTES S.A./ JAIMES P.R./ FRITZ P.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989
60	Isotopos ambientales y estudio geoquimico del agua subterranea de la parte noroccidental del Estado de Morelos, Mexico	MORALES P./ CORTES A./ CASAR I./ ARIZBALO R.D./ ARAVENA R.	Proceedings regional seminar on the use of isotope regional seminar in hydrology	Mexico	1989
59	Management of water quality in Guanabara Bay, Brazil	MONTEIRO BARBOSA COELHO V./ MONTEIRO DE BARROS DA FONSECA M.R.	Water management and environment in Latin America - U.N. economic commission for Latin America. Pergamon Press	USA	1979
76	The pollution of the Bogota River, Colombia: alternatives for its management	SALDARRIAGA SANIN J./ GARCIA DURAN G.	Water management and environment in Latin America - U.N. economic commission for Latin America. Pergamon Press	USA	1979
16	Intensification of water use from the Maipo River, Chile	COURT MOOCK L./ BAEZA SOMMERS H./ GOMEZ DIAZ R.	Water management and environment in Latin America - U.N. economic commission for Latin America. Pergamon Press	USA	1979
44	Alternative proposals for water quality management in greater Sao Paulo, Brazil	HERMANN R. MAX	Water management and environment in Latin America - U.N. economic commission for Latin America. Pergamon Press	USA	1979
54	Regional development and environmental disturbances in the Aconcagua Valley, Chile	LEE T.R./ GROSS P.	Water management and environment in Latin America - U.N. economic commission for Latin America. Pergamon Press	USA	1979
71	Urbanization in Chile	ROBIN J.P./ TERZO F.C.	The Ford Foundation	USA, New York	1972
83	Urbanization in Jamaica	TROWBRIDGE J.W.	The Ford Foundation	USA, New York	1972
72	Urbanization in Peru	ROBIN J.P./ TERZO F.C.	The Ford Foundation	USA, New York	1972
31	Mecanismos de Salinizacao em regioes semi-aridas	FREITAS Santiago M.M./	Tesis de Douturamento U. de Sao Paulo	BRAZIL, Sao Paulo	1984
56	Tendencias de Industrializacao no interior do Estado de Sao Paulo	MARIANI NETO F./ GANZELI J.P./ SAKURAI K./ dE SOUZA O.	Revista CETESB de Tecnologia. Vol. 2 No. 2	BRAZIL, Sao Paulo	1988

28	Determinacion del riesgo de contaminacion de aguas subterraneas	FOSTER S./ HINATA R.	CEPIS - OMS - OPS	PERU, Lima	1988
8	The human consequences of urbanization	BERRY Brian J.L.	The Macmillan Press Ltd	London	1974
30	Groundwater	FREEZE Allan R./ CHERRY John A.	Prentice-Hall Inc.	USA, New Jersey	1979
22	The urban environment	DOUGLAS Ian	E. Arnold Publishers	USA, Baltimore	1983
79	An introduction to urban geography	SHORT John R.	Ed. Routledge and Kegan Paul	London/ New York	1987
81	Remaking Mexico	THE GLOBE AND MAIL		Canada, Toronto	03/02/90
23	Groundwater and wells	DRISCOLL Fletcher C.	E. Johnson Inc.	USA	1984
7	Studies of Geology and Hydrology in the basin and range province	BEDINGER ET AL	USGS, Profess. Paper 1370-A	USA	1989
62	Analysis of regional groundwater flow and boundary conditions in the basin of Mexico	ORTEGA Adrian	U. of Waterloo (Thesis)	Canada, W Canada	1988
65	Origen y evolucion de la cuenca del Lago de Valencia, Venezuela	PEETERS Leo	I. para la Conservacion del Lago de Valencia	Venezuela, Caracas	1968
53	Laguna de Asososca - Consideraciones sobre su aprovechamiento y proteccion	KRASNY Jiri	INETER	Nicaragua, Managua	1987
51	More and better water for thirsty Sao Paulo - Brazil	KAWAMURA S./ PACHECO L.A./ de SOUZA P.E.A./ OMONI M.	American Water Works Association Journal	USA	Oct. 1989
66	Novos aspectos de salinizacao das aguas subterraneas do Cristalino do Rio Grande do Norte	POMPEU DOS SANTOS J./ GOUVEIA DE AZEVEDO S./ MISTRETTA Gildo	Instituto de Pesquisas Tecnologicas do Estado de Sao Paulo - Comunicacao Tecnica 314	Brazil, Sao Paulo	1984
25	20 anos de geotecnica (Rio de Janeiro)	EQUIPE TECNICA DIRECTORIA GEOTECNICA	Revista Saers. Edicao especial Ano XVI - No.20	Brazil, Rio de Janeiro	Dic. 1986
42	Invasion que pone en peligro los mantos aquiferos del Sur	GRANADO VELAZCO A.	Diario El Dia. Suplemento Metropoli	Mexico	20/03/88
24	Extension urbana y mercado	EL MERCURIO (Diario)		Chile, Santiago	20/10/89
40	Aspectos generales de las aguas subterraneas en Cuba	GONZALEZ PIEDRA Ivan J.	Universidad de La Habana, Facultad de Geografia	Cuba, La Habana	1989
41	El uso de los recursos hidricos de Cuba en treinta anos de revolucion socialista	GONZALEZ PIEDRA Ivan J.	Universidad de La Habana, Facultad de Geografia	Cuba, La Habana	1989
61	Informe final-Estudio de aguas subterraneas en el Valle de la Ciudad de Guatemala		Ministerio de Comunicaciones y Obras Publicas INSIVUMEH	Guatemala, Guatemala	1978

80	Environmental chemistry: air and water pollution. 2nd. edition	STOKER S. H./ SEAGER S.L.	Scott, Foresman and Company	USA	1980
70	Agua subterranea en Puerto Rico	QUIÑONES F./ ALICEA-ORTIZ J.	U.S. Geological Survey - Open-file report 85-642	Puerto Rico	1985
34	Planning report for the Caribbean Islands regional aquifer - system analysis project	GOMEZ-GOMEZ P.	U.S. Geological Survey - Water resources investigations - Report 86-4074	Puerto Rico	1986
92	National water summary 1986 - Groundwater quality: Puerto Rico	ZACK, A. et al	U.S. Geological Survey - Water Supply, paper 2325	Puerto Rico, San Juan	1986
63	Mapa geologico de Bolivia	PAREJA J. et al	YPFB - Servicio Geologia de Bolivia	Bolivia, La Paz	1974
17	Hidrologia subterranea	CUSTODIO Emilio/ LLAMAS Manuel Roman	Ediciones Omega	Barcelona, Espana	1980
78	Carte climatique de la region andine, Bolivie	SHERIFF S.	Universite Laval, Quebec	Canada, Quebec	1984
89	Volcanic rocks	WOOD W.W./ FERNANDEZ L.A.	The geology of North America, Chapter 39, Vol. O-2 - Hydrogeology, The Geological Society of America	USA	1988
12	La sociedad de la basura: Caciquismo en la ciudad de Mexico	CASTILLO BERTHIER H.F.	Cuadernos de investigacion Social (UNAM)	Mexico	1983
32	Urbanization in Brazil	GARDNER J.A.	International urbanization survey report Ford Foundation	USA	1977
48	Informacion sobre la Primera Campana Isotopica	INETER	Estudio hidrogeologico regional "Las Sierras"	Nicaragua, Managua	1988
57	Mapa hidrogeologico de Venezuela 1:500.000 (y documentos relaciones)	MENENDEZ A. et al	Ministerio de Minas e Hidrocarburos, Direccion de Geologia, Division de Hidrogeologia	Venezuela, Caracas	1972
43	Estudo das possibilidades de aguas subterraneas no Rio Grande do Sul	HAUSMAN Abrao	Boletin da Sociedad Brasileira de Geologia Vol.9, No.1	Brazil	1960
21	Lake Xolotlan's poisoned water	de GARCIA Ana Laura	One World	---	Apr. 1987
9	Manejo de los recursos aquiferos de la Gran Lima	BINNIE & PARTENERS	Informe final for SEDAPAL	Peru, Lima	Ene. 1987
3	Agua subterranea: reserva estrategica	ASESORIA RECURSOS HIDRICOS - DAEE	Aguas e energia eletrica. Año 5, No. 13 Dpto. de Aguas e Energia Eletrica do S. Paulo	BRAZIL, Sao Paulo	1988
18	Hidrogeologia das rochas volcanicas do Brasil	DA CUNHA FRAGA Carlos Gilberto	Revista da Associacao Brasileira de Aguas Subterraneas	BRAZIL, Sao Paulo	12/08/88
58	Caracteristicas hidraulicas e hidroquimicas del acuifero Tacuarembo - Area Rivera	MONTANO Jorge/ PESSI Malena	Revista da Associacao Brasileira de Aguas Subterraneas	BRAZIL, Sao Paulo	12/08/88

4	Hidrogeologia del Partido de Salliquelo Provincia de Buenos Aires, Rep. Argentina	AUGE M./ NAGY M.I./ MENDEZ ESCOBAR R.	Revista da Associacao Brasileira de Aguas Subterraneas	BRAZIL, Sao Paulo	12/08/88
46	El sistema acuifero de la Cuenca de Mexico Introduccion	HERRERA I.	Geofisica Internacional (UNAM) Vol.28 No.2	Mexico	01/04/89
90	Industrial wells fields of the Texcoco saline aquifer system near Mexico City	YATES R.	Geofisica Internacional (UNAM) Vol.28 No.2	Mexico	01/04/89
39	Monitoreo geofisico en el entorno de un basurero industrial de desechos de cromo	GONZALEZ-MORAN T./ RODRIGUEZ-CASTILLO R.	Geofisica Internacional (UNAM) Vol.28 No.2	Mexico	01/04/89
75	An investigation of inorganic nitrogen compounds in the groundwater in the Valley of Mexico	RYAN M.C.	Geofisica Internacional (UNAM) Vol.28 No.2	Mexico	01/04/89
15	Hidrologia hisotopica de la influencia de una tormenta en la descarga natural del agua subterranea en la Sierra de Monte Alto	CORTES A./ JAIMES L.R./ FARVOLDEN R.N.	Geofisica Internacional (UNAM) Vol.28 No.2	Mexico	01/04/89
87	UNDP-WORLD BANK Water and sanitation program Annual report 1988	WATER AND SANITATION PROGRAM	UNDP - World Bank	USA, Washington	1988-1989
91	Management and operational practices of municipal and regional water and sewerage companies in Latin America and the Caribbean	YEPES C.	Discussion paper - World Bank	USA, Washington	1990
88	Country and Global Work plan 1988-1990	WATER AND SANITATION PROGRAM	UNDP - World Bank	USA, Washington	1988
13	Water resources: problems and issues for the water supply and sanitation sector	CESTTI R.	INUWS	----	1989
33	Long-term hydrochemical and isotopic study on groundwater recharge and exploitation in Recife, Brazil	GEYH M./ ZIMMER J./ KREYSING K.	UNESCO / International Association of Hydrogeologists	Holland	1983
10	Hydrogeochemistry of groundwater resources in Central Amazonia, Brazil	BRINKMANN/ W.L.P	UNESCO / International Association of Hydrogeologists	Holland	1983
67	Aguas subterraneas: problemas generales de contaminacion	PORRAS MARTIN J./ THAUVIN J.P.	Cuadernos de CIFCA	España, Madrid	1978
68	Aguas subterraneas: contaminacion urbana industrial y agricola	PORRAS MARTIN J./ NIETO P./ CALVIN VELASCO J.	Cuadernos de CIFCA	España, Madrid	1978
35	El medio fisico y la planificacion	GOMEZ OREA D.	Cuadernos de CIFCA	España, Madrid	1978
1	Dwindling water in the sinking cities	ANTON D.	IDRC reports - Vol. 15 No. 2	Canada, Ottawa	1986
6	Water quality and urbanization in Latin	BARTONE C.R.	Water International, 15	USA	1990

America

37	Lexico hidrogeologico	GONZALEZ N./ HERNANDEZ M.A./ VILELA C.R.	C.I.C.P.B.A.	Argentina	1986
45	Estudio de hundimiento y balance de los acuiferos subterraneos a la ciudad de Mexico	HERRERA I./ YATES R./ HENNART J.P	I.I.M.A.S. - UNAM	Mexico	1982
69	Water and sanitation: CIDA development issues paper	PROFESSIONAL SERVICES BRANCH	CIDA	Canada	1988
50	Environment and the poor: development strategies for a common agenda	JEFFREY H./ LEONARD AND CONTRIBUTORS	U.S. - Third world policy perspectives overseas development council	USA	1989
47	Groundwater exploration in the central zone of La Pampa province	HERRERO J.J.	UNESCO / International Association of Hydrogeologists	Holland	1983
29	Diagnostico de los problemas de explotacion de aguas subterraneas como fuente de agua potable en Bolivia	FOSPOR S.	Comunicacion tecnica 535 - CEPIS-OMS-OPS	Peru, Lima	1989
49	Chemical Nightmare	JACKSON J. et al	Between the lines	Canada, Waterloo	1982
27	Hydrogeology of the Parana Medio region	FILI M.	UNESCO / International Association of Hydrogeologists	Holland	1983
85	Underground water in volcanic rocks	VELASQUEZ E.	UNESCO / International Association of Hydrogeologists	Holland	1983