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PLANNING AND DESIGN OF URBAN WATER SUPPLIES

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I PLANNING WATER SUPPLIES

1. Introduction

In the development of metropolitan areas, there is one important and common factor directly responsible for the rapid advance or stagnation of such urban communities. This agent is the availability of sufficient water and the possibility of its use for domestic and industrial purposes. For this reason we have to emphasize the high priority that should be given to planning sound water systems for urban communities and their development by stages if we want to have an orderly expansion and sanitation as a final result of such urban concentrations.

Apart from these considerations we face another universal problem consisting of an accelerated growth of urban population to the detriment of the rural increase. The world population grows at an average rate of approximately 1.7 per cent per year while the urban centres grow at a rate of over 3 per cent. This difference in the rate of growth explains the

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dangerous velocity of increase of urban population against the slow advance in rural areas. The fact of accumulation of people in urban centres is called "implosion".

At the beginning of the XIX Century only 2 per cent of the world population lived in communities which could be classified as cities and there were only fifty cities that had more than 100 000 inhabitants. By the end of the XXI Century the world will have increased its population to six billions of which 60 per cent will live in urban districts.

With this information in hand we can predict an urban population over three billions at the end of our century. Other social investigators forecast this population to be 2.5 billions. At present the urban world population is above 1.2 billions and very likely will get to 1.7 billions in ten years more.

The tendency of the world's urban population growth for the next ten years produces an increase of around forty millions per year as a conservative average figure while the predicted maximum is over ninety millions per year.

There is no doubt that we are suffering an explosive increase of urban population all over the world and this fact should govern the planning for future expansion of basic sanitary services.

Another important reference to this problem is found in the reports of international agricultural experts that emphasize the decrease of handwork needed in rural areas for efficient farm production due to mechanization of land production and improvements in farming procedures. Farming experts predict that 8 per cent to 12 per cent of the total world population devoted to agricultural production will satisfy the future demand, leaving the rest to be concentrated in urban communities.

From the available information regarding population movements and tendencies in the world, a country can be defined as urbanized country in saturation stage and without sizable increase, when 80 per cent of its population is concentrated in communities of over 5 000 inhabitants.

Some countries have already reached this urban concentration as Australia for climatic conditions. Others are getting near to it as in United States of America with around 70 per cent urban population producing megalopolis (union of two or more large metropolises). Some other countries have industrial areas well developed having urban concentrations around 80 per cent, although the country as a whole is far from this figure as is the case of Sao Paulo, Brazil.

Large cities in Latin America are growing at a dangerous, accelerated velocity which is out of control, like Caracas in Venezuela which has a present population five times larger than twenty years ago. Mexico D.F. in Mexico has increased its population three times in the same period. Bogota in Colombia and Santiago in Chile have doubled their population during the last fifteen years.

In Latin America 230 million inhabitants are having water problems that require a capital investment of over four billions dollars to cover their water needs during the next thirty years.

2. Demographic Factors

A decrease in birth rates is observed in countries with high cultural level due perhaps to the fact that with the cultural advance children are no longer considered as productive beings but expensive consumers. The birth rate in Europe is 19/1000 when in Asia it is 42/1000 and in Africa it is 46/1000.

Other demographic studies[1] show that the birth rate is also deteriorating with the increase of urban concentration according to the following chart:

Urban Population in the country per cent	Number of countries	Birth Coefficient per thousand
30 - 40	12	42.2
41 - 50	5	39.1
51 and more	5	38.4

The population of a country is determined by census which should be performed at least once every ten years. It is of common practice to carry out selective surveys to study several changing factors like birth rates, death rates and migration, specially in large countries with many millions of inhabitants like Russia, India, etc. Nevertheless one has to bear in mind that selective surveys can give reliable information when they cover at least 10 000 single investigations to be applied to a universe at most twenty times larger.

3. **Demographic Investment**

The production growth (P.G.) can be rendered in per capita terms for a given country or region in order to introduce the human aspect of the development. Furthermore, the annual rate of growth can be lower, equal, or larger than the production growth index.

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[1] Demographic Year Book - 1962. All countries of Asia, Africa and Latin America included, except Japan, Israel and Argentina.

For seventy-one countries of Asia, Africa and Latin America the following table of population for the period 1960-1965 has been compiled:

Average annual rate of population growth per cent	Number of countries
0.0 - 0.4	0
0.5 - 0.9	1
1.0 - 1.4	2
1.5 - 1.9	8
2.0 - 2.4	23
2.5 - 2.9	14
3.0 - 3.4	16
3.5 - 3.9	6
4.0 - 4.4	1

In this table we can see that 85 per cent of the countries have a growth over 2 per cent per year and 33 per cent of the countries have 3 per cent and more. Among this last group are several Latin American countries like Dominican Republic, El Salvador, Hondura, Nicaragua, Costa Rica and Venezuela.

Due to the decrease of death rate the annual population growth will increase more rapidly than before unless a clear reduction of birth rate takes place. If we compare the above mentioned figures with the average population growth of Western Europe, we conclude that the countries of Asia, Africa and Latin America are growing three to four times faster.

It is well known that the increase of population requires considerable capital investment even if we insist in remaining with the actual standard of living, without considering the need for improving such standards which, in most cases, is low.

We call demographic capital investment the expenditure that is needed for construction of schools, hospitals, land reclamation and urbanization, housing and expansion of industries, to cover the demand of the population growth. The higher the rate of population growth the higher is the demographic capital investment and greater the share of such expenditure taken out of the country's total income.

The economic figures given by several studies carried out in developing countries show that increase of 1 per cent in population requires the expenditure of 4 per cent of the national income for demographic investment.

When the population increase is in the range of 2 to 3 per cent, the demographic investment is 8 to 12 per cent of the national income and when the population growth is 4 per cent there is a need of 16 per cent of the national income to be used for demographic investment.

When there is a 3 per cent of population increase, as is the case in Latin America, the demographic investment should amount to an increase of 12 per cent of the national income. When this amount equals the total national income there is no remaining income for capital investment.

As a result of this situation the standard of living of the population remains practically the same and the scope of economic development is limited or deteriorates. When this condition happens, the governments prefer to reduce the necessary demographic investment, postponing the construction of schools, hospitals, housing, community water and sewerage facilities, leaving a limited amount for increase of industries and basic production units and hoping that extra revenues coming from such capital investment will be available in the future for demographic investment.

4. Solution of Water Problems

We believe that the delay in solving the water problems satisfactorily is due, to a great extent, to the lack of basic information in City Master Plans regarding urban developments and to the absence of continuity in city planning. On the other hand there is, from the technical point of view, a scarcity of experienced professionals to tackle properly the planning, design, construction and operation of water systems. We expect a significant improvement in the national water supply planning when the problems of salt water conversion will be solved at competitive unit prices.

A well designed and constructed city water supply will not serve fully its purpose if there is not a good and efficient organization at national or local level to operate and maintain such service.

The operation and maintenance of water supply systems is of paramount importance and, in the final analysis, it is the visible contact with the community to serve. A poor operation and lack of maintenance can render deficient service, receiving complaints from the public, destroying confidence and good relationship with customers and making null the effort put on designing and the construction investment.

5. <u>House Connections</u>

Some countries have developed good public water supply programmes but, in some cases, the necessary importance has not been given to the promotion of facilities for house connections schemes.

When there is no house connection promotion in developing countries the statistic figures show a large amount of population served because of the area covered by the public water system, but in practice there are far less inhabitants really connected to the public water system.

This fact leads to the suggestion of a thorough revision of the national, regional and municipal water construction programmes giving emphasis to the proper use of the public water facilities already available before enlarging the area covered by the water net.

It is of common practice to extend the city water and sewer service to new areas to satisfy the insistent demand of the real estate officers or of government housing authorities for new settlements but frequently forgetting that there is no more water available at the source or the sewer mains are already flowing at full capacity. This pleasing attitude from water authorities damage normal service to the community who will suffer from a scarcity of water and congestion of sewers.

6. City Water Programmes

The extension of city water and sewer services should be made according to Master Plans that contemplate the enlargement of their basic facilities with the increase of demand.

In recent international meetings[1] it was established that the allocation of 8 per cent of the total national product (T.N.P.) for public health and national education programmes (social sector) in developing countries with economy in expansion, will allow such countries to become part of the group of nations where the basic needs are solved and all the people have the same opportunity to enjoy the benefits of economical and social development.

Within the 8 per cent of T.N.P. suggested to be invested in the social sector, 0.5 per cent of such T.N.P. can be identified for national water and sewerage construction programmes. When making the suggestion to separate 0.5 per cent of T.N.P. for a minimum national water and sewerage construction programme we had in mind the effect of such investment in the commercial, industrial, and sanitary fields that will increase the T.N.P. value far beyond the investment made in the water field.

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[1] Water and Sewerage Symposium, Mexico, April 1966

On the other hand we have to bear in mind that water and sewerage system for urban areas are designed and constructed to serve an increasing population which is supported by the working opportunities available in the region. The conclusion is that the cities are the final result of the regional development and not the other way round. The people have the tendency to concentrate where there is a potential or a real demand for their services.

As an example of this phenomenon we can mention the case of Arica City in the northern part of Chile where city planning was developed according to the historical tendency of growth, but in the last ten years, a regional development programme was put into action and the city started to grow far beyond the expected increase and now a fifth revision of a new Master Plan is being made. A similar case is being produced in Rancagua City in the central part of Chile due to a new copper mine development.

We have found in Chile that the growth of cities has different rates, along the years, according to prevailing regional activities. For instance, in agricultural zones the growth is linear, in industrial areas the growth is parabolic more or less accentuated according to the type, number and size of the industries. In mining areas the city growth is also parabolic with irregular pattern according to the mining work intensity and the kind and size of the existing mines.

We also have areas in Chile where population is diminishing due to the reduction of mining activities (Tarapaca) and immigration from poor agricultural areas into industrial or commercial centres (Cautin).

It is then accepted that urban water demand is directly dependant on the regional development programme and consequently a priority plan should be established to cover the future water demand of new industries, housing projects, irrigation, mining, etc.

To illustrate this point we want to consider the water demand in Chile for the period 1960-1980 as a result of a national development plan which is being implemented:

Water Demand	Million Cubic Metres			
	1960	1980	Per cent of 1960 Total	Per cent increase 1960 - 1980
City water	500	1 200	4.25	140
Industrial	170	800	1.45	370
Mining	80	150	0.68	88
Irrigation	11 000	17 000	93.62	55
Total	11 750	19 150	100.00	

Hydraulic power water demand is not included as separate item because it is included in the irrigation project with only a few exceptions.

A great increase in city water demand and industrial demand is expected in the period 1960-1980. The actual total city water demand amounts to 12 m^3/second and it is expected to be 27 m^3/second in 1980, consequently, new water sources have to be developed to cover 15 m^3/second of more water demand in twenty years.

To satisfy this coming new water demand and at the same time improve the existing water systems, including the corresponding sewerage projects, there is a need of an annual investment of 30 million dollars per year (20 million dollars for water and 10 million dollars for sewers). This total annual investment represents approximately 0.5 per cent of T.N.P. Actually there are water and sewer projects under development for the equivalent to 0.2 per cent of T.N.P.

In countries that are in the same condition of Chile, where agricultural irrigation takes more than 90 per cent of the total water used, it is very important to start, early, multipurpose water projects taken by hydrological areas, in order to define priorities and water production programmes giving a clear first status to potable water demand.

II DESIGN OF URBAN WATER SUPPLY SYSTEMS

1. Introduction

The following four factors are the most important in the design of water systems:

- Demographic aspects of the country or community to be studied
- Public health aspects
- Financial and economic conditions
- Technical aspects

1.1 Demographic Aspects

We have tackled this problem in detail when referring to planning of water supply and sewerage systems. Nevertheless we have to emphasize the need of determining the future population to be served, within a reasonable period of time which should be not less than fifteen years and could reach thirty to fifty years. The estimated population has to be divided into districts and small areas that produce effluents to one main sewer.

1.2 Public Health Aspects

From the public health point of view the following matters have to be satisfied:

- Chemical and bacteriological quality of water
- Water production to satisfy the actual and future demand
- Piped service to the house and in the house
- Permanent service under pressure

1.2.1 Chemical and Bacteriological Quality of Water

The basic recommendation is to choose an intake of raw water that does not contain toxic chemical products or water that could have an ill effect on the human body.

We should reject raw water which is, in some degree, polluted with:

- Domestic sewage
- Industrial effluents
- Irrigation water containing residual of insecticides or pesticides, considered toxic to the human being

Anyhow, if in the vicinity of the urban population, there is no raw water available that is free from one or more of the above mentioned pollutants, we have to use the available raw water which should be processed through treatment plants to the point of producing potable water. This treatment costs money and this should be taken into consideration when making the cost estimate of the water system.

The public health authorities of the different countries have developed standards of quality to protect the population from water-borne diseases. Some of these standards are more strict than others in particular regarding the acceptable amount of toxic products. As an example we can mention the acceptable percentage of arsenic in drinking water; in USA the maximum accepted percentage is 0.05 ppm and a 0.01 ppm is recommended; in Argentina it is 0.12 ppm; in Chile it was 0.05 ppm and now it is 0.20 ppm and WHO recommends 0.20 ppm in the International Standards.

The international standards for drinking water recommended by WHO simplify the methods of inspection and suggest limits of tolerance which are more in accordance with the practical possibility of the developing countries. We believe that the adoption of these international standards will represent a big advance in the safety of the water used in metropolitan centres and will greatly assist programmes for the improvement and extension of existing services.

The difference observed in the acceptable amount of toxic material in water is due mainly to the acceptance of the human body and the amount which exists in the raw water available. For instance, the underground water in Argentina has a high content of arsenic and the superficial water from the Andes in the north part of Chile has also a high content of arsenic.

As a guideline in the selection of natural raw water for supplying an urban centre, it is important to fix certain limits of concentration of selective indexes. As a good example we can mention a tentative table recommended in the chilean standards:

	Raw Water		
	Good*	Fair**	Deficient***
1. BOD (5 days) Monthly average Max. daily	 0.75-1.50 mgr/lt 1.00-3.00 mgr/lt	 1.51-2.50 3.01-4.00	 2.55 4.10
2. B. Coli. M.P.N. 100 ml Monthly average Max. daily	 50-100 > 100 in 5%	 101-5 000 > 5 000 in 20%	 ≥ 5 000 > 20 000 in 5%
3. Dissolved oxygen Saturation	4.0 mgr/lt (min) ≥ 75%	4.0 min. ≥ 60%	4.0 prom. -
4. pH (average)	6.0-8.5	5.0-9.0	3.8-10.5
5. Chlorides	≤ 50 mgr/lt	51-250	> 250
6. Fluorides	< 1.5 mgr/lt	1.51-3.0	> 3.0
7. Iron Compounds	0 mgr/lt	0.005	> 0.005
8. Arsenic	≤ 0.2 mgr/lt	0.21-0.5	> 0.5
9. Colour	0-20	21-150	> 150
10. Turbidity	0-10	11-250	> 250

* Good . Raw water requiring only disinfection for use as drinking water.

** Fair . Raw water which requires standard treatment (sedimentation and filtration with disinfection) for use as potable water.

*** Deficient : Raw water which requires special treatment and disinfection for use as drinking water.

In regard to the bacteriological condition of drinking water practically all the public health services in the world have adopted standards of quality which demand certain number of samples to be tested monthly in order to assure the good bacteriological quality of the water delivered through the water system. These standards run from two samples monthly for a population of 2 000 inhabitants to ten samples daily for a city of 1 000 000 persons. These samples have to be lower in pathogenic concentration than certain fixed acceptable maximum concentration.

1.2.2 Water Production to Satisfy the Actual and Future Demand

The amount of water which should be supplied by a system expressed in average consumption per inhabitant per day depends on the distribution of the centres to be served, and whether these are of residential, industrial, commercial or mixed nature. To this amount should be added provision for fire protection which is essential for large metropolitan centres.

The amount of water needed per head in residential areas varies considerably according to climatic conditions, habits and customs of the populations, economic level and the existence of sewers. Similarly, the percentage of hourly maximal consumption varies in relation to the daily average consumption. These basic data have repercussions on engineering design and consequently on the cost of the most advisable system. In general, we may say that the average daily consumption may be estimated within the range of 100 to 2 000 litres per day per person. It is difficult to define industrial consumption in terms of litres per person per day, nevertheless, it is advisable to express it in terms called "equivalent population". The large variety of industries existing all over the world and the new ones which are emerging as civilization advances make it very difficult to produce a long-term forecast of the amount of water that should be reserved for industrial consumption in a metropolitan water supply system. Due to this difficulty, large industries are compelled sometimes to develop their own industrial supply and using the urban water system only for the limited consumption of the employees and workers. The lack of industrial connection to the metropolitan water system has an adverse repercussion on the financing of the urban water programme and its development.

When designing a metropolitan water system we should bear in mind that industry, in general, is a good customer of water supply systems and in some cases produces considerable revenues that makes it possible to improve and extend the existing services.

Even when it is difficult to establish the "equivalent population" for industries, it is convenient to predict some percentage figures compared with total consumption. In the United States the industries use from 15 to 65 per cent of the total urban consumption. In less industrialized regions, this percentage is considerably lower. In Santiago, Chile, the industrial consumption is around 10 per cent of the total amount distributed to the population.

Commercial Consumption: Is also variable reaching a maximum of 900 m^3/day/hectare in centres with a high commercial density. This daily consumption may lead to a maximum of 200-300 m^3/hour/hectare.

Public Use: Is the amount of water used for street cleansing, park irrigation and miscellaneous. It is generally accepted to be 5 to 10 per cent of total consumption.

Wastage: Is the amount of water lost due to poor pipe connections and house water connections. This volume could reach 5 to 20 per cent of the total amount of water delivered to the city. The following table is a résumé of all the variations of percentage in city water consumption:

Domestic use	30 to 70%
Commercial and Industrial use	6 to 65%
Public use	5 to 10%
Waste	5 to 20%

1.2.3 Piped Water

This is an indispensable requisite to assure that the water will reach the consumer in the acceptable condition in which it left the purification plant. All the risk of manipulation of such potable water must be avoided before it will serve its purpose and the only practical means is to conduct the water through a piped system under pressure. This piped system should go as far as the water faucets in the house. An external service such as the public faucets or outlets are not considered safe from a public health point of view. It is, however, a temporary solution for low class housing developments, and accepted as such in order not to increase the total cost of housing at the first stage of development. On the other hand a public faucet will not deliver enough water for the normal domestic consumption and certainly does not meet the minimum sanitary requirements.

1.2.4 Permanent Service Under Pressure

The volume of water supplied to the metropolitan areas should be sufficient at all times to cover the needs and to maintain a continuous pressure service. Unfortunately very often we come across water systems which have not been planned with the necessary capacity to cover the near future expansion and whose sources are inadequate even to cover the present demand, while the distribution system itself is insufficient. To avoid these problems we have repeatedly recommended that the town planning schemes should be carefully reviewed to assure that proper attention is given to the future expansion of housing developments and industrial programmes. We are aware that in practice we have generally fallen short in forecasting the growth of our large communities, since very little consideration has been given to the impact of regional development and the attraction exercised by the large metropolitan areas on the people looking for better opportunities and prospects in their work.

These short-sighted water projects offer the opportunity for all kinds of protests from the metropolitan citizen and very often we can detect cross connections due to the sudden drop of pressure in water mains. This type of service is insanitary and insecure and should be condemned by the public health authorities.

1.3 Financial and Economic Conditions

The present tendency of having urban water supply services self-supporting both technically and financially is becoming more and more accepted all over the world. In order to attain this goal it is most important to include environmental sanitation professionals in the national or regional planning teams. With a voice at the highest planning level better opportunities may be expected for securing the capital investment needed for an early and complete solution of the metropolitan water problems. It is most important that sanitary engineers get prepared for selling their sanitation programmes to technical, administrative and political circles which will secure the proper public support. It is unreasonable for sanitation experts to be left with the guilty feeling that they have not done their part to achieve a significant advance in the supply of water for the inhabitants of the world as the first measure in sanitation, while satelites and space transports are being launched to reach other planets.

The economic sacrifices made by the whole of mankind and the time and effort devoted by its technicians in order to excel one another in the scientific and space field, is in striking contrasts to the slow progress towards a solution and the modest resources we are willing to make available for overcoming the basic problems of our existing communities. If we assume that 200 litres/day/capita is the average water consumption needed in the world we conclude that new sources and enlargements have to take place by the year 2000 to produce an extra flow of 3 000 m^3/second of water and make it potable to run into thousands of water supply systems.

This is only to serve 70 per cent of the urban population estimated at the end of the century[1].

In 1964, fifteen dollars were estimated as average per capita cost for supplying water to urban centres suffering of deficient or non-existent water services[2]. This unit cost represents an investment of 7.5 million dollars per m^3/second and 22 500 million dollars per 3 000 m^3/second. Eight per cent of this amount is needed for water supply of the urban areas in Latin America.

The Inter-American Economic and Social Council (CIES) established the goal of supplying water and sewerage to 70 per cent of the urban population and to 50 per cent of the rural population within a period of ten years. It looks like the urban goal will be reached but the rural one is far from its original aim.

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1 R. Casanueva, 1965, Resources and Financing for Water Supply Programmes, Washington D.C., PASB.

2 B.H. Dieterich - J.M. Henderson, 1963, WHO, Geneva, Publ. Hlth Pap. No. 23 (Urban Water Supply Conditions and Needs in Seventy-five Developing Countries).

In order to investigate the financial resources necessary to develop a programme of water supply we should study the different components of the water supply cost. This cost can be divided as follows:

- Study and design (engineering)
- Construction and supervision of work
- Operation and maintenance of the system
- Improvements and developments
- Cost of financing

In a self-supporting water administration, these five items of the total cost of the system are covered by water rates, according to the amount of water consumed and/or by land taxation or a combination of both.

Water rates have to be adjusted to the cost of production and service, specially in those developing countries with high influence of the inflation factor. In some of the Latin American countries, with an important annual inflation factor, water rates have deteriorated badly to the point that actually they cover only part of the cost of operation and maintenance. This condition should be avoided early, before it interferes seriously with proper management of the system, by introducing approved higher rates.

In reference to this subject we want to mention the exact approach to the problem made by E.R. Black, ex-President of the International Bank for Reconstruction and Development, when he emphasized the fact that permanent expansion of public utility service was an unavoidable requisite for the economical development of any country, and that the cost of these services should be paid, in their greatest part, by those interested by means of adequate rates[1].

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[1] A. Wohman (1960), Technical Financial and Administration Aspects of Water Supply in the Urban Environment in the Americas. AIDIS Proceedings Vol. 13, April 1960, 291.

The most important part of the expenses is in the construction of works and for this part of the problem there exist various financing schemes which mobilize the national resources (governments, municipalities, banks, private capital) and external credits.

For developing countries it is advisable to request loans from external sources for their water systems up to the amount needed for obtaining the material and equipment not available or produced in the country, and only in cases justified by the national or regional planning board, it would be advisable to request foreign loans to cover also part of the national cost (foreign currency to be converted to national). This limitation is justified for the national need of avoiding the inflation factor.

1.4 Technical Aspects

The technical consideration for the design of water systems have changed according to the development of new materials and equipment and the advance of the knowledge of sedimentation and filtration.

All these techniques are compiled by the professional organizations responsible for water systems in the various countries and are produced under the so called "Technical Standards for Design of Water Systems". These standards have to be revised from time to time in order to introduce the new developments.

The action of the engineer in city water system can be divided in four periods as follows.

- Planning and development of water programmes
- Design of water systems
- Construction of water systems
- Operation and maintenance

1.4.1 Planning and Development of Water Programmes

These activities define the need of the work to be carried out and the terms of reference as well as the size of the job followed by a feasibility study including the economical, financial and technical aspects. The planning covers also the promotion of such improvements at all levels in particular at the community level.

1.4.2 Design of Water Systems

This includes the engineering and the structural plans, technical and administrative specifications, geological ground classification, amount of work to be done with cost estimates and the topographical bench marks in the field to start construction.

At the end of the programme and design of work it is good practice to prepare a summary with the principal characteristics and bases of design following the general list given below:

i. **Basic Technical Design Data**

- Forecast of period of service (years)
- Actual population to be served (inhabitants)
- Future population to be served (inhabitants)
- Summer population to be served (inhabitants)
- Per capita actual consumption (litre/day/hour)
- Per capita future consumption (litre/day/hour)
- Summer per capita consumption (litre/day/hour)
- Maximum daily per capita consumption (litre/day/hour)
- Maximum hourly per capita consumption (litre/day/hour)
- Fire consumption per hydrant (litre/second)
- Fire hydrants working simultaneously (number)
- Fire duration (design) (hours)
- Water elevation (hours)
- Regulation volume (m^3)

- Reserve capacity (m^3)
- Total storage capacity (m^3)
- Maximum water system pressure (m)
- Minimum water system pressure (m)
- Maximum pipe velocity (m/second)
- Minimum pipe velocity (m/second)
- Coagulation period (minutes)
- Settling period (hours)
- Superficial settling rate $(m^3/m^2/day)$
- Filtration rate $(m^3/m^2/day)$
- Contact period of disinfectant (minutes)

ii. Technical Characteristics of the Water System

- Intake (superficial, underground)
- Water treatment and disinfection
- Water mains (gravity, pressure)
- Water pumps capacity
- Pumping programme
- Water storage capacity - number of storage tanks
- Pipe system: diameter, capacity, velocity, loss of head, length
- Characteristic and capacity of water treatment plants
- Valves: number, diameter and characteristic
- Number of hydrants
- Area covered by the water system
- Cost of work
- Annual cost of operation

iii. Sanitary Characteristics

- Chemical and bacteriological quality of water
- Capacity of water intake works
- Sanitary protection of water intake
- Physical and biological purification needed

1.4.3 The Construction of Water Systems

This comprises the call for bids, the financial time-table and the proper utilization of funds, organization of field work and supervision of the job, proper technical tests and final reception of the work done.

1.4.4 Operation and Maintenance

This means the technical and administrative measures to run the system properly and give a good and efficient service to the community according to the standards established in the design.

2. Water Systems

2.1 Water Works

We can divide a water system in four characteristic items as follows:

- Intake works
- Pumping stations (when necessary)
- Treatment and disinfection (when necessary)
- Distribution systems

2.1.1 Intake Works

The intake of water can use either surface or underground water available.

Surface water intakes may be of different designs according to the topographical and hydrological conditions. Variations can take the following patterns:

i. Submerged intake

ii. Lateral intake

iii. Floating intake with mechanical elevation

iv. Mobile intake with mechanical elevation

v. Spring intake

vi. Filtration galeries

vii. Cisterns (rain water)

viii. Sea water conversion by different methods

Underground water intakes may take the following patterns:

i. Pit well (excavated)

ii. Drill well

2.1.2 Pumping Stations

The water supply systems by gravity are desirable, whenever possible, because they are more simple and economical in their construction, operation and maintenance and they also offer more security for continuous service.

Unfortunately the gravity systems are not always possible, specially in large cities located in high altitudes where surface water is not abundant due to the restricted hydrological area available. Nevertheless there are some privileged cities located at high altitudes with ample gravity water service, for example La Paz, Bolivia, in South America at 3 000 m above sea level.

On the other hand we have also examples of urban communities located at high altitudes that were served by gravity flow but are no longer able to satisfy the actual demand by using the same limited intakes due to the rapid increase of urban population. They are now anxiously seeking for water available at lower levels and will have to pump such water to the gravity centre of demand (e.g. Caracas, Mexico D.F.).

The establishment of pumping stations for water supplies are now in clear competition against the construction of long gravity mains in large urban communities for the following reasons:

i. Pumping stations have a relatively low cost and can be expanded according to the needs of service. On the other hand, the gravity water mains have to be designed and constructed for future population covering periods of thirty to fifty years. According to the economical feasibility study, only in few cases the forecast period can be reduced to fifteen or twenty years.

ii. The cost production of electric power is being reduced due to the advance of techniques, consequently reducing the operation cost of pumping stations.

iii. The permanent improvement in efficiency, durability and simplicity of water pumps and motors.

iv. The improvement and availability of technical personnel in most of the semi-advanced developing countries makes it possible to operate mechanical equipment. At the same time there is a big advance in technical assistance provided by the manufacturers due to the tight commercial competition.

If after a feasibility study water elevation plants are desirable we have to decide whether one elevation plant for raw water and gravity flow to the water treatment and distribution is more convenient than two plants, one for raw water to the treatment plant, and another from there to the water distribution tanks.

In both cases it is advisable to observe the following recommendations:

i. When planning the water system of urban communities it should be clearly established where, when and how to construct the pumping stations as well as the volume of water to be handled in order to cover the security requirements of permanent water service to the cities.

ii. To elaborate the engineering design of pumping stations carefully, taking into consideration the need of proper equipment for local conditions including the automation that will be acceptable in the area served.

iii. To construct the pumping stations following the recommendations given by the manufacturers of the equipment selected and in accordance with the structural practice accepted by the authorities concerned.

iv. To organize and keep a good operation and maintenance team of workers to secure an efficient service.

v. Whenever possible it is convenient to install vertical pumps with electric motors operating at a higher level to be out of danger of floods.

vi. It is also desirable to have available two different sources of power.

2.1.3 Water Treatment Plants and Disinfection

In the production of potable water from raw water which needs adjustments to remove settleable solids and germs of disease we can distinguish the following necessary elements.

- Sand settling tanks (when necessary)
- Conditioning structures (when necessary)
- Settling tanks (primary - secondary)
- Filters
- Disinfection

2.1.3.1 Sand Settling Tanks

They are designed to settle coarse and heavy particles, easily falling down at low water velocity, the diameters of which are around 1 to 0.085 millimetres.

It is known by experience that this phenomenon takes place when the water velocity and vertical settling velocity ratio is less than 20. The length of settling tanks depends on the necessary settling period.

2.1.3.2 Conditioning Structures

These are the different devices used for mixing the coagulants with the water to be treated and can be classified into two types:

i. Hydraulic : including hydraulic jumps, around the end of the tanks (vertical and horizontal) and injection of coagulant under pressure.

ii. Mechanics : including coagulated feeding at the suction side of water pumps, mechanical agitators and compressed air agitators.

Each of these methods have their advantages and restrictions that the designing engineers should evaluate carefully to select the most desirable one for the existing local conditions.

2.1.3.3 Settling Tanks

They are designed to settle the remaining particles in the water body of less than 0.085 millimetres in diameter which can settle by gravity or by mixing with others (flocculation) to produce the proper weight for settling. The water velocity in settling tanks should run around 0.018 m/second to 0.003 m/second. The velocity for settling particles is 20 to 40 times less than the water velocity accepted.

The efficiency coefficient of settling tanks is 60 per cent to 80 per cent with a reduction in bacteriological count of 60 per cent to 80 per cent and over 60 per cent reduction in B. Coli content.

2.1.3.4 Filters

These are required to retain the fine floc and particles in suspension which cannot settle. The maximum turbidity accepted in water to be filtered is 15 to 20 ppm.

The filtration rate for low sand filters is around 4 m^3/m^2/day and for high rate filters can be up to 120 m^3/m^2/day, improving thirty times the initial figure. The number of filtration units is selected for economical reasons.

Low rate filters have a very good coefficient for reduction of bacteriological count, being over 98 per cent and are well recommended for small water treatment plants. Their cost of operation is low compared with high rate filters.

High rate filters have a bacteriological efficiency less than 80 per cent and their construction and operation costs are higher than low rate filters. This type of filters are recommended for large installations due to the small space needed.

There are a large number of commercial patents of rapid filters differing on the mechanical equipment used, in the composition and amount of filtration material and in the disposition of filter beds.

The selection of the proper rapid filter to be used is left to the evaluation and study of the designing engineer who has to weigh all the factors involved.

The disinfection of treated water can be produced by the addition of commercial disinfectants available including chlorine and ozone in different forms. In the Americas chlorine is generally used with residual values of 0.05 to 0.1 ppm for health security.

The chlorine demand in water depends principally on the water temperature (T) and its pH value. In order to estimate the amount of chlorine generally necessary in different kinds of water we can mention the following figures:

- Chlorine demand in surface water 1.5 to 2.0 ppm
- Chlorine demand in lake water without excess of algea 1.0 to 1.5 ppm
- Chlorine demand in filtered water, groundwater and spring water 0.5 to 1.0 ppm

2.1.4 Water Distribution Systems

The water pipe diameters are determined by the amount of water to flow in the pipes and the loss of head accepted to maintain the designed minimum pressure in the water net.

During the process of designing we have calculated the future population of the urban area to be served by the water system which is designated as the "design population". To this population is assigned a projected per capita water consumption, which can be predicted using the increasing water demand factor during the last twenty or more years, taking into consideration the improvement in water use expected in the future.

If this statistical information is not available for the urban community to be served we can use special formulas deducted in other regions or areas with similar water problems. For example, the use of the formula deducted by Capen has been recommended in Chile with slight modifications.

The original Capen formula is :

$$d = 54 \sqrt[8]{P}$$

(d = per capita consumption in gallons/day)

(P = population in thoudands)

The Capen formula has been modified for the chilean conditions as follows[1]:

$$d = 80\sqrt[8]{P}$$

(d = per capita consumption in litres/day)

(P = population)

A per capita water consumption of 300 litres/day has been deducted in Chile for a population of 50 000 inhabitants applying the above mentioned formula.

When the per capita water consumption is mentioned it refers to the mean value. The maximum could reach up to 150 per cent of the above mentioned average and the minimum could be 50 per cent of the same. The hourly consumption of water also varies with the different sizes of the community. In a small community (1 000 inhabitants) the maximum hourly water consumption could reach 300 per cent over the average and in large urban communities this maximum could reach only 150 per cent of the same.

2.2 Water Pipes

The material to be used for water pipes depends very much on the quality of the water, the internal and external pressure and the aggressivity of the ground surrounding the pipes.

Another important consideration is the kind of pipe manufactured locally and ready available which can be paid in local currency.

2.3 Hydraulic Formulas

It is accepted in the design of water pipe systems that use be made of the rational formulas within the terms of reference of which they were deducted. It is of common practice to use the following formulas: Blasius, Prandel, Nikuradse, von Karman, Poiseuille and Colebrook.

[1] E. Munizaga, 1967, Seminar of Water Standard, University of Chile, Santiago.

Also the use of the following empirical formulas for the design of water nets is generally accepted: Scobey, Manning, Luding and William and Hazen.

For open channels design it is common practice to use the following formulas: Manning and Ganguillet and Kutter.

2.4 Regulation Tanks

Regulation water tanks are designed to co-ordinate the intake water flow and the consumption in the water pipe system. These tanks should also have enough capacity to accumulate water for fire protection and accidents on the main feeder.

It is often required in Latin America that the regulation tanks capacity should not be less than 20 per cent of the maximum daily water consumption for the projected future population to be served.

The water system should be able to supply the maximum hourly demand of the day of maximum consumption for the projected future population.

2.5 Maximum and Minimum Water Pressure

A minimum water pressure in the system is required in order to have continuity of service and water pressure in the house connections.

On revising many water design standards we have found variations of this minimum pressure from 10 to 14 metres.

The acceptable maximum water pressure depends mainly on the kind of pipe to be used and the general layout of the water system. For urban communities in flat areas the accepted maximum water pressure varies from 40 to 60 metres. For communities developed on hilly land the maximum water pressure could reach 90 metres.

The minimum water pressure accepted for fire hydrant is found to be different in the various design standards reviewed, the range is from 2.5 to 4 metres.

2.6 Minimum Pipe Diameters

Minimum pipe size accepted is also a figure that varies according to the different design standards and it goes from 2" to 4" according to the urbanization standard of the community.

As an example we can mention that the minimum pipe size of 2" is accepted in Chile for water system serving low class housing units consisting of one-story small house with only one water outlet. In the other cases 3" is the minimum water pipe diameter accepted.