CHAPTER 1 QUANTITY OF WATER

1.1. General Introduction

All human beings require water and food to sustain life. Many experts have produced figures that clearly demonstrate that physical output and life expectancy are much increased by adequate and safe supply of water. Indeed, one of the millennium development targets under Goal 7, i.e. Environmental sustainability, is to halve, by 2015, the proportion of people without sustainable access to safe drinking water and sanitation.

Most of the world still does not have centralized water supply with connections to individual households according to the World Health Organization roughly 1.1 billion of the world's 6 billion people do not have access to an improved water supply.

The estimated water supply coverage for Ethiopia is 41.2 % for rural and 78.8 % for urban without considering the functional condition of the facilities making the country's water supply coverage 47.3 %.

- *Drinking water* is water used for domestic purposes, drinking, cooking and personal hygiene;
- Safe drinking water is water with microbial, chemical and physical characteristics that meet WHO guidelines or national standards on drinking water quality;
- Access to water-supply services is defined as the availability of at least 20 liters per person per day from an "improved" source within 1 kilometer of the user's dwelling.
- An "improved" source is one that is likely to provide "safe" water, such as a household connection, a borehole, etc.

An improved water supply is defined as:

- Household connection
- Public standpipe
- Borehole
- Protected dug well
- Protected spring
- Rainwater collection

Only 48% of the world's population is connected at the household level.

Water supply engineering deals with the planning, design, construction, operation and maintenance of water supply systems. While planning a water supply project care should be taken to come up with economical, socially acceptable, and environmentally friendly schemes that meet the present as well as future requirement. A water supply system is designed to attain the following objectives:

- To supply safe and wholesome water to the users
- To supply water in adequate quantity
- To make water readily available to the users to encourage personal and household hygiene

The system comprises the following major elements:

- Source (groundwater or surface water)
- Raw water collection structures (intake structure, transmission line)

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- Treatment plant
- Distribution systems (pipes, pumps, reservoir, different appurtenances)

1.2. Water supply system planning

Water supply system planning involves identification of service needs, evaluation of options, determination of optimal strategy to meet services, and development of implementation strategies. The planning exercise involves collection of pertinent data, consideration of relevant factors, and preparation of project documents and cost estimates.

Required data sets

a) Geological data: Geological data and survey of ground water is done in the vicinity of the area, to know the quantity of available water at various depths in the ground.

b) Hydrological data: The hydrological and the available surface water sources data in the vicinity of the area are collected to determine the quantity of water available in the surface sources.

c) Sanitary conditions of the area: The sanitary condition of the area and data regarding possible sources of water pollution are collected for deciding the preventive measures against them.

d) Topography of the area: Survey works are done to prepare the topographical map of the area, showing elevation of the various points, density of population in the different zones. This map helps in deciding the position of intake works and treatment plants type of system to be adopted for conveyance and distribution of water.

e) Legal requirements: Applicable legal requirements like land use, social and environmental considerations, etc.

f) Public opinion: Data on the public opinions are also collected, regarding the project.

g) Level of water demand: Current and future demands of water.

h) Existing water supply system: If the project is concerned with expansion of the existing water supply scheme, the details of collection, conveyance, treatment and distribution systems should be thoroughly studied. The spare capacity of the existing water works should also be utilised.

Factors to be considered:

The following factors should be considered and kept in mind during preparation of the water supply design project:

i) ***Population.*** Factors affecting the future increase in the population are to be studied and taken into account while determining the future population for the design work.

ii) ***Per capita Requirement***. The per capita demand of water should be determined by taking into account the various factors and will be according to the living standard of the public and the number and type of industries, number and type of the commercial establishments in the town etc.

iii) ***Public places, parks, institutions etc***. Water is required for the development of parks, fire fighting and so many other purposes at public places.

iv) ***Industries***. The water requirement of the existing industries as well as future industries should be thoroughly determined and, provision made in the project accordingly.

v) ***Sources of water***. Detailed survey of the various sources of water available in the vicinity of the area should be made. Survey of the existing sources should also be made. In case the present source of water is well, which cannot cater for future needs, alternative water source should be considered.

vi) ***Conveyance of water***. Conveyance of water from source to water treatment units depend on the relative levels of the two points. It may flow directly by gravity, if source is at higher elevation. In case pumping is required, then the capacity of the pumps should be determined.

vii) ***Quality of water***. The analysis of the raw water quality should be made to know the various impurities present in it, and to decide on the required treatment processes.

viii) ***Treatment works***. The various sizes and number of treatment units in the water works depend on the quality and quantity of raw water and the limiting water quality standards.

ix) ***Pumping units for treated water***. The pump-house is designed by considering the future population water demand. The required number of pumps is installed in the pump house for the present water pumping requirement, with provision of 50% stand-by pumps for emergency.

x) ***Storage***. The entire city or town should be divided into several pressure zones and storage facility should be provided in each zone. The altitude of the storage facility should ensure supply of water at the required pressure.

xi) ***Distribution system***. The distribution system should be designed according to the master plan of the town, keeping in mind the future development. The design of the main should be based on peak hour demands. The design of the pipes should also take into account the fire demand.

xii) ***Economy and reliability***. The water supply scheme should be economical and reliable. It should draw sufficient quantity of water from the source at cheapest cost and the purification should meet desired limits.

Project documents:

In general the following drawings of the project are prepared and used for estimating the cost and execution of the project:

- Topographical Map: Showing roads, location of water sources, limits of the town with its roads, layout of pipes from the source to water works etc. at a scale of 1:500
- Site Plan: Showing the location of the scheme and the area to be served is also prepared at a scale of 1: 500
- Contour Map: The contour map or plan of the entire area is prepared at a scale of 1: 100, showing the location of water mains, sub-mains, branches, valves, fire hydrants, pumping stations, service reservoirs, roads, streets etc.
- Flow Diagrams: The flow diagram of the entire scheme is prepared showing the sequence of operations and all aspects of the scheme. The approximate sizes of purification and distribution mains are also given on these diagrams.
- Detailed Drawings: The detailed drawings of the various units and components of the scheme are prepared.

The cost of a water supply project depends on the types of water sources, length of rising mains, required treatment processes, pumping and storage facilities, distribution system etc. The cost of various parts of the water supply schemes may be taken approximately as follows for guidance.

Table 1.1 Approximate percentage costs of water supply components

S.N	Items	Cost (% of the total cost)
1	Pumping stations	18 %
2	Storage facilities	6 %
3	Treatment plants	10 %
4	Distribution system	50 %
5	Intakes and buildings	2 %
6	Source development	9 %
7	Water meters and other contingencies	5 %
	Total	100 %

Note: The above percentages are for guidance and can be used for preparation of preliminary estimates for administrative approval

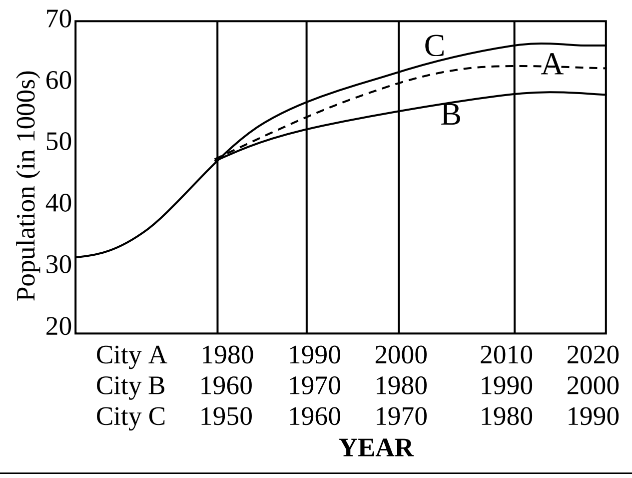
A preliminary report for the purpose of determining the most economical, dependable, and safe community water supply should be prepared. The contents of the report may cover the following areas:

- existing water supply facilities and need for expansion
- design periods
- population projections, water consumption projections, and design capacities
- water quality objectives and source selection
- site selection for intake, treatment plant and conveyance systems
- Evaluation of raw water quality and treatment processes
- Preliminary design and cost estimates
- Recommended capital improvement plan
- Environmental impact assessment

1.3. Population forecasting

Elements of a water supply system are designed to serve present and future population. It is therefore necessary to forecast the future population using suitable methods (see Table 1.2). The date in the future for which the projection is made depends on the component of the system which is being designed.

Table 1.2 Methods of population forecasting

Method	**Description**	**Basic equation or procedure**
Arithmetic	Population is assumed to increase by a constant rate. Average value of proportionality constant over several decades may be used. The method is commonly used for short-term estimates (1-5 years).	$\frac{dP}{dt} = K_a; \quad P_t = P_2 + K_a(T - T_2)$ $K_a = \frac{P_2 - P_1}{T_2 - T_1}$
Geometric	Population is assumed to increase in proportion to the number present. Average value of proportionality constant over several decades may also be used. The method is commonly used for short-term estimates (1-5 years).	$\frac{dP}{dt} = K_g P; \quad \ln P_t = \ln P_2 + K_g(T - T_2)$ $K_g = \frac{\ln P_2 - \ln P_1}{T_2 - T_1}$
Decreasing rate of increase	Population is assumed to reach some limiting value or saturation point.	$\frac{dP}{dt} = K_d(P_s - P); \quad P_t = P_2 + (P_s - P_2)(1 - e^{-kd(T - T_2)})$ $P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$ $K_d = \frac{1}{T_2 - T_1}\ln(\frac{P_s - P_2}{P_s - P_1})$
Logistic curve fitting	It is assumed that the population growth follows a logistical mathematical relationship.	$P_t = \frac{P_s}{1 + ae^{b(T - T0)}}$ $a = \frac{P_s - P_0}{P_0}; \quad b = \frac{1}{n}\ln\left[\frac{P_0(P_s - P_1)}{P_1(P_s - P_o)}\right]$ n = constant interval between T_1, T_2, T_3
Graphical comparison	The procedure involves the graphical projection of the past population data for the city being studied. The population data of other similar but larger cities are also plotted in such a manner that all the curves are coincident at the present population value of the city being studied. These curves are used as guides in future projections.	
Ratio	In this method, the population of the city in question is assumed to follow the same trends as that of the zone, region, or country.	From the population records of a series of census years, the ratio is plotted and then projected to the year of interest. From the estimated population of the zone, region, or country and the projected ratio, the population of the city concerned is obtained.

1. **Arithmetic method**: here it is assumed that the rate r of population growth is constant. Mathematically the hypothesis may be expressed as

$$\frac{dp}{dt} = k \quad \text{.................................... (1.1)}$$

k is determined graphically of from successive population figures. And the future population is given by

$$P_t = P_o + kt \quad \text{................................ (1.2)}$$

Where, P_t = population at some time in the future

P_o = present population

t = period of projection

2. **Geometric or uniform percentage method**: This hypothesis assumes a rate of increase which is proportional to the population.

$$\frac{dp}{dt} = kp \quad \text{.................................... (1.3)}$$

Integrating equation (1.3) yields

$$\ln p = \ln p_o + k\Delta t \quad \text{......................... (1.4)}$$

This hypothesis could be verified by plotting recorded population growth on semi-log paper. If a straight line can be fitted to the data, the value of k can be estimated from the slope.

3. **Geometric increase method**: in this hypothesis, the average percentage of the last few decades is determined, and the forecasting is done on the basis that percentage increase per decade will be same. Thus, the population at the end of n years or decades is given as

$$P_n = P_o\left(1 + \frac{AGR}{100}\right)^n \quad \text{..................... (1.5)}$$

Where, AGR = annual growth rate of the population

P_n = population at time n in the future

P_o = present population

n = periods of projection

Example 1.1. The census figure of a city shows population as follows

Present population	50000
Before one decade	47100
Before two decades	43500
Before three decades	41000

Work out the probable population after one, two and three decades using arithmetic increase and geometric increase method.

Example 1.2. The Annual Growth Rate of a town in Ethiopia is 3.5%. Assuming the present population of the town (in 2007) is 4500, what would be the population in 2020?

Example 1.3. The following data shows the variation in population of a town from 1944 to2004. Estimate the population of the city in the year 2014 and 2019 by arithmetic and geometric increase methods.

Year	1944	1954	1964	1974	1984	1994	2004
Population	40185	44522	60395	75614	98886	124230	158800

Good judgment in population estimation should be used to avoid underestimation or overestimation. Those methods that are inapplicable to the situation under consideration should be dropped. The population growth of an area with limited land and resources for future expansion may be modelled by the declining growth or logistic curve method. An area with abundant potential for land and resources may follow geometric type of population growth. In nearly all cases, comparison is made to the recorded growth patterns of similar cities.

1.4. Population density

It is important to know the population density in different parts of a city in order to estimate the flows and to design the distribution network. Population density varies widely within a city, depending on the land use.

1.5. Components of water demands

Water demand is defined as the volume of water required by users to satisfy their needs. It is often considered to be identical to water consumption, although conceptually the two terms do not have the same meaning. This is because in some cases, especially in rural parts of Ethiopia the theoretical water demand considerably exceeds the actual consumptive water use. Design of a water supply scheme requires knowledge of water demand and its timely variations. The demand for public water is made of authorised consumption by domestic and non-domestic consumers and water losses. Various components of a water demand are residential, commercial, industrial, public water uses, fire demand and unaccounted for system losses.

Residential Water Demand

This includes the water required in residential buildings for drinking, cooking, bathing, lawn sprinkling, gardening, sanitary purposes, etc. The amount of domestic water consumption per person varies according to the living standards of the consumers. In most countries the residential demand constitutes 50 to 60% of the total demand. Domestic in-house consumption for average middle class properties having a kitchen, a bath facility and waterborne sanitation falls into a fairly narrow range of 120 – 160 lcd, irrespective of climate or country.

Suggested design allowances of domestic per capita consumptions by dwelling type are given in Table 1.3.

Table 1.3 In-house domestic water and standpipe demand- suggested design allowances (lcd)

Type of property	Design allowances (lcd)
Tenement blocks:	
• Block centrally metered	160
• Individual household metered	130
Tenement blocks, high density occupation with one shower, one Asian toilet, one or two taps:	
• Building centrally metered or free	130
• Individual metered	90
Lowest income groups: low grade tenement blocks with one or two room dwellings and high density occupation:	
• Communal wash rooms	110
• One tap and one Asian toilet per household	90
• One tap dwellings with shared toilet or none; dwellings with intermittent supplies	50-55
Standpipe supplies	
• Urban areas with no control	70
• Rural areas under village control	45

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• Rural with washing and laundering facilities at the standpipe • Absolute minimum for drinking, cooking and spillage allowance	65 25

Table 1.4 gives typical average domestic demand in our country.

Table 1.4 Typical average domestic water demand

Town	Unit	2007	2017	2027
House Connection	lpcd	90	100	110.0
Own Yard Connection	lpcd	25.4	31.7	38.0
Shared Yard Connection	lpcd	16.9	18.9	21.0
Public Tap	lpcd	11.3	12.6	14.0

Non-Domestic Water Demand

Non domestic demands comprise:

Commercial water demand includes that portion required by establishments such as hotels, shopping centres, service stations, movie houses, airports, etc. The commercial water demand may vary greatly depending on the type and number of establishments.

Industrial water demand constitutes water consumptions by various industries like tanning, brewery, dairy, etc.

The quantity of water required for commercial and industrial purposes can be related to such factors as number of employees, floor area of the establishment, or units produced.

Institutional water demand: Hospitals, schools, universities, government offices, military establishments, etc.

Agricultural water demand: use for crops, livestock, horticulture, greenhouses, dairies and farmlands.

Estimating industrial demand can be complex. The same industry in a different environment can use significantly different quantities of water per processed unit. This could be due to variations in production process, water use, water efficiency, water recycling and possibly tariff structure influence the specific usage by an industry.

Public water use

This is the quantity of water required for public utility purposes and includes water for public institutions like schools, watering of public parks, washing and sprinkling of roads, use of public fountains, clearing wastewater conveyance, etc. Usually the demand may range from 2-5% of the total demand. Often the quantity of water used for public watering is only limited by the available supply. However, in some cities, raw water or 'grey water' is used for these purposes. Typical average public water uses are indicated in Table 1.5 below.

Table 1.5 Typical Institutional and Public water demands

Category	Typical rate of water use per day	
Day schools	5	l/pupil
Boarding schools	50	l/pupil

Hospitals	100	l/bed
Hostels	80	l/bed
Mosques	5	l/visitor
Cinema houses	5	l/visitor
Offices	5	l/person
Public baths	100	l/visitor
Hotels	100	l/bed
Restaurant/Bar	10	l/seat
Camp	60	l/person
Prison	30	l/person

Unaccounted system losses and leakage

This includes water lost or unaccounted for because of leaks in main and appurtenances, faulty meters, and unauthorized water connections. These and other components of non-legitimate use are categorised as:
Apparent losses: source and supply meter errors, unauthorised or unrecorded consumption, and
Real losses: leakage from transmission and distribution mains and service pipes upstream of consumers' meters, from valves, hydrants and washouts and leakage and overflows from the water utility's storage facilities.
These losses should be taken in to account while estimating the total requirements. Losses and leakage may reach as high as 35% of the total consumption in the case of Addis Ababa.

Fire demand

The quantity of water required for fire protection should be easily available and kept always stored in storage reservoirs. Fire hydrants are usually fitted to the water mains and fire-fighting pumps are connected to these mains by the fire brigade personnel when a fire breaks out. Although the actual amount of water used for fire fighting in a year is small, the rate of use is high. The following empirical equation may be used to estimate fire demand.

National Board of Fire Underwriters (NBFU)

$$Q_F = 231.6\sqrt{P}(1-0.01\sqrt{P})$$

Where, Q_F = is fire demand (m^3/hr); P = Population in 1000's.
Examples of required fire flow for single family residential areas not exceeding two stories in height is given in Table 1.6.

Table 1.6

Distance b/n dwelling units (m)	Required fire flow m^3/min
Over 30.5	1.9
9.5 – 30.5	2.8-3.8
3.4 – 9.1	3.8-5.7
3.1 or less	5.7-7.6
Continuous building	9.5

The fire flow should be available from 2 hrs to 10 hrs depending on the estimated fire demand (Table 1.7).

Table 1.7 Fire flow rate and duration

Required fire flow, m^3/min	Duration, hrs
7.6	2
11.3	3
15.1	4
18.9	5
22.7	6
26.5	7
30.2	8
34.0	9
37.8	10

Factor Affecting Water Use

1. Climatic conditions
2. Cost of water
3. Living Standards
4. Industries
5. Metering water lines
6. Quality of water supply
7. Size of city

1.6. Variations in water demand

Due to various factors there are great fluctuations in seasonal, daily and hourly water demands. Such factors include size of the city, climatic conditions, living standard, industrial and commercial activities, pressure in the distribution system, system of supply, cost of water, policy of metering and method of charging.

The water demands used for the planning and design of water supply systems include annual average day demand, maximum day demand and peak hour demand.

Annual average day demand ($Q_{day\text{-}avg}$) represents the average daily demand over a period of one year. For economical calculations and fire fighting.
Maximum day demand ($Q_{day\text{-}max}$) represents the amount of water required during the day of maximum consumption in a year. Important for water treatment plants and water storages.
Peak hour demand ($Q_{hr\text{-}max}$) represents the amount of water required during the maximum hour in a given day. Important for design of distribution systems.
Coincident draft (Q_{cd}). This is the sum of maximum daily demand, $Q_{day\text{-}max}$, and the fire demand (Q_F).

The fluctuations among the above demands can be conveniently expressed as a ratio to the mean average daily flow. These ratios vary greatly for different localities and as such a careful study for each locality must be made from past data to develop these fluctuations. In the absence of past data, the following empirical formula may be used.

$$p = 180t^{-0.10}$$

Where,

p = percent of annual average demand for time, t
t = time, d. The time t in days varies from 2/24 to 365.

The peak hourly demand may be estimated as 150 percent of maximum day demand.

Estimating per capita water demand

Design of water supply system components requires knowledge of per capita water demands at the initial and design years. The following procedure is generally used to project the water demand;

1. Estimate the future population of the service area for the initial and design years.
2. From the historical annual water usage data and population served, determine the average per capita daily water demand.
3. Plot annual average per capita demand versus the year.
4. Considering water-conservation efforts and other general trends in water demand, establish for the desired future years the annual average per capita water demands.
5. Develop the ratio of maximum day (of the year) usage record and the annual average day data developed in step 2.
6. Establish an appropriate maximum day to average day ratio for future projections.
7. From records taken during high-demand hours, establish the ratio of peak hour to maximum day demand.
8. Determine the projected average day, maximum day, and peak hour demands.

1.7. Design periods for water supply components

A water supply system is generally designed and constructed to serve the needs of a community for a number of years in the future. The initial year is the year when the construction is completed and the initial operation begins. The design year is the year when the facility is expected to reach its full design capacity and further expansion may become necessary.

Several factors need to be considered to select an appropriate design period. The major ones include:

- Useful life of structures
- Convenience of future expansion
- Likelihood of obsolescence by technological advancement
- Trends in interest rates, cost of present and future construction, and availability of funds
- Growth pattern of the community

The design period and design capacity of the different system components (Fig. 1.1) may vary as indicated in Table 1.8.

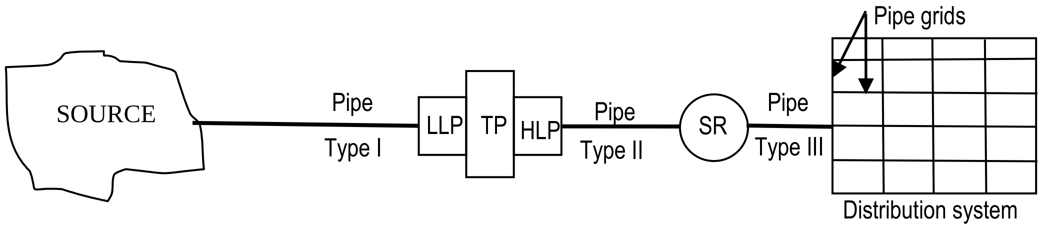

Fig. 1.1 Typical water supply system (LLP: Low Lift Pump; HLP: High Lift Pump; TP: Treatment Plant; SR: Service Reservoir)

Table 1.8 Design periods and design capacities of water supply components

Component	**Special characteristics**	**Design period (Years)**	**Design capacity**
Source: Groundwater Surface sources (River intakes, Reservoirs)	✓ Easy to expand ✓ Uneasy to expand	5-10 20-50	$Q_{day\text{-}max}$ during the design period
Pipe mains (Type I and Type II)	✓ Long life ✓ Cost of material is only a small portion of the cost of construction	>25	✓ $Q_{day\text{-}max}$ ✓ Suitable velocities under all anticipated flow conditions
Treatment plant	✓ Expansion is simple	10-15	$Q_{day\text{-}max}$ or $1.6Q_{day\text{-}avg}$ whichever is greater
Pumping units	✓ Easy to modify and expand	10	LLP: $2Q_{day\text{-}avg}$ or $4/3Q_{day\text{-}max}$ whichever is greater HLP: $3Q_{day\text{-}avg}$ or $4/3Q_{day\text{-}max}$, whichever is greater
Service reservoir	✓ Long life ✓ Easy to construct ✓ Relatively inexpensive	Very long	Design should consider: ✓ Hourly fluctuations of flow ✓ The emergency reserve ✓ The provision required when pumps satisfy the entire days demand in less than 24 hrs. ✓ The fire demand.
Type III pipe and distribution pipes	✓ Long life ✓ Replacement is very expensive	Indefinite	$Q_{hr\text{-}max}$ or $Q_{day\text{-}max}+Q_F$, whichever is greater (calculated for anticipated maximum growth)

1.8. Water conservation

Water conservation in homes, commercial establishments, and industries is gaining popularity. It reduces both water use and wastewater generation. For water conservation efforts to be successful, cooperation of the public and local government commitment are required. Methods of water conservation include:

- Following water saving practices (e.g. turn off water while soaping in a shower)
- Use of water saving devices (water saving toilets, shower heads, etc.)
- Reducing water pressure
- Metering water usage
- Leak detection and repair
- Recycling of "grey water"