Chapter 3

WATER REQUIREMENT

3.1 Introduction

Water conveyance in a water supply system depends on the rates of production, delivery, consumption and leakage (Figure 3.1).

Water production (Q_{wp}) takes place at water treatment facilities. It normally has a constant rate that depends on the purification capacity of the treatment installation. The treated water ends up in a clear water reservoir from where it is supplied to the system (Reservoir A in Figure 3.1).

Water delivery (Q_{wd}) starts from the clear water reservoir of the treatment plant. Supplied directly to the distribution network, the generated flow will match certain demand patterns. When the distribution area is located far away from the treatment plant, the water is likely to be transported to another reservoir (B in Figure 3.1) that is usually constructed at the beginning of the distribution network. In principle, this delivery is done at the same constant flow rate that is equal to the water production.

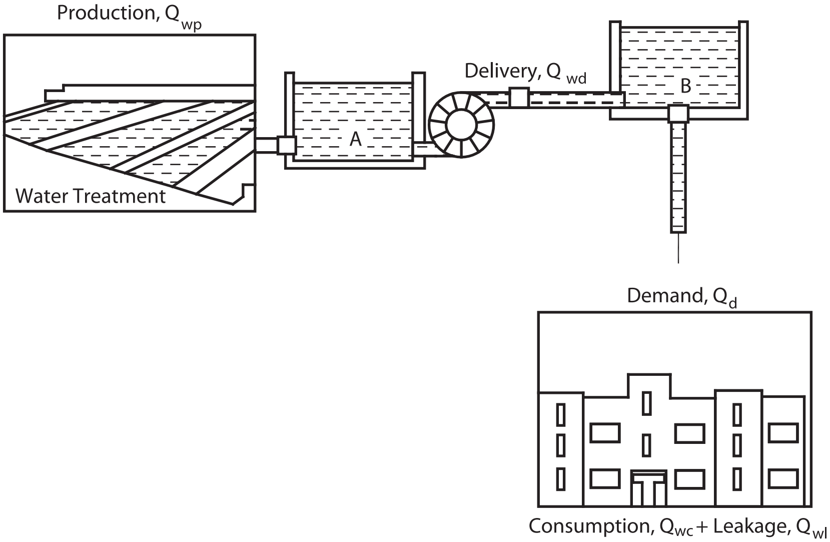


Figure 3.1: Flows in water supply systems.

Water consumption (Q_{wc}) is the quantity directly utilised by the consumers. This generates variable flows in the distribution network caused by many factors: users' needs, climate, source capacity etc.

Water leakage (Q_{wl}) is the amount of water physically lost from the system. The generated flow rate is in this case more or less constant and depends on overall conditions in the system.

In theory, the term (Q_d) coincides with water consumption. In practice, however, the demand is often monitored at supply points where the measurements include leakage, as well as the quantities used to refill the balancing tanks that may exist in the system. In order to avoid false conclusions, a clear distinction between the measurements at various points of the system should always be made. It is commonly agreed that $Q_d = Q_{wc} + Q_{wl}$. Furthermore, when supply is calculated without having an interim water storage, i.e. water goes directly to the distribution network: $Q_{wd} = Q_d$, otherwise: $Q_{wd} = Q_{wp}$. Water demand is commonly expressed in cubic meters per hour (m^3/h) or per second (m^3/s), litres per second (l/s), mega litres per day (ML/day) or litres per capita per day (l/c/d or lpcpd). Typical Imperial units are cubic feet per second (ft^3/s), gallon per minute (gpm) or mega gallon per day (mgd). The mean value derived from annual demand records represents the average demand. Divided by the number of consumers, the average demand becomes specific demand (unit consumption per capita).

Apart from neglecting leakage, the demand figures can often be misinterpreted due to lack of information regarding the consumption of various categories. Table 3.1 shows the difference in the level of specific demand in Netherlands depending on what is, or is not, included in the figure. The last two groups in the table coincide with commercial and domestic water use, respectively.

Table 3.1: **Water demand in the Netherlands in 2001**

	Annual ($10^6 m^3$)	**Q_d(l/c/d)[1]**
Total water delivered by water companies	1247	214
Drinking water delivered by water companies	1177	202
Drinking water paid for by consumers	1119	192
Consumers below 10,000 m^3/y per connection (metered)	940	161
Consumers below 300 m^3/y per connection (metered)	714	122

Source: Ratnayaka, Brandt et al. 2009

[1] Based on total population of approx. 16 million

Accurate forecasting of water demand is crucial whilst analysing the hydraulic performance of water distribution systems. Numerous factors affecting the demand are determined from the answers to three basic questions:

- *For which purpose is the water used?* The demand is affected by a number of consumption categories: domestic, industrial, tourism etc.
- *Who is the user?* Water use within the same category may vary due to different cultures, education, age, climate, religion, technological process etc.
- *How valuable is the water?* The water may be used under circumstances that restrict the demand: scarce source (quantity/quality), bad access (no direct connection, fetching from a distance), low income of consumers etc.

Answers to the above questions reflect on the quantities and moments when the water will be used, resulting in a variety of demand patterns. Analysing or predicting these patterns is not always an easy task. Uncritical adoption of other experiences where the field information is lacking is the wrong approach; each case is independent and the conclusions drawn are only valid for local conditions.

Variations in water demand are particularly visible in developing countries where prosperity is predominantly concentrated in a few major, usually overcrowded, cities with peripheral areas often having restricted access to drinking water. These parts of the system will be supplied from public standpipes, individual wells or tankers, which cause substantial differences in consumption levels within the same distribution area. Figure 3.2 shows average specific consumption for a number of large cities in Asia.

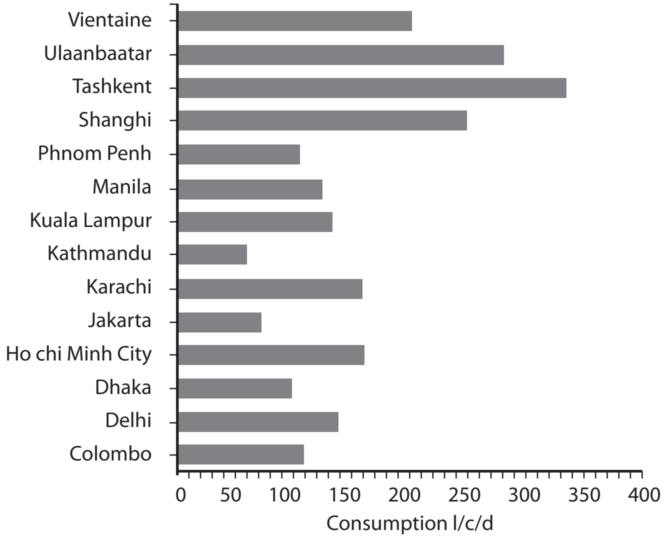


Figure 3.2: Specific consumption in Asian cities (McIntosh 2003).

Comparative figures in Africa are generally lower, resulting from the range of problems that cause intermediate supply, namely long distances, electricity failures, pipe bursts, polluted ground water in deep wells, etc. A water demand survey was conducted for the region around Lake Victoria, covering parts of Uganda, Tanzania and Kenya. The demand where there is a piped supply (the water is tapped at home) was compared with the demand in un-piped systems (no house connection is available). The results are shown in Table 3.2.

Table 3.2: **Specific demand around Lake Victoria in Africa**

	Piped (l/c/d)	**Un-piped (l/c/d)**
Average for the entire region	45	22
Average for urban areas (small towns)	65	26
Average for rural areas	59	8
Part of the region in Uganda	44	19
Part of the region in Tanzania	60	24
Part of the region in Kenya	57	21

Source: IIED 2000

An unavoidable component of water demand is *unaccounted-for water* (UFW), the water that is supplied 'free of charge'. In quite a lot of transport and distribution systems in developing countries this is the most significant 'consumer' of water, accounting sometimes for over 50% of the total water delivery.

Causes of UFW differ from case to case. Most often it is a leakage that appears due to improper maintenance of the network. Other nonphysical losses are related to the water that is supplied and has reached the taps, but is not registered or paid for (under-reading of water meters, illegal connections, washing streets, flushing pipes, etc.)

3.2 Factors Affecting per Capita Consumption

The various factors and the way they affect the per capita water consumption are as follows:

- **Size of the city:** The per capita use of the water tends to be higher to large cities that in small town. Average the large cities are about 100 gpcd as compared with 60 gpcd for the country as a whole. The different results from greater industrial use more parks and other public facilities, greater commercial use perhaps more loss and waste in the larger cities.

- **Characteristics of the people:** Water use is influenced by the economic status of the people. The per capita use of water in slum areas will be much less than that in the high-class residential areas, because of extra water use for gardening, car washing, air conditioning and for some ornamental display.

- **Climate conditio:** More water is used in warm, dry climate than humid and cold climate for bathing, lawn and garden watering, air conditioning, etc. In extremely cold climate water may be wasted at faucets prevent freezing of pipes.

- **Commerce and industries:** Industry uses large volumes of water in its manufacturing process and in supporting operations. Indeed the production of foodstuffs, metals, chemicals and other basic commodities calls for a tonnage of water that far exceed the combined tonnage of other raw use materials. The actual amount depends on the extent of the manufacturing and the type of industry. Some industries develop their own water supply and place little or no demand on the municipal water supply system. Zoning of the city affects the location of the industries and may help in estimating future industrial demands; Commercial areas include office buildings, warehouses and stores. The per capita demand in such area is not high, averaging about 10 gpcd per full time employee. However, the amount of water used by industry varies widely.
  About 80 percent of industrial water is for cooling and need not be of high quality. Water used for process purposes or for boiler feed must be of good quality. In some cases, industrial water must have a lower content of dissolved salts than can be permitted in drinking water. The location of industry is often much influenced by the availability of water supply. However, when other factors dictate the plant location, water requirements may be reduced far below the industry average.

  Commercial consumption of water is sometimes taken as 50,000 to 100,000 gallons per acre per day.

- **Pressure of water:** The rate of use of water increases when the pressure on the distribution system is increased. This is due, in part, to the greater loss through lakes and the greater amount run to waste through open faucets. Increases in the rates of use of water with pressure have been known to reach 30 percent for a change from 25 to 45 psi. This fact should lead the designer to provide the lowest pressure that well gives satisfactory service. Excess pressure means wastage of water.

- **Quality of water:** Improvement of the quality of the water supply will result in increased use of water in part because of the availability of the water for more uses and a feeling of safety on the part of the public in using it. The water quality also influences the industrial uses. If the water is soft and meets the standards of industrial water, the rate of consumption will be high.

- **Sewerage facilities:** The effect of the installation of sewers in a city is to increase the rate of water consumption because of increase is plumbing facilities. In an unsewered area water consumption generally does not exceed 15 gpcd while in a sewered area the consumption will be equal or exceed 50 gpcd.

- **Water rate and metering:** If the cost of water is high, people may become more conservative in water use and industries will often develop their own supply to obtain cheaper water. Metered consumers are more likely to repair leaks and use water with discretion. The installation of meters in some countries has reduced water use by as much as 40 percent.

- **Nature of supply:** If the water is supplied intermittently (only for some parts of the day), the rate of water consumption is much less than when it is supplied continuously. This may due to decrease in losses and other wasteful uses.

- **Availability of the private supplies:** The demand for municipal water is reduced to a great extent if the people and industrialists develop their own private supplies from wells, springs, etc. High cost and poor quality of municipal supply often compel the users to go for own supplies.

- **Efficiency of the management:** The efficiency of the management of a water-works will affect consumption by controlling loss and waste; there is always some leakage in the collection, transportation and distribution system of water-works. In a well-managed water-works, loss and waste of water through leaks and faulty joints are carefully controlled; therefore, an efficient water-works management will keep the loss and waste of water to a minimum.

- **Number of inhabitants:** This would affect the extent to watch use is made of private water supply. Thus, in large cities, the public water supply is almost a necessity while in small towns and villages, the private supplies may remain in use even long water the introduction of the public water supply. Generally per capita consumption is found to increase with increase of population.

3.3 Consumption Categories

3.3.1 Water use by various sectors

Water consumption is initially split into domestic and non-domestic components. The bulk of non-domestic consumption relates to the water used for agriculture, occasionally delivered from integral water supply systems, and for industry and other commercial uses (shops, offices, schools, hospitals, etc.). The ratio between the domestic and non-domestic consumption in The Netherlands in the period 1960–2000 is shown in Figure 3.3.

In the majority of developing countries, agricultural- and domestic water consumption is predominant compared to the commercial water use, as the example in Table 3.3 shows. However, this water is rarely supplied from an integral system.

In warm climates, the water used for irrigation is generally the major component of total consumption; Figure 3.4 shows an example of some European countries around the Mediterranean Sea: Spain, Italy and Greece. On the other hand, highly industrialised countries use huge quantities of water, often of drinking quality, for cooling; typical examples are Germany, France and Finland, which all

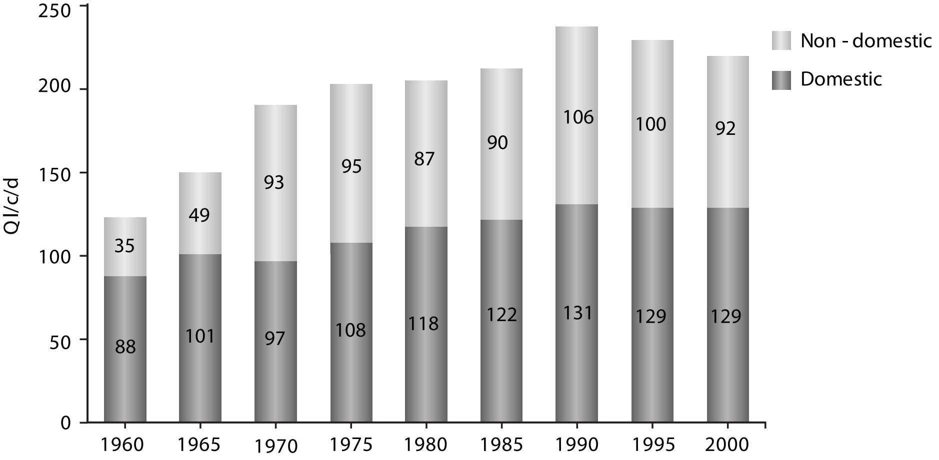


Figure 3.3: Domestic and nondomestic consumption in The Netherlands (Ratnayaka, Brandt et al. 2009)

Table 3.3: Domestic vs. non-domestic consumption in some African states

Country	Agriculture (%)	Industry (%)	Domestic (%)
Angola	76	10	14
Botswana	48	20	32
Lesotho	56	22	22
Malawi	86	3	10
Mozambique	89	2	9
South Africa	62	21	17
Zambia	77	7	16
Zimbabwe	79	7	14

Source: SADC 1999

use more than 50% of the total consumption for this purpose. Striving for more efficient irrigation methods, industrial processes using alternative sources and recycling water have been and still are a concern in developed countries for the last few decades.

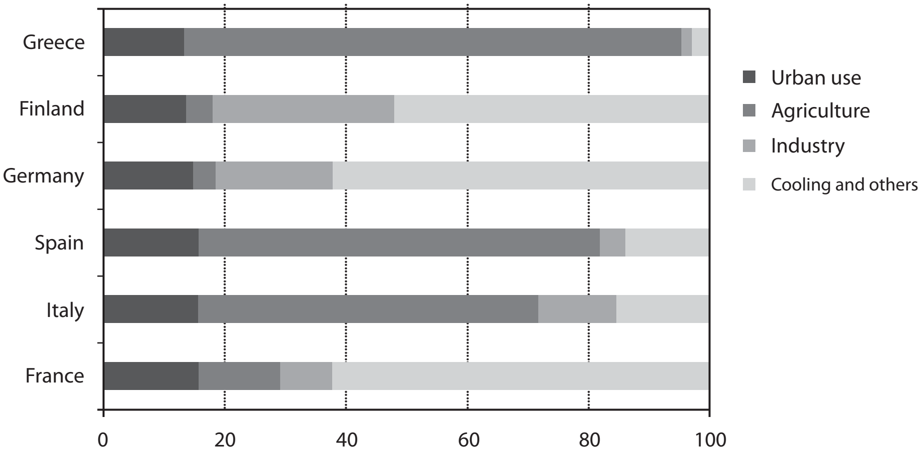


Figure 3.4: Water use in Europe (Ratnayaka, Brandt et al. 2009)

3.3.2 Domestic consumption

Domestic water consumption is intended for toilet flushing, bathing and showering, laundry, dishwashing and other less water intensive or less frequent purposes: cooking, drinking, gardening, car washing, etc. The example in Figure 3.5 shows rather wide variation in the average domestic consumption of some industrialised countries. Nevertheless, in all the cases indicated 50–80% of the

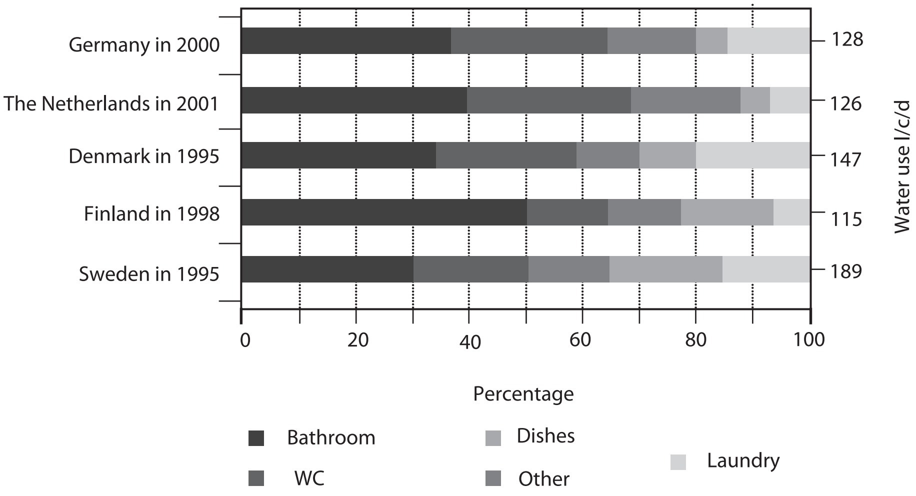


Figure 3.5: Domestic water use in Europe (Ratnayaka, Brandt et al. 2009)

total consumption appears to be utilised in bathrooms and toilets.

The habits of different population groups with respect to water use were studied in The Netherlands (Achttienribbe 1993). Four factors compared were age, income level, household size and region of the country. The results are shown in Figure 3.6. The figures prove that even with detailed statistics available, conclusions about global trends may be difficult. In general, the consumption is lower in the northern part of the country, which is a less populated, mostly agricultural region. Nonetheless, interesting findings from the graphs are evident: the middle-aged group is the most moderate water user, more frequent toilet use and less frequent shower use is exercised by older groups, larger families are with a lower consumption per capita, etc.

In cases where there is an individual connection to the system, the structure of domestic consumption in water scarce areas may well look similar but the quantity of water used for particular activities will be minimised. Apart from the change of habits, this is also a consequence of low pressures in the system directly affecting the quantities used for showering, gardening, car washing, etc. On top of this, the water company may be forced to ration the supply by introducing regular interruptions. In these situations consumers will normally react by constructing individual tanks. In urban areas where supply with individual tanks takes place, the amounts of water available commonly vary between 50–100 l/c/d.

3.2.3 Non-domestic consumption

Non-domestic or commercial water use occurs in industry, agriculture, institutions and offices, tourism, etc. Each of these categories has its specific water requirements.

Water in industry can be used for various purposes: as a part of the final product, for the maintenance of manufacturing processes (cleaning, flushing, sterilisation, conveying, cooling, etc) and for the personal needs (usually comparatively marginal). The total quantities will largely depend on the type of industry and technological process. They are commonly expressed in litres per unit of product or raw material. Table 3.4 gives an indication in general for a number of industries; an extensive overview can be found in HR Wallingford (2003).

Water consumption in agriculture is mainly determined by irrigation and livestock needs. In peri-urban or developed rural areas, this demand may also be

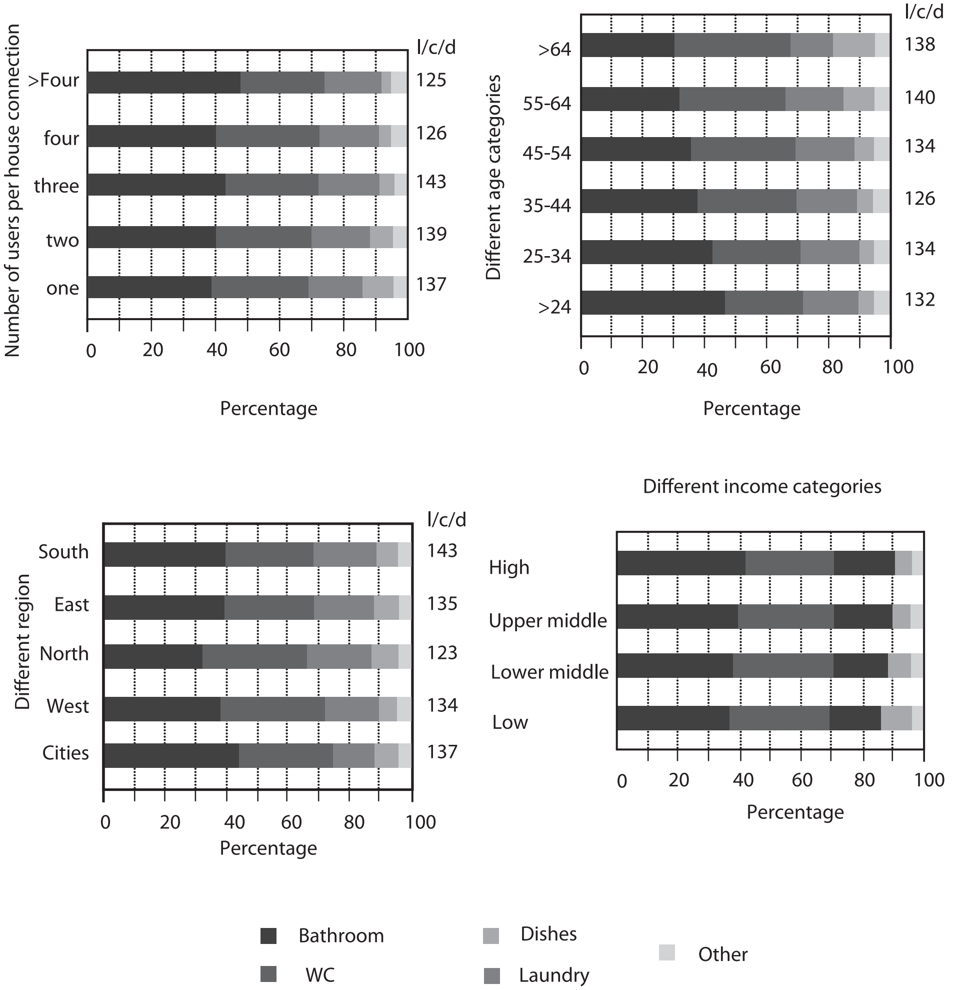


Figure 3.6: **Structure of domestic consumption in The Netherlands (Achttienribbe 1993)**

Table 3.4: Industrial water consumption

Industry	Litres per unit product
Carbonated soft drinks[1]	1.5-5 per litre
Fruit juices[1]	3-15 per litre
Beer[1]	4-22 per litre
Wine	1-4 per litre
Fresh meat (red)	1.5-9 per litre
Canned vegetables/fruits	2-27 per kg
Bricks	15-30 per kg
Cement	4 per kg
Polyethylene	2.5-10 per kg
Paper[2]	4-35 per kg
Textiles	100-300 per kg
Cars	2500- 8000 per car

Source: Wallingford 2003

[1] Largely dependent on the packaging and clearing of bottles, [2] Recycled paper.

supplied from the local distribution system. The amounts required for irrigation purposes depend on the plant sort, stage of growth, type of irrigation, soil characteristics, climatic conditions, etc. These quantities can be assessed either from records or by simple measurements. A number of methods are available in literature to calculate the consumption based on meteorological data. According to Brouwer and Heibloem (1986), the consumption is unlikely to exceed a monthly mean of 15 mm per day, which is equivalent to 150 m^3/d per hectare. Approximate values per crop are given in Table 3.5. Water required for livestock depends on the sort and age of the animal, as well as climatic conditions. Size of the stock and type of production also play a role. For example, the water consumption for milking cows is 120–150 l/d per animal, whilst cows typically need only 25 l/d (Brandon 1984) (Table 3.6).

Commercial consumption in restaurants, shops, schools and other institutions can be assessed as a total supply divided by the number of consumers (employees, pupils, patients, etc.). Accurate figures should be available from local records at water supply companies. Some indications of unit consumption are given in Table 3.7. These assume individual connection with indoor water installations and waterborne sanitation, and are only relevant during working days.

Table 3.5: Seasonal crop water needs

Crop	Season (days/years)	Consumption (mm/season)
Bananas	300-365	1200-2200
Beans	75-110	300-500
Cabbages	120-140	350-500
Citrus fruit	240-365	900-1200
Corn	80-180	500-800
Potatoes	105-145	500-700
Rice	90-150	450-750
Sunflowers	125-130	600-1000
Tomatoes	135-180	400-800
Wheat	120-150	450-650

Source: Wallingford 2003

Table 3.6: Animal water consumption

Animal	Litres per day
Cows	25-150
Oxygen, horses, etc	15-40
Pigs	10-30
Sheep, goats	5-6
Turkeys (per 100)	65-70
Chickens (per 100)	25-30
Camels	2-3

Source: Wallingford 2003

Table 3.7: Water consumption in institutions

Premises	Consumtion
Schools	25-75l/d per pupil
Hospitals	350-500l/d per bed
Laundries	8[1]-60 litre per kg washing
Small business	25l/d per employee
Retail shops/stores	100-135l/d per employee
Offices	65l/d employee

[1] Recycled water used for rising

Source: Wallingford 2003

Tourist and recreational activities may also have a considerable impact on water demand. The quantities per person (or per bed) per day vary enormously depending on the type and category of accommodation; in luxury hotels, for instance, this demand can go up to 600 l/c/d. Table 3.8 shows average figures in Southwest England.

Table 3.8: Tourist water consumption in Southwest England

Accommodation	Consumption (l/c/d)
Camping sites	68
Unclassified hotel	113
Guest houses	130
1 and 2 stars hotels	168
3, 4 and 5 star hotels	269

Source: Brandon 1984

Water consumption that does not belong to any of the above-listed groups can be classified as miscellaneous. These are the quantities used for fire fighting, public purposes (washing streets, maintaining green areas, supply for fountains, etc.), maintenance of water and sewage systems (cleansing, flushing mains) or other specific uses (military facilities, sport complexes, zoos, etc.). Sufficient information on water consumption in such cases should be available from local records.

Sometimes this demand is unpredictable and can only be estimated on an empirical or statistical basis. For example, in the case of fire fighting, the water use is not recorded and measurements are difficult because it is not known in advance when and where the water will be needed. Provision for this purpose will be planned with respect to potential risks, which is a matter discussion between the municipality (fire department) and Water Company. On average, these consumers do not contribute substantially in overall demand. Very often they are neither metered nor accounted for and thus classified as UFW.

Example 3.1: A water supply company has delivered an annual quantity of 80,000,000 m^3 to a city of 1.2 million inhabitants. Find out the specific demand in the distribution area. In addition, calculate the domestic consumption per capita with leakage from the system estimated at 15% of the total supply, and billed non-domestic consumption of 20,000,000 m^3/y.

Solution:

Gross specific demand can be determined as:

$$Q_{avg} = \frac{80{,}000{,}000 \times 1000}{1{,}200{,}000/365} \approx 183\ l/c/d$$

The leakage of 15% of the total supply amounts to an annual loss of 12 million m^3. Reducing the total figure further for the registered nondomestic consumption yields the annual domestic consumption of 80-12-20 = 48 million m^3, which is equal to a specific domestic consumption of approx.110 l/c/d.

3.4 Water Demand Patterns

Each consumption category can be considered not only from the perspective of its average quantities but also with respect to the timetable of when the water is used. Demand variations are commonly described by the *peak factors*. These are the ratios between the demand at particular moments and the average demand for the observed period (hour, day, week, year, etc.). For example, if the demand registered during a particular hour was 150 m^3 and for the whole day (24 hours) the total demand was 3000 m^3, the average hourly demand of 3000/24 = 125 m^3 would be used to determine the peak factor for the hour, which would be 150/125 = 1.2. Other ways of peak demand representation are either as a percentage of the total demand within a particular period (150 m^3 for the above hour is equal to 5% of the total daily demand of 3000 m^3), or simply as the unit volume per hour (150 m^3/h). Human activities have periodic characteristics and the same applies to water use. Hence, the average water quantities from the previous paragraph are just indications of total requirements. Equally relevant for the design of water supply systems are consumption peaks that appear during one day, week or year. A combination of these maximum and minimum demands defines the absolute range of flows that are to be delivered by the water company. Time-wise, we can distinguish the *instantaneous, daily (diurnal), weekly and annual (seasonal)* pattern in various areas (home, building, district, town, etc.). The larger the area is, the more diverse the demand pattern will be as it then represents a combination of several consumption categories, including leakage.

3.4.1 Instantaneous demand

Instantaneous demand (in some literature *simultaneous demand*) is caused by a small number of consumers during a short period of time: a few seconds or minutes. Assessing this sort of demand is the starting point in building-up the demand pattern of any distribution area. On top of that, the instantaneous demand is directly relevant for network design in small residential areas (tertiary networks and house installations). The demand patterns of such areas are much more unpredictable than the demand patterns generated by larger number of consumers. *The smaller the number of consumers involved, the less predictable the demand pattern will be.* The following *hypothetical* example illustrates the relation between the peak demands and the number of consumers. A list of typical domestic water activities with provisional unit quantities utilised during a particular period of time is shown in Table 3.9. Parameter Q_{ins} in the table represents the average flow obtained by dividing the total quantity with the duration of the activity, converted into litres per hour.

Table 3.9: **Example of domestic unit water consumption**

Activity	Total quantity (litres)	Duration (minutes)	Q_{ins} (l/h)
A- Toilet flushing	8	1	480
B- Showering	50	6	500
C- Hand washing	2	½	240
D- Face and teeth	3	1	180
E- Laundry	60	6	600
F- Cooking	15	5	180
G- Dishes	40	6	400
H- Drinking	¼	$^1/_{20}$	300
I- Others	5	2	150

For example, activity 'A–Toilet flushing' is in fact refilling of the toilet cistern. In this case there is a volume of 8 l, within say one minute after the toilet has been flushed. In theory, to be able to fulfil this requirement, the pipe that supplies the cistern should allow the flow of 8 × 60 = 480 l/h within one minute. This flow is thus needed within a relatively short period of time and is therefore called the *instantaneous flow.*

Although the exact moment of water use is normally unpredictable, it is well known that there are some periods of the day when it happens more frequently. For most people this is in the morning after they wakeup, in the afternoon when they return from work or school or in the evening before they go to sleep. Considering a single housing unit, it is not reasonable to assume a situation in which all water-related activities from the above table are executed simultaneously. For example, in the morning, a combination of activities A, B, D and H might be possible. If this is the assumed maximum demand during the day, the maximum instantaneous flow equals the sum of the flows for these four activities. Hence, the pipe that provides water for the house has to be sufficiently large to convey the flow of:

$$480 + 500 + 180 + 300 = 1460 \ l/h$$

With an assumed specific consumption of 120 l/c/d and, say, four people living together, the instantaneous peak factor will be:

$$pf_{ins} = \frac{1460}{120 \times 4/24} = 73$$

Thus, there was at least one short moment within 24 hours when the instantaneous flow to the house was 73 times higher than the average flow of the day. Applying the same logic for an apartment building, one can assume that all tenants use the water there in a similar way and at a similar moment, but never in exactly the same way and at exactly the same moment. Again, the maximum demand of the building occurs in the morning. This could consist of, for example, toilet flushing in say three apartments, hand washing in two, teeth brushing in six, doing the laundry in two and drinking water in one. The maximum instantaneous flow out of such a consumption scenario case would be:

$$3A + 3B + 2C + 6D + 2E + 1H = 6000 \ l/h$$

Which is the capacity that has to be provided by the pipe that supplies the building? Assuming the same specific demand of 120 l/c/d and for possibly 40 occupants, the instantaneous peak factor is:

$$pf_{ins} = \frac{6000}{120 \times 40/24} = 30$$

Any further increase in the number of consumers will cause the further lowering of the instantaneous peak factor, up to a level where this factor becomes independent from the growth in the number of consumers. As a consequence, some large diameter pipes that have to convey water for possibly 100,000 consumers would probably be designed based on a rather low instantaneous peak factor, which in this example could be 1.4.

A simultaneity diagram can be obtained by plotting the instantaneous peak factors against the corresponding number of consumers. The three points from the above example, interpolated exponentially, will yield the graph shown in Figure 3.7. In practice, the simultaneity diagrams are determined from a field study for each particular area (town, region or country). Sometimes, a good approximation is achieved by applying mathematical formulae; the equation:

$$pf_{ins} \approx 126 \times e^{(-0.9 \times \log N)}$$

Where N represents the number of consumers, describes the curve in Figure 3.7. Furthermore, the simultaneous curves can be diversified based on various standards of living i.e. type of accommodation, as Figure 3.8 shows. In most cases, the demand patterns of more than a few thousand people are fairly predictable. This eventually leads to the conclusion that the water demand of larger group of consumers will, in principle, be evenly spread over a period of time that is longer than a few seconds or minutes. This is illustrated in the 24 hour demand diagram for the northern part of Amsterdam. In this example there were nearly 130,000 consumers, and the measurements were executed at 1 minute intervals.

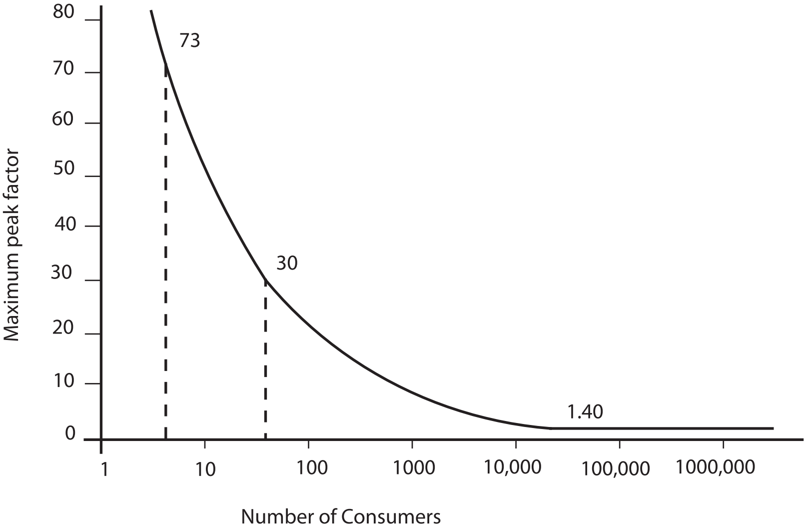


Figure 3.7: **Simultaneity diagram**

One-hour durations are commonly accepted for practical purposes and the instantaneous peak factor within this period of time will be represented by a single value called the *hourly (or diurnal) peak factor*, as shown in Figure 3.9.

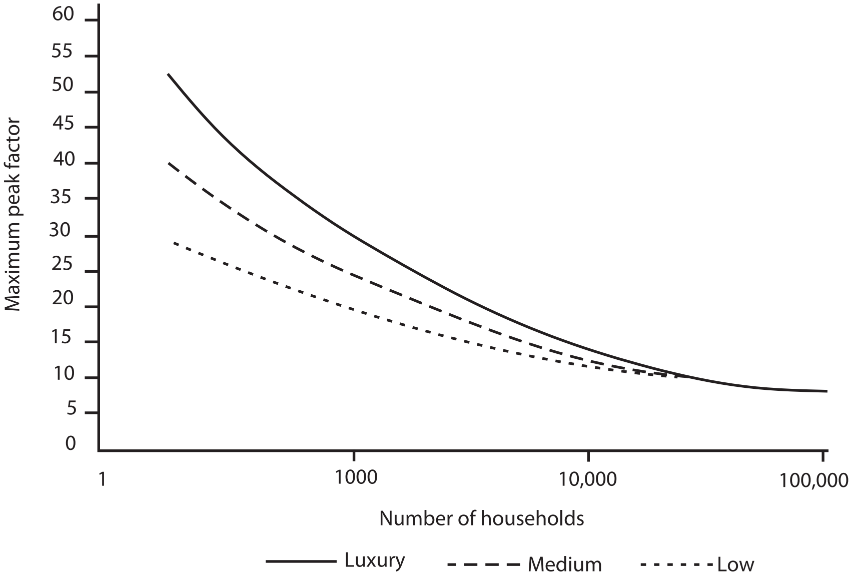


Figure 3.8: Simultaneity diagram of various categories of accommodation

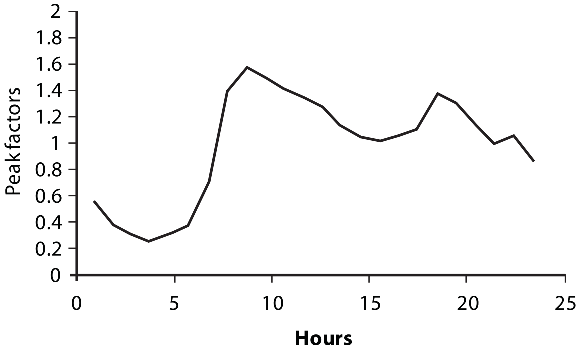


Figure 3.9: Instantaneous demand

Box 3.1

Instantaneous Demand during football game

There are extraordinary situations when the instantaneous demand may substantially influence the demand pattern, even in the case of large numbers of consumers. Figures 3.10 and 3.11 show the demand pattern (in m^3/min) during the TV broadcasting of two football matches when the Dutch national team played against Saudi Arabia and Belgium at the 1994 World Cup in the

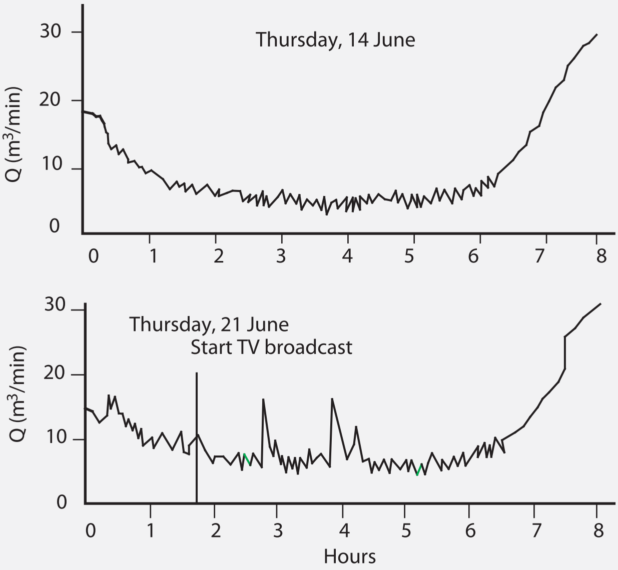


Figure 3.10: Night-time demand during football game (Checkley, Checkley et al. 2008)

United States of America. The demand was observed in a distribution area of approximately 135,000 people. The excitement of the viewers is clearly confirmed through the increased water use during the break and at the end of the game, despite the fact that the first match was played in the middle of the night (with different time zones between The Netherlands and USA). Both graphs point almost precisely to the start of the TV broadcast that happened at 01:50 and 18:50, respectively. The water demand dropped soon after the start of the game until the half time when the first peak occurs; it is not difficult to guess for what purpose the water was used! The upper curves in both figures show the demand under normal conditions, one week before the game at the same period of the day. This phenomenon is not only typical in The Netherlands; it will be met virtually everywhere where football is sufficiently popular. Its consequence is a temporary drop of pressure in the system while in the most extreme situations a pump failure might occur. Nevertheless, these demand peaks are rarely considered as design parameters and adjusting operational settings of the pumps can easily solve this problem.

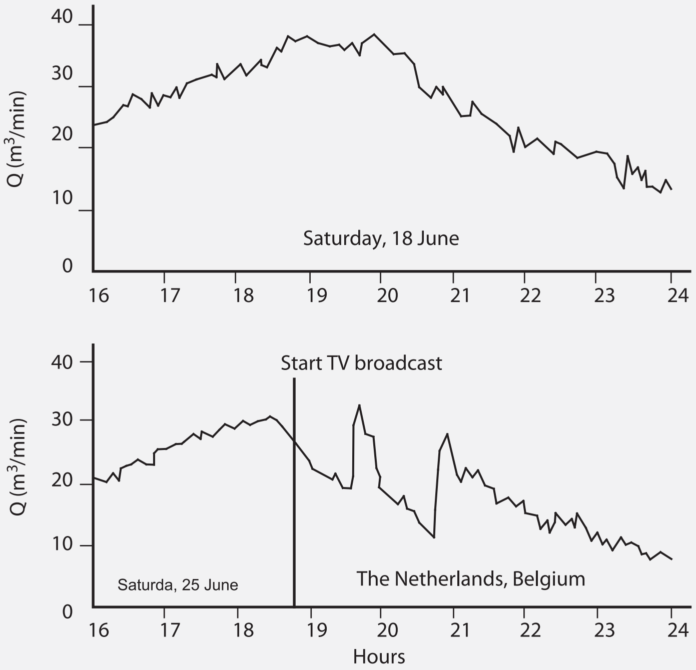


Figure 3.11: Evening demand during football game (Checkley, Checkley et al. 2008).

Example 3.2: In a residential area of 10,000 inhabitants, the specific water demand is estimated at 100 l/c/d (leakage included). During a football game shown on the local TV station, the water meter in the area registered the maximum flow of 24 l/s, which was 60% above the regular use for that period of the day. What was the instantaneous peak factor in that case? What would be the regular peak factor on a day without a televised football broadcast?

Solution:

In order to calculate the peak factors, the average demand in the area has to be brought to the same units as the peak flows. Thus, the average flow becomes:

$$Q_{avg} = \frac{10{,}000 \times 100}{24 / 3600} \approx 12\ l/c/d$$

The regular peak flow at a particular point of the day is 60% lower than the one registered during the football game, which is $24/1.6 = 15\ \mathrm{l/s}$.

Finally, the corresponding peak factors will be 24/12 = 2 during the football game, and 15/12 = 1.25 in normal supply situations.

3.4.2 Diurnal patterns

For sufficiently large group of consumers, the instantaneous demand pattern for 24-hour period converts into a *diurnal (daily) demand diagram*. Diurnal diagrams are important for the design of primary and secondary networks, and in particular their reservoirs and pumping stations. Being the shortest cycle of water use, a one-day period implies a synchronised operation of the system components with similar supply conditions occurring every 24 hours. The demand patterns are usually registered by monitoring flows at delivery points (treatment plants) or points in the network (pressure boosting stations, reservoirs, and control points with either permanent or temporary measuring equipment). With properly organised measurements the patterns can also be observed at the consumers' premises.

First, such an approach allows the separation of various consumption categories and second, the leakage in the distribution system will be excluded, resulting in a genuine consumption pattern. A few examples of diagrams for different daily demand categories are given in Figures 3.12–3.15. A flat daily demand pattern reflects the combination of impacts from the following factors:

Figure 3.12: **Urban demand pattern {adapted from: (Trifunović and Blokland 1993; Gabrić 1996)}.**

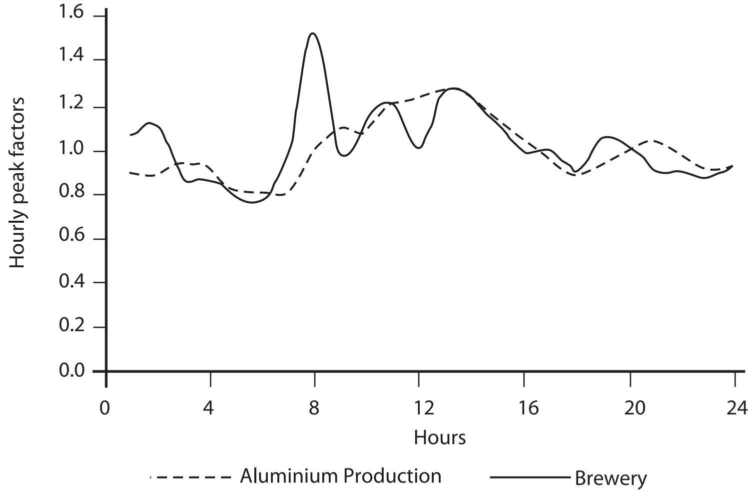


Figure 3.13: **Industrial demand pattern – example from Bosnia and Herzegovina (Rossman 2000).**

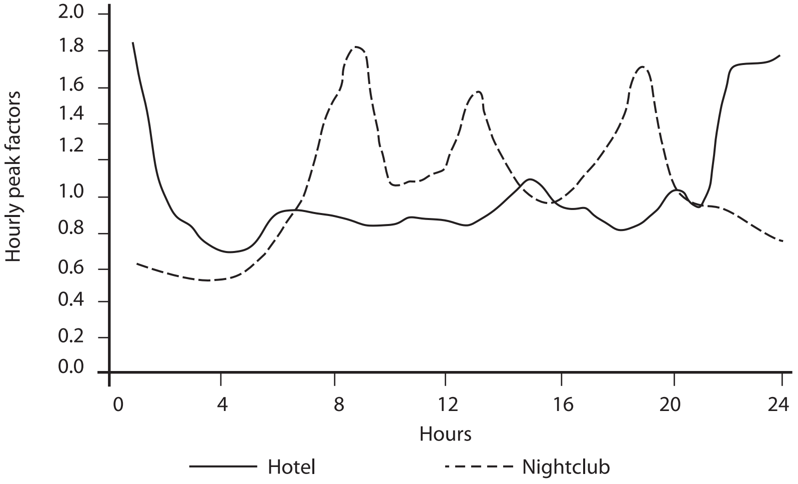


Figure 3.14: **Tourist demand pattern – example from Croatia (Rossman 2000).**

- large distribution area,
- high industrial demand,
- high leakage level,
- scarce supply (individual storage).

Commonly, the structure of the demand pattern in urban areas looks as shown in

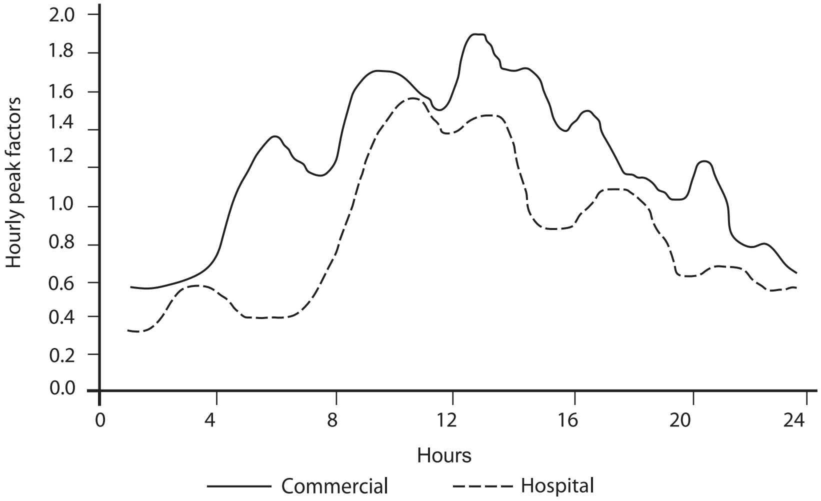


Figure 3.15: Commercial/ institutional demand pattern – example from USA(Rossman 2000).

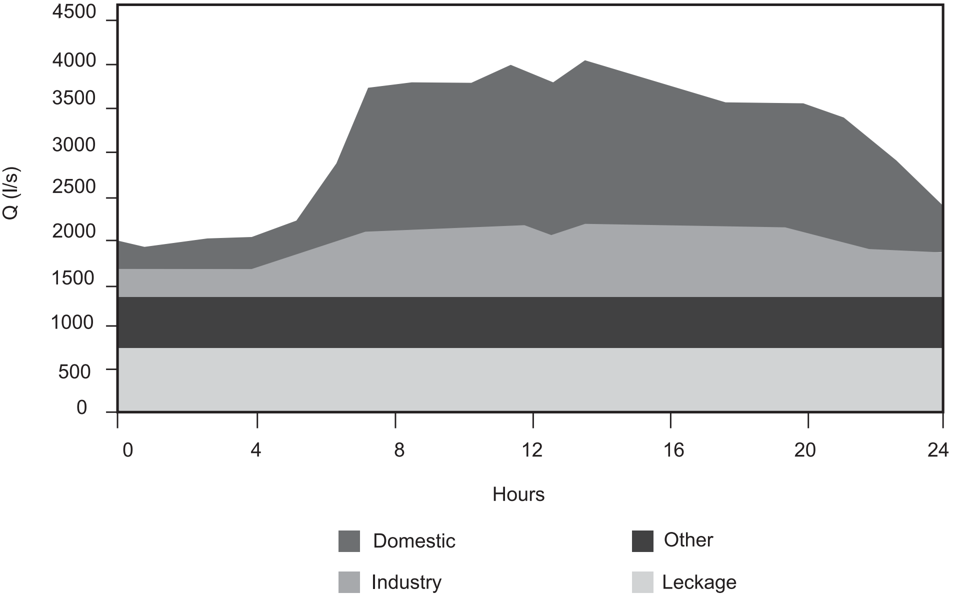


Figure 3.16: Typical structure of diurnal demand in urban areas.

Figure 3.17: Peak factor diagrams of various categories from Figure 3.16.

Figure 3.16: the domestic category will have the most visible variation of consumption throughout the day, industry and institutions will usually work in daily shifts, and the remaining categories, including leakage, are practically constant.

By separating the categories, the graph will look like Figure 3.17, with peak factors calculated for the domestic consumption only, then for the total consumption (excluding leakage), and finally for the total demand (consumption plus leakage). It clearly shows that contributions from the industrial consumption and leakage flatten the patterns.

3.4.3 Periodic variations

The peak factors from diurnal diagrams are derived on the basis of average consumption during 24 hours. This average is subject to two additional cycles: weekly and annual.

Weekly demand pattern is influenced by average consumption on working and non-working days. Public holidays, sport events, etc. play a role in this case as well. One example of the demand variations during a week is shown in Figure 3.18. The difference between the two curves in this diagram reflects the successful implementation of the leak detection programme. Consumption in urban areas of Western Europe is normally lower over weekends. On Saturdays

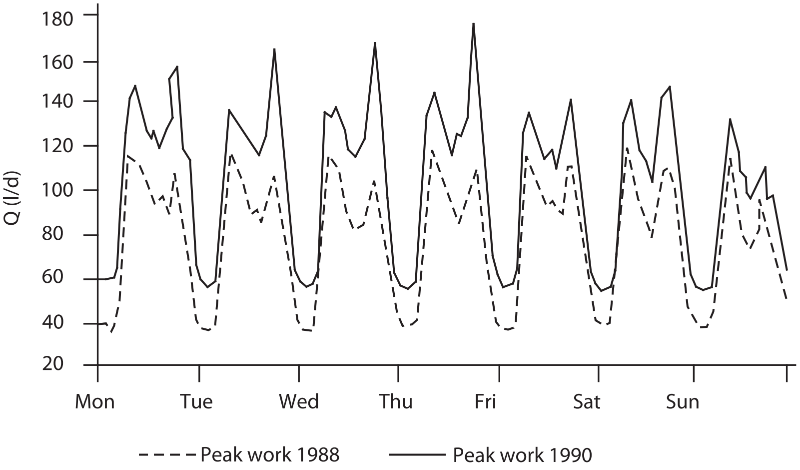


Figure 3.18: Weekly demand variations – Alvington, UK (Dovey and Rogers 1993).

and Sundays people rest, which may differ in other parts of the world. For instance, Friday is a non-working day in Islamic countries and domestic consumption usually increases then.

Annual variations in water use are predominantly linked to the change of seasons and are therefore also called *seasonal variations*. The unit consumption per capita normally grows during hot seasons but the increase in total demand may also result from a temporarily increased number of consumers, which is typical for holiday resorts. Figure 3.19 shows the annual pattern in Istria, Croatia on the Adriatic coast; the peaks of the tourist season, during July and August, are also the peaks in water use.

Just as with diurnal patterns, typical weekly and annual patterns can also be expressed through peak factor diagrams. Figure 3.20 shows an example in which the peak daily demand appears typically on Mondays and is 14% above the average, while the minimum on Sundays is 14% below the average daily demand for the week. The second curve shows the difference in demand between summer and winter months, fluctuating within a margin of 10%.

Generalising such trends leads to the conclusion that the absolute peak consumption during one year occurs on a day of the week, and in the month when the consumption is statistically the highest. This day is commonly called

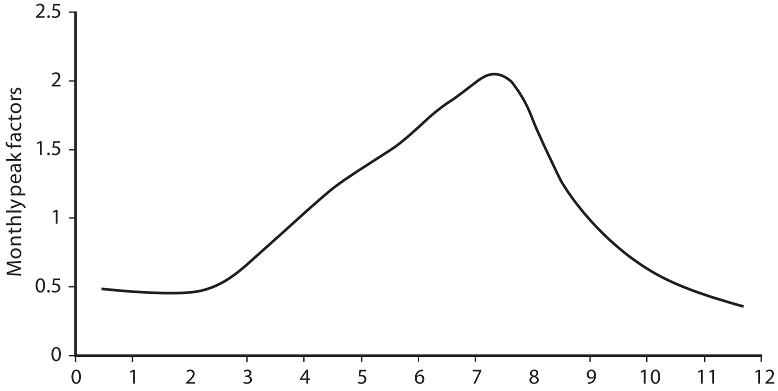


Figure 3.19: **Seasonal demand variation in a sea resort (Oâ Keefe, Rose et al. 2008).**

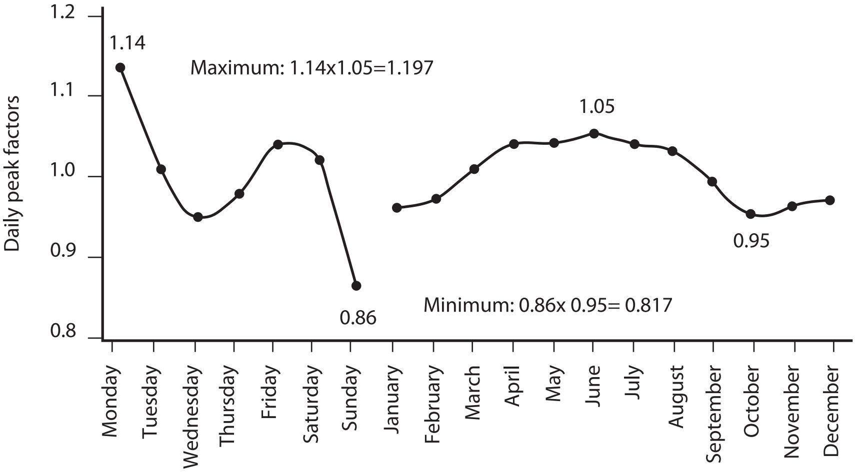


Figure 3.20: **Weekly and monthly peak factor diagrams.**

the *maximum consumption day*. In the above example, the maximum consumption day would be a Monday somewhere in June, with its consumption being 1.14 × 1.05 = 1.197 times higher than the average daily consumption for the year. In practice however, the maximum consumption day in one distribution area will be determined from the daily demand records of the water company. This is simply the day when the total registered demand was the highest in a particular year.

Finally, the daily, weekly and annual cycles are never repeated in exactly the same way. However, for design purposes a sufficient accuracy is achieved if it is assumed that all water needs are satisfied in a similar schedule during one day, week or year. Regarding the seasonal variations, the example in Figure 3.21 confirms this; the annual patterns in the graph are more or less the same while the average demand grows each year as a result of population growth.

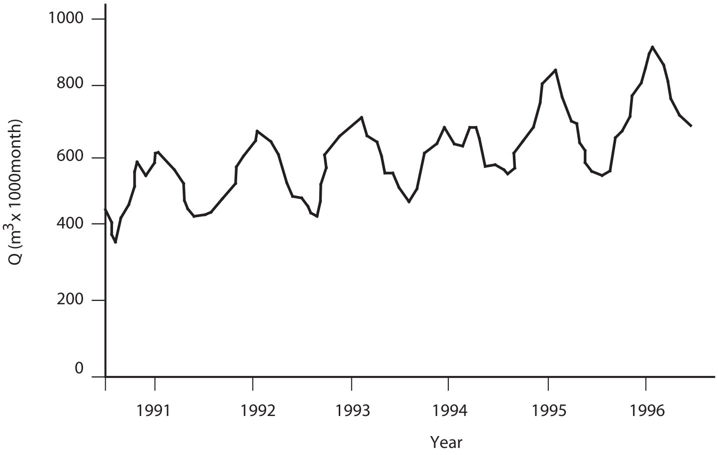


Figure 3.21: Annual demand patterns in Ramallah, Palestine (Barret et al. 2003).

Example 3.3: A water supply company delivered an annual quantity of 10,000,000 m^3, assuming an average leakage of 20%. On the maximum consumption day, the registered delivery was as follows:

Hour	1	2	3	4	5	6	7	8	9	10	11	12
m^3	989	945	902	727	844	1164	1571	1600	1775	1964	2066	2110
Hour	13	14	15	16	17	18	19	20	21	22	23	24
m^3	1660	1309	1091	945	1062	1455	1745	2139	2110	2037	1746	1018

Determine:

a. diurnal peak factors for the area,
b. the maximum seasonal variation factor,
c. diurnal consumption factors.

Solution:

a. From the above table, the average consumption on the maximum consumption day was 1454.75 m^3/h leading to the following hourly peak factors:

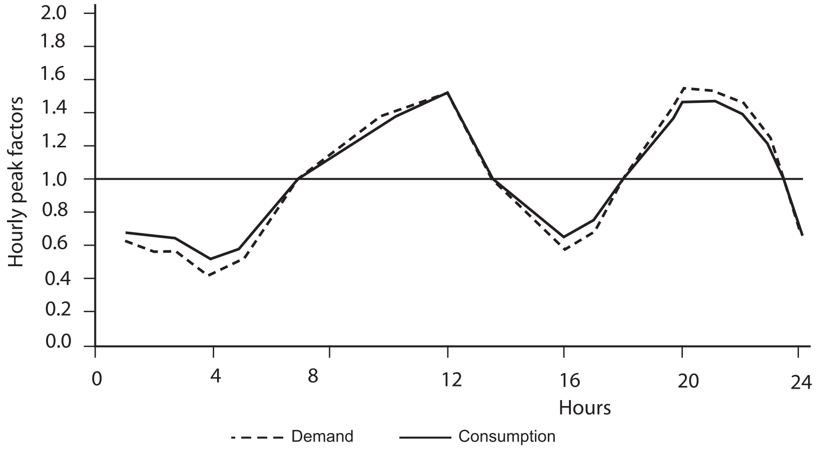
Hour	1	2	3	4	5	6	7	8	9	10	11	12
m^3	0.680	0.650	0.620	0.500	0.580	0.800	1.080	1.100	1.220	1.350	1.420	1.450
Hour	13	14	15	16	17	18	19	20	21	22	23	24
m^3	1.100	0.900	0.750	0.650	0.730	1.000	1.200	1.470	1.450	1.400	1.200	0.700

b. The average consumption, based on the annual figure, is 10,000,000/365/24 = 1141.55 m^3/h. The seasonal variation factor is therefore 1454.75/1141.55 = 1.274.

c. The average leakage of 20% assumes an hourly flow of approx 228 m^3/h, which is included in the above hourly flows as water loss. The peak factors for consumption will therefore be recalculated without this figure, as the following table shows:

Hour	1	2	3	4	5	6	7	8	9	10	11	12
m^3	761	717	674	499	616	936	1343	1372	1547	1736	1838	1882
pf_n	0.620	0.584	0.549	0.407	0.502	0.763	1.095	1.118	1.261	1.425	1.498	1.534
Hour	13	14	15	16	17	18	19	20	21	22	23	24
m^3	1372	1081	863	717	834	1227	1517	1911	1882	1809	1518	790
pf_n	1.118	0.881	0.730	0.584	0.680	1.000	1.237	1. 558	1.534	1.47 5	1.237	0.644

The diagram of the hourly peak factors for the two situations will look as follows:



3.5 Fire Demand

Fire protection is an important function of a water-works. The total amount of water used in a year for extinguishing fires is usually a negligible part of the total use, but during a fire the rate of demand of is so great as to be the deciding factor, in all but the largest communities, in designing the pump, reservoirs and distribution systems. The fire demands is a function of population, with a minimum limit because the greater the population the greater the number of buildings and the greater the risk of the fire. The minimum limit of the fire demand is the amount and the rate of supply that are required to extinguish the largest probable fire that could be started in a community.

At least four streams should be available at all points within the area protected. Each stream should be capable of delivering at least 175 gpm of water in low risk districts and 250 gpm in high risk districts, the above quantity of water should be available for at least 5 hours. The pressure to be less than about 80 psi where mobile fire pumping engines are used, and 80 to 100 psi otherwise authoritative recommendations concerning allowance to be made for peak fire demands in water works design are listed in the Table 3.10. The maximum rate of demand to be provided for design is the sum of the fire demand and the general service demand occurring simultaneously.

Table 3.10: Empirical formula for computing rate of fire demand

Name of the Authority	Formula	Rate in gpm for 100,000 population
National Board of fire Underwriters	$Q = 1{,}020\sqrt{p}\,(1 - .01\sqrt{p})$	9,180
Kuichling (on basis of fire streams of 250 gpm)	$Q = 700\sqrt{p}$	7,000
Freeman, John R	$Q = 250(\frac{p}{5} + 10)$	75,000
Where, Q= Fire demand in gpm and P= Population in thousands		

The National Board of Fire Underwriters (NBFU) requirements of fire protection water very between 1,000 gpm for 1,000 persons and 12,000 gpm for 200,000 persons, with a maximum of 20,000 gpm. There must be enough water in the reservoir to provide for a 5 hr fire for towns of less than 2,500 persons and a 10 hr fire for larger cities.

Based on the experience of water supply engineers and fire departments, a number of empirical formula for the required number of fire streams (F) has been derived. The following formula devised by kuichling is most commonly used.

$$F = 2.8\sqrt{p}$$

Example 3.4: Calculate the total stream flow in gpm for a town having a population of 10,000. Assume that each stream will spray 250 gpm on the fire simultaneously.

Solution:

Required number of fire streams

$$F = 2.8\sqrt{10} = 9$$

Total stream flow $= 250 \times 9 = 2{,}250$ gpm.

But the amount recommended by the NBFU is 3000 gpm (Table 3.6) therefore, the values in the Table 3.11 are generally used.

Table 3.11: Flow required by the National Board of Fire Underwrites

Population	Recommended fire flow, gpm	Population	Recommended fire flow, gpm
1,000	1,000	28,000	2,000
2,000	1,500	40,000	6,000
4,000	2,000	80,000	7,000
6,000	2,000	100,000	8,000
10,000	3,000	125,000	9,000
13,000	3,500	150,000	10,000
17,000	4,000	200,000	12,000
22,000	4,500		

Example 3.5: What fire flow and storage are required for fire protection (10 hr) in a city of 200,000 populations according to the recommendation of the National Board of the Fire Underwrites?

Solution:

Total fire flow $= 13{,}000 \times 60 \times 10 = 7{,}80{,}0000$ gallons, addition to the reserve for normal use during the fire.

The computed quantity of water to the provided for fire demand is then divided by the estimated population of the city or town to obtain the provision to be made per person for fire fighting, the quantity of water required for fire fighting should always be stored in the distribution reservoir below its normal low water level, the required number of hydrants are to be located at suitable point in the distribution system to allow the specific number of streams to play upon the fire at a time. Fire engines are to be kept in readiness at different parts in the city. They are summoned to draw the water from the hydrants and to deliver it in the form of streams on the fire. Sometimes, they are to carry pumps to booster the supply pressure available at the hydrant level.

3.6 Fire Hydrants

A hydrant is an outlet from a water main and is provided chiefly for the purpose of forming a connection for fire hose. One type is shown in the Figure 3.1. Hydrants are usually of post type. But flush hydrants set in boxes below the footpath or street corner are occasionally used in some cities, Hydrants are usually placed at or near street intersections and at intermediate points also. Since fire hose cannot deliver an effective stream at distances greater than about 400 ft hydrants should be so spaced that each section of the community can be conversed with hose from two or more hydrants. The National Board of Fire Underwrites recommends a spacing of about 200 ft. for a community of 25000 to 30000 populations requiring a fire flow of 5000 gpm and a spacing of not more than 300 ft for small communities requiring only 1000 gpm for fire flow. Hydrants are generally placed near the curb line but far enough from it to be protected from normal traffic hazard.

Fire hydrants are usually made of cast iron with brouze surfaces. It is frequently desire that a gate valve be placed on the connection to the distribution system, in addition to the main valve on the hydrant. The drain should be connection to a drainage channel (storm sewer) in Figure 3.22.

The National Board of Fire Underwrites requires that the hydrants shall be able to deliver 600 gpm with a loss of rot more than 2.5 psi in the hydrant and a total loss of not more than 5 psi between the street main and the outlet; they shall not have less than 2.5 inch outlets and also a large suction connection where engine service is necessary. They shall be of such design that when the hydrant barrel is broken off the hydrant will remain closed. Street connections should not be less than 6 inch in diameter and shall be gated.

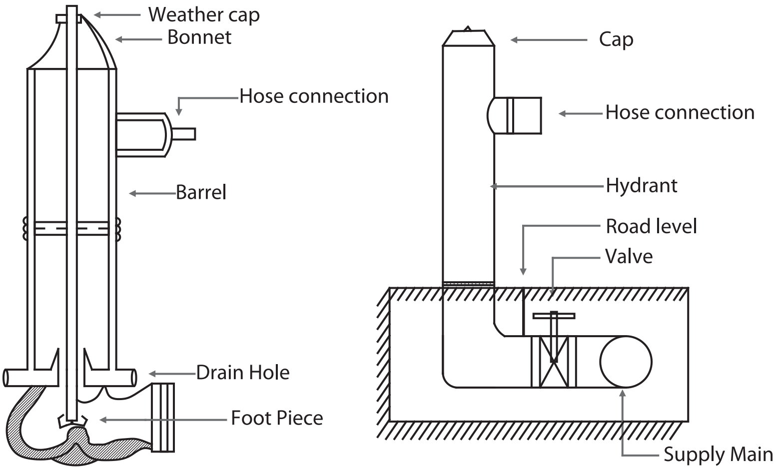


Figure 3.22: Fire Hydrant

The size of fire hydrant is designed in terms of the minimum opening of the seat ring of the main valve. It must be at least 4 inch for two 2.5 inch nozzles, at least 5 inch for three 2.5 inch nozzles, and at least 6 inch for four 2.5 inch nozzles. The rate of discharge from a hydrant can be approximate determined by expression:

$$Q = 27\, d^2 p^{0.5}$$

When, Q = flow, gpm
d = diameter of the hydrant nozzle, inch,
p = gauge reading, psi

Fire hose 2.5 inch in diameter and 100 ft long with a 1 inch nozzle will deliver about 240 gpm with a nozzle pressure of 60psi and a hydrate pressure of about 85 psi. The flow will be less for longer lines or for lower hydrant pressure. To deliver 240 gpm, hydrant pressure of about 105 psi must be provided for 200 ft long hose, 125 psi for 300 ft, and 145 psi for 400 ft.

The details of installation of fire hydrant are described in the chapter 9 (article 9.10.2).

3.7 Demand Calculation

3.7.1 Estimation of demand flow

Knowing the daily patterns and periodical variations, the demand flow can be calculated from the following formula:

$$Q_d = \frac{Q_{wc,avg} \times pf_o}{(1 - l/100) \times f_c} \qquad 3.1$$

The definition of the parameters is as follows: Q_d is the water demand of a certain area at a certain moment, $Q_{wc,avg}$ the average water consumption in the area, pf_o the overall peak factor (this is a combination of the peak factor values from the daily, weekly and annual diagrams: $pf_o = pf_h \times pf_d \times pf_m$; the daily and monthly peak factors are normally integrated into one (seasonal) peak factor: $pf_s = pf_d \times pf_m$), l is the leakage expressed as a percentage of the water production and f_c the unit conversion factor.

The main advantage of Equation 3.1 is its simplicity although some inaccuracy will be necessarily introduced. Using this formula, the volume of leakage increases with higher consumption i.e. the peak factor value, despite the fixed leakage percentage. For example, if $Q_{wc,avg} = 1$ (regardless of the flow units), $pf_o = 1$ and the leakage percentage is 50%, then as a result $Q_d = 2$. Thus, half of the supply is consumed and the other half is leaked.

If $pf_o = 2$, $Q_d = 4$. Again, this is 'fifty-fifty' but this time the volume of leakage has grown from 1 to 2, which implies its dependence on the consumption level. This is not true as the leakage level is usually constant throughout the day, with a slight increase over night when the pressures in the network are generally higher (already shown in Figure 3.16). Hence, *the leakage level is pressure dependent rather than consumption dependant.*

Nonetheless, the above inaccuracy effectively adds safety to the design. Where this is deemed unnecessary, an alternative approach is suggested, especially for distribution areas with high leakage percentages:

$$Q_d = (Q_{wc,avg} \times Q_{wl}) \frac{1}{f_c} \qquad 3.2$$

Where:

$$Q_{wl} = \frac{l}{100} \times Q_{wp} \qquad 3.3$$

In the case of $pf_o = 1$, demand equals production and assuming the same units for all parameters ($f_c = 1$):

$$Q_{wp} = Q_{wc,avg} + \frac{l}{100} \times Q_{wp} \qquad 3.4$$

This can be re-written as:

$$Q_{wp} = \frac{Q_{wc,avg}}{(1 - l/100)} \tag{3.5}$$

By plugging Equation 3.5 into 3.3 and then to 3.2, the formula for water demand calculation evolves into its final form:

$$Q_d = \frac{Q_{wc,avg}}{f_c} \times \left(pf_o + \frac{l}{100 - l} \right) \tag{3.6}$$

Where reliable information resulting from individual metering of consumer is not available, the average water consumption, $Q_{wc,avg}$, can be approximated in several ways:

$$Q_{wc,avg} = ncq \tag{3.7}$$

$$Q_{wc,avg} = dAcq \tag{3.8}$$

$$Q_{wc,avg} = Acq_a \tag{3.9}$$

$$Q_{wc,avg} = n_u q_u \tag{3.10}$$

Where *n* is the number of inhabitants in the distribution area, *c* coverage of the area. It can happen that some of the inhabitants are not connected to the system, or some parts of the area are not inhabited. This factor, which has a value of between 0 and 1, converts the number of inhabitants into the number of consumers. *q* is the specific consumption (l/c/d), *d* the population density (number of inhabitants per unit surface area), *A* the surface area of the distribution area, q_a the consumption registered per unit surface area, n_u the production capacity (it represents a number of units (kg, l, pieces, etc.) produced within a certain period), q_u the water consumption per unit product. The data for *n, c, d, A* and nu are usually available from statistics or set by planning: local, urban, regional, etc.

As already mentioned, the demand in large urban areas is often composed of several consumption categories. More accuracy in the calculation of demand for water is therefore achieved if the distribution area is split into a number of sub-areas or districts, with standardised categories of water users and a range of consumptions based on local experience.

The average consumption per district can then be calculated from Equation 3.9, which has been modified:

$$Q_{wc,avg} = A\sum_{i=1}^{n} (q_{a,i} p_i c_i) \tag{3.11}$$

where A is the surface area of the district, n the number of consumption categories within the district, $q_{a,i}$ the unit consumption per surface area of category i, p_i the percentage of the district territory occupied by category i, c_i the coverage within the district territory occupied by category i. With a known population density in each district, the result can be converted into specific demand (per capita).

Regarding the pf_o values, the following are typical combinations:

- $pf_h = 1$, $pf_s = 1$; Q_d represents the average consumption per day. This demand is the absolute average, usually obtained from annual demand records and converted into required flow units.
- $pf_h = 1$, $pf_s = \max$; Q_d represents the average demand during the maximum consumption day.
- $pf_h = \max$, $pf_s = \max$; Q_d is the demand at the maximum consumption hour on the maximum consumption day.
- $pf_h = \min$, $pf_s = \min$; Q_d is the demand at the minimum consumption hour on the minimum consumption day.

The entire range of demands that appear in one distribution system during one year is specified by the demands above 3rd and 4th option, which are shown in Figure 3.23. These peak demands are relevant as parameters for the design of all system components: pipes, pumps and storage.

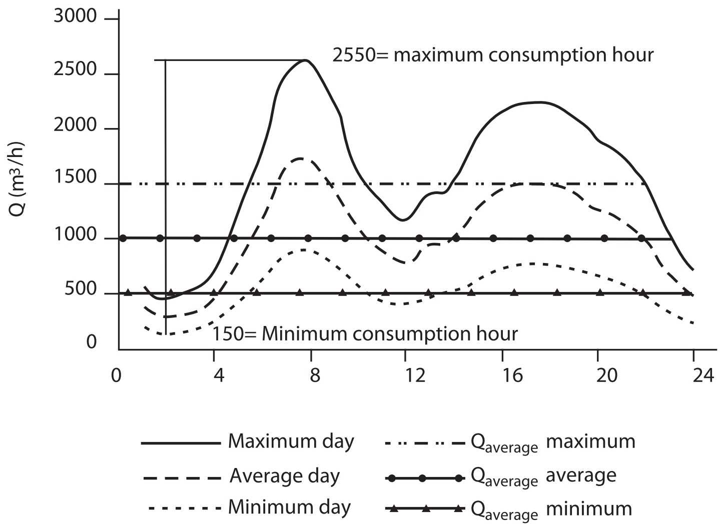


Figure 3.23: **Hypothetical annual range of flows in a distribution system.**

Example 3.6: A water supply company in a town with a total population of approx. 275,000 conducted a water demand survey resulting in the following categories of water users:

The city is divided into 8 districts, each with a known population, contribution to demand from each of the categories, and estimated coverage by the distribution system, as shown in the table below.

Category of water users		q_a (m^3/d/ha)
A	Residential area, apartments	90
B	Residential area, individual houses	55
C	Shopping areas	125
D	Officers	80
E	Schools, Colleges	100
G	Hotels	150
H	Public green areas	15

Solution:

Based on Equation 3.11, a sample calculation of the demand for district 1 will be as follows:

$$
\begin{aligned}
Q_{1,avg} &= A\sum_{i=1}^{5}(q_{a,i}\, p_i c_i) \\
&= 250 \times (90 \times 0.37 + 55 \times 0.23 + 125 \times 0.1 + 100 \times 0.04 + 15 \times 0.26 \times 0.40) \\
&= 666.77 \text{m}^3/\text{h}
\end{aligned}
$$

The remainder of the results are shown in the table below. The specific demand has been calculated based on the registered population in each district.

3.7.2 Demand forecasting

Water demand usually grows unpredictably as it depends on many parameters that have their own unpredictable trends. Figure 3.24 illustrates how the rate of increase in consumption may differ even in countries from the same region and with a similar level of economic development.

The experience from Germany proves again how uncertain the forecast can be. Figure 3.25 shows the development of domestic consumption in the period 1970–2000. The forecast made by experts in the Seventies and the Eighties was

Districts		A	B	C	D	E	F	G	H
86,251	p_1 (%)	37	23	10	0	4	0	0	26
A_1=250 ha	c_1 (%)	100	100	100	0	100	0	0	40
74,261	p_2 (%)	20	5	28	11	12	0	5	19
A_2=185 ha	c_2 (%)	10	18	3	0	0	42	0	27
18,542	p_3 (%)	100	100	100	0	0	100	0	35
A_3= 57 ha	c_3 (%)	25	28	20	2	15	0	0	10
42,149	p_4 (%)	100	100	95	100	100	0	0	36
A_4= 88 ha	c_4 (%)	50	0	11	0	10	0	0	29
22,156	p_5 (%)	24	11	13	15	13	8	0	16
A_5= 54 ha	c_5 (%)	100	100	100	100	100	100	0	35
9958	p_6 (%)	22	28	8	19	6	0	10	7
A_6= 29 ha	c_6 (%)	100	100	100	100	100	0	100	50
8517	p_7 (%)	22	28	8	19	6	0	10	7
A_7= 17 ha	c_7 (%)	100	100	100	100	100	0	100	50
12,560	p_8 (%)	0	0	0	0	55	20	15	10
A_8= 16 ha	c_8 (%)	0	0	0	0	85	100	100	45

Determine the total average demand of the city.

	Q_{mg} (m^3/h)	Population	Q_{mg} (l/c/d)
District 1	666.67	86,251	186
District 2	651.97	74,261	211
District 3	216.76	18,542	281
District 4	288.90	42,149	165
District 5	161.05	22,156	174
District 6	99.74	9958	240
District 7	58.03	8571	164
District 8	67.95	12,560	130
Total	**2211.16**	**274,394**	**193**

that the demand in the year 2000 would grow to as much as 220 l/c/d, while in reality it fell to approximately 140 l/c/d. Awareness for the environment in the last decade, combined with low population growth, caused a drop in domestic water use in many countries of Western Europe. In addition, lots of home appliances (i.e. shower heads, taps, washing machines, dishwashers, etc.) have been replaced with more advanced models, able to achieve the same effect with less water (see Figure 3.26).

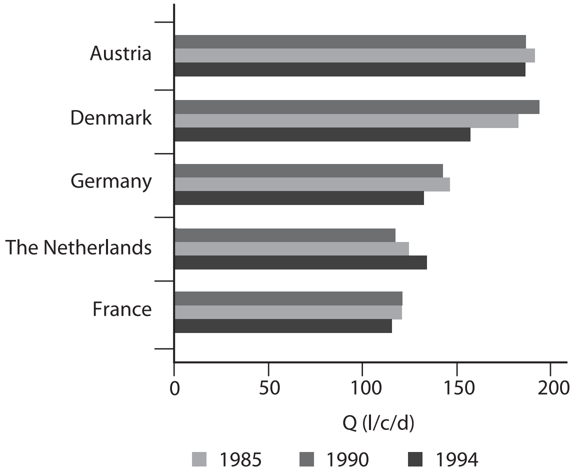


Figure 3.24: **Domestic consumption increase in some European countries (Barret et al. 2003).**

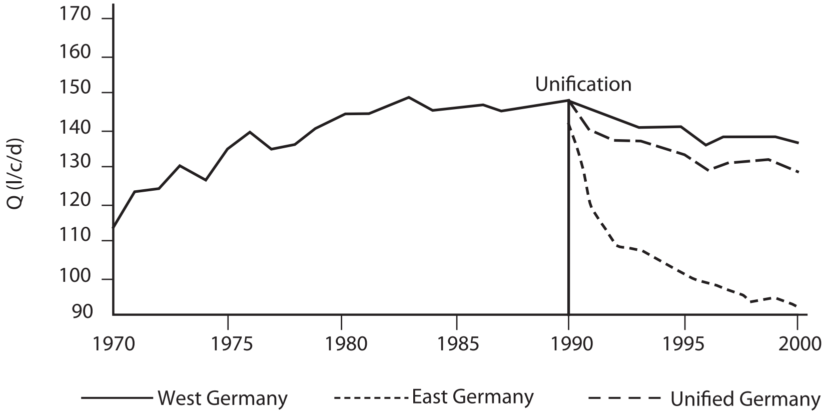


Figure 3.25: **Domestic consumption increase in Germany (Barret et al. 2003)**

Finally, industry has been moving towards alternative water-saving production technologies, positively influencing the overall water demand. This is unfortunately not the case in many developing countries, where the population growth is much higher, consumers' attitude towards water conservation is comparatively low, and outdated technologies and equipment are still widely used. Apart from monitoring technological developments, several other assessments must be taken into account while estimating future demand:

- historical demand growth trends

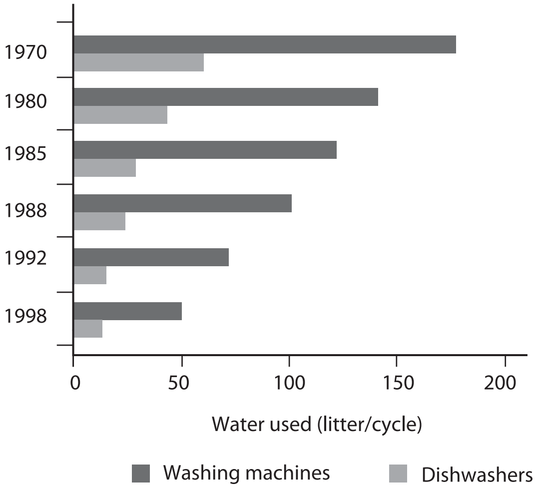


Figure 3.26: Water consumption of washing appliances in Europe (Barrett, Barret et al. 2003).

- projection-based on per capita consumption and population growth trends for domestic category,
- forecast-based on assessment of growth trends of other main consumer categories (industry, tourism, etc.).

When combined, all these projections can yield several possible scenarios of consumption growth. While thinking, for instance, about population growth, which is for many developing countries still the major factor in an increase in water demand, useful conclusions can be drawn if the composition of the existing population, fertility and mortality rates, and particularly the rate of migration, can be assessed. That the population and demand growth match reasonably well in general is shown by the example in Figure 3.27. Two models are commonly used for demand forecast: linear and exponential.

- Linear model $Q_{i+n} = Q_i\left(1+n\frac{a}{100}\right)$ 3.12

- Exponential model $Q_{i+n} = Q_i\left(1+n\frac{a}{100}\right)^n$ 3.13

In the above equations Q_i is the water demand at year i, Q_{i+n} the forecast water demand after n years, n the design period, a the average annual population growth during the design period (%).

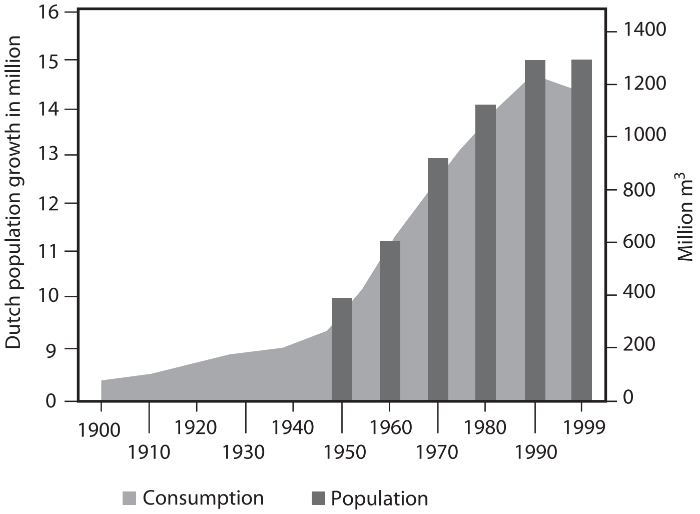


Figure 3.27: **Population and demand growth**

Which of the models will be more suitable will depend on the conclusions from the above-mentioned analyses. These are to be reviewed periodically, as trends can change within a matter of years. Figure 3.28 shows the annual demand in a typical country in the period 1955–1995. In the first part of this period, up until 1970, the exponential model with an average annual growth of 5.5% (a in Equation 3.13 = 5.5) matches the real demand very closely. However, keeping it unchanged for the entire period would show demand almost three times higher than was actually registered in 1995.

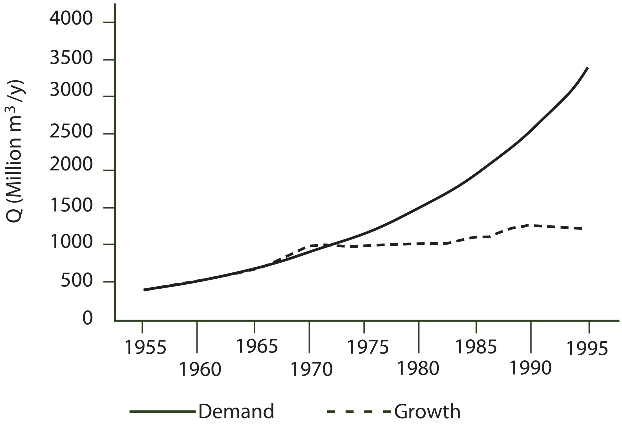


Figure 3.28: **Consumption growth according to the exponential model.**

Example 3.7: In a residential area of 250,000 inhabitants, the specific water demand is estimated at 150 l/c/d, which includes leakage. Calculate the demand in 20 years' time if the assumed annual demand growth is 2.5%. Compare the results by applying the linear and exponential models.

Answers:

The present demand in the city is equal to:

$$Q_{avg} = \frac{250,000 \times 150 \times 365}{1000} = 91,250 m^3/y$$

Applying the linear model, the demand after 20 years will grow to:

$$Q_{21} = 91,250\left(1 + 20\frac{2.5}{100}\right) = 136,875 m^3/y$$

Which is an increase of 50% compared to the present demand, In the case

$$Q_{21} = 91,250\left(1 + \frac{2.5}{100}\right)^{20} \approx 149,524 m^3/y$$

Which is an increase of approximately 64% compared to the present demand.

3.8 Demand Frequency Distribution

A water supply system is generally designed to provide the demand at guaranteed minimum pressures, for 24 hours a day and 365 days per year. Nevertheless, if the pressure threshold is set high, such a level of service may require exorbitant investment that is actually non-affordable for the water company and consumers. It is therefore useful to analyse how often the maximum peak demands occur during the year. The following example explains the principle. Knowing both a typical diurnal peak factor diagram (such as the one shown in Figure 3.29) and the range of seasonal peak factors allows for integration of the two. The hourly peak factors corrected by the seasonal peak factors will result in the annual range of the hourly peak hours (Figure 3.30). These are absolute values that refer to the average hour of the average consumption day (Figure 3.31). Consequently, each hour of the year (total 24 × 365) will have a unique peak factor value assigned to it.

Applying this logic, the diagram with the frequency distribution of all hourly peak factors can be plotted, as the example in Figure 3.32 shows. Converting this

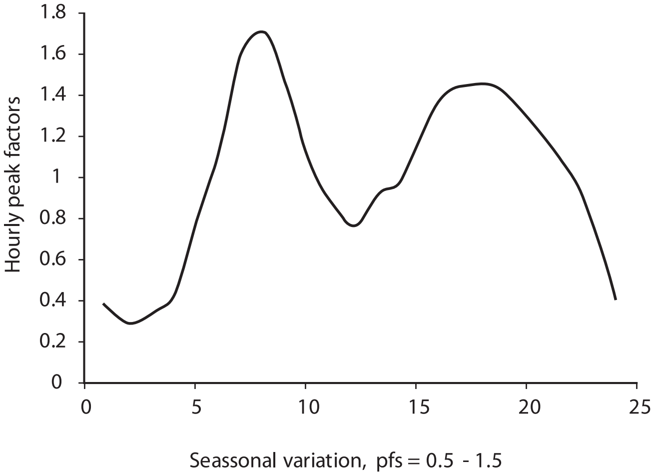


Figure 3.29: **Example of a typical diurnal demand pattern.**

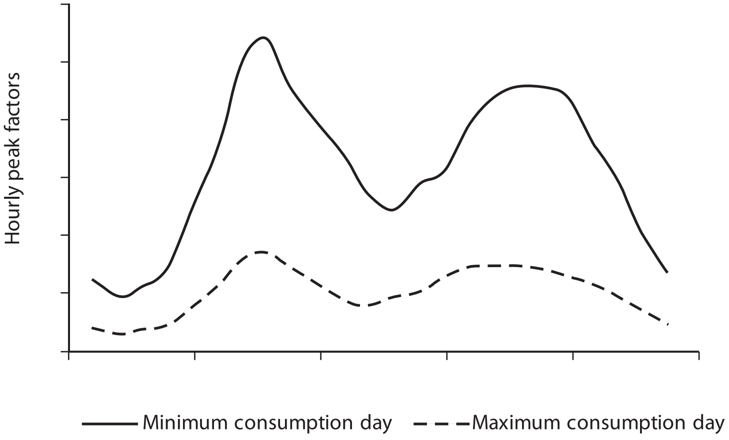


Figure 3.30: **Example of the annual range of the peak factors.**

diagram into a cumulative frequency distribution curve helps to determine the number of hours in the year when the peak factors exceed the corresponding value. This is illustrated in Figure 3.33, which for instance shows that the peak factors above 2.0 only appear during some 500 hours or approximately 5% of the year. In theory, excluding this fraction from the design considerations would eventually create savings based on a 20% reduction of the system capacity. The consequence of such a choice would be the occasional drop of pressure below the threshold, which the consumers might consider acceptable during a limited period of time.

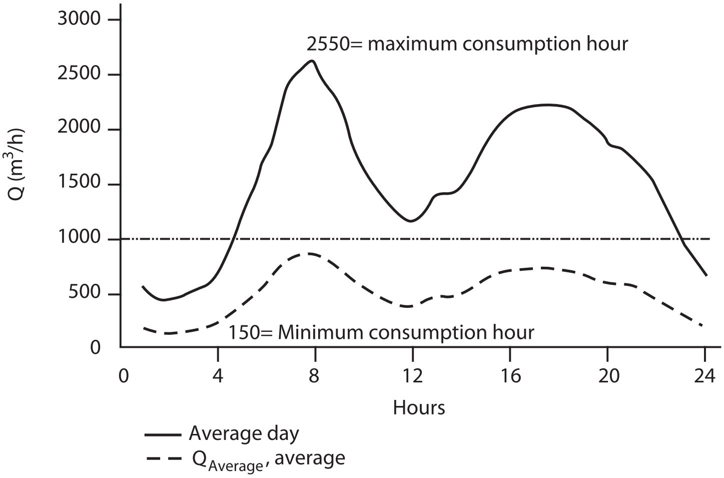


Figure 3.31: **Example of the annual range of hourly demands.**

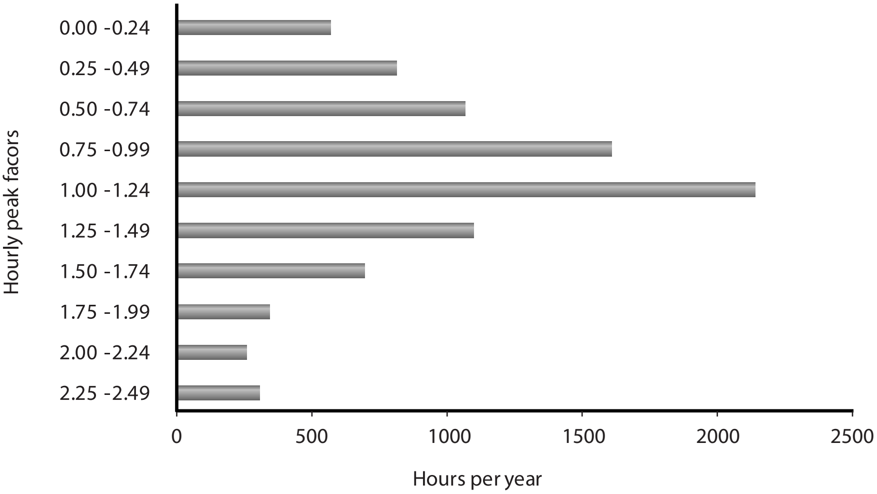


Figure 3.32: **Frequency distribution of the diurnal peak factors.**

In practice, the decision about the design peak factor results from the comparison between the costs and benefits. Indeed, it seems rather inefficient to lay pipes that will be used for 80% of their capacity for less than 5% of the total time. However, where there is a considerable scope for energy savings from daily use by lowering the energy losses on a wider scale, such a choice may look

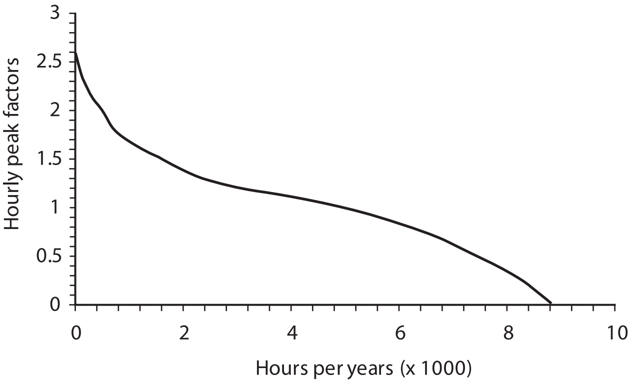


Figure 3.33: Cumulative frequency distribution of the diurnal peak factors.

reasonable. Moreover, careful assessment of the network reliability could justify the laying of pipes with reserve capacity that could be utilised during irregular supply situations.

Box 3.2

Demand of water in Dhaka city

Dhaka mega city includes Dhaka City Corporation, the entire Narayanganj Sadar, Bandar, Keraniganj, Uttara, Savar, Gazipur Sadar Thana. The present population of the city is about 15 million and area is about 300 sq. km. Dhaka water supply and sewerage authority (DWASA) is responsible for water supply in this region. For reasons of convenience, DWASA has divided the whole area into seven distinct zones. There are deficits in water production in almost six zones. With limiting water sources the increasing demand with time makes it a serious threat to the city dwellers.

Present demand of water is about 2120 MLD and in the year 2020, the projected demand will be more than 4000 MLD assuming a water consumption of 175 liter per capita per day (lpcd). There are 278368 connections of DWASA where 261,674 are domestic connections with a demand of 2120 MLD. Beside of domestic water demand, industrial and commercial institutions exert a significant demand on DWASA water. Table 3.12 shows year wise gross water demand and shortage of DWASA and the Table 3.13 shows water connection and water production by DWASA.

Table 3.12: Water demand and production by DWASA

Year	Approximate Population (million)	Water demand (Million liter)	Water supply capacity (Million liter)	Shortage	No of deep tube wells
2004	11.576	1850	1400	450	402
2005	12.15	1940	1460	480	418
2006	12.65	1900	1540	460	441
2007	13.15	1980	1660	320	465
2008	13.65	2050	1760	290	490
2009	14.15	2120	1880	240	519

Source: (Rahman and Al- Muyeed 2009)

Table 3.13: Year wise water connection and water production

	2004-2005	2005-2006	2006-2007	2007-2008	2008-2009
Deep tube well	418	441	465	490	519
Water treatment plant	4	4	4	4	4
Water Production (MLD)	1600	1669	1700	1760	1880
Water line (Km)	2500	2520.91	2533.73	2600	
Water connection	2,19,726	2,32,907	2,43,477	2,56,447	2600 2,783,68

Source: (Rahman and Al-Muyeed 2009)

By the end of 2009, DWASA had a production capacity of 1880 MLD out of which the major portion comes from ground water by deep tube-wells extraction. In the beginning of 2003 Saidabad Water Treatment Plant added 225 MLD to the distribution channels of DWASA. Hence a total 310.1 MLD from surface water is contributed to capacity of DWASA with capacity of Dhaka water works (Chandnighat) 18.5 MLD and Narayanganj water works 18.81 MLD. To meet the future demand of water to the city dwellers, DWASA is proposing some water supply and distribution projects. If all the above mentioned projects will be successful by the year 2010, the distribution capacity of DWASA will be 2700 MLD, which still lags behind the demand of the city dwellers.

Finally, some spare capacity is also useful for practical reasons since it can postpone the construction of phased extensions to expand the system.

3.9 Elements for Water Supply System

Most water supply system include relatively' massive structures (dam, intake, reservoirs, treatment plants distribution systems including overhead water tanks, etc) that require a long time in construction and are not easily and readily expanded. Accordingly, the principle system components are purposely made large enough to satisfy community needs for reasonable number of years. Selecting the initial or design capacity is not very simple. It calls for skill in prediction social and economic trends and a sound judgment in analyzing past experience and predicting future requirements. Among the needed estimates are following:

- The number of years, or design period for which the proposed water supply system and its component structures and equipment are to be adequate.
- The number of people, or design population, to be served.
- The rates of water use or design flows, in terms of per capita water consumption including industrial, commercial and fire requirements,
- The area to be served, or design area, and the allowances to be made for population density and areal water consumption from residential, commercial and industrial districts.

3.10 Designing Water Consumption

Design periods are chosen with the following factors in mind:

- Useful life of component structures and equipment taking into proper account of wear and tear.
- Ease or difficulty of extending or adding to the existing and planned works, including a consideration of their location
- Anticipated rate of population growth, including possible shift community, industrial and commercial development.
- Available water in source after design life.
- Performance rate of the works during their early years when the will not be loaded to the capacity.

Thus, it is seen that the economical period of design of structure of a water works is related to its length of life, initial cost, ease and cost of increasing its capacity, and possibility of obsolescence. In connection with the design water consumption at the end of the design period must also be estimated. Different units of the water works require different rates of consumption for design.

Design periods and water consumption data require commonly employed in practice are as follows:

- **Source structures**: The design period will depend upon the type of source. In case of groundwater it is easy to drill additional wells, the design period be short, usually 10 to 15 years. If a dam or an impounding reservoir is to be constructed for surface to supply, it is very difficult and costly to enlarge and therefore, the design period is considered to be 30 to 50 years. The design consumption will be the annual average.
- **Intakes and transmission lines from source to treatment plants:** The design period will depend upon the length of the life of the pipes and the type of intake structures used. It is very difficult to enlarge or replace these units and generally design consumption will depend upon the amount of storage provide in the city. Generally the average annual consumption is used.
- **Water treatment plants:** Design period is usually 20 to 30 years as additions can generally be made easily. Consumption required is annual average, maximum daily and sometimes maximum weekly.
- **Pumping plants:** The design period is generally in between 10 to 15 years, as additions and alterations can be done easily. Water consumptions needed are maximum hourly including fire demand and minimum hourly.
- **Distribution System:** The design period is 20 to 30 years as they are easy (comparatively) to extend. Sometimes, distribution systems are designed for indefinite period and the capacity of the system is made adequate for the highest development of the portion of the city it serves. Maximum hourly consumption including fire demand is required.
- **Overhead storage tanks:** The design period is generally 50 to 80 years as the construction cost is very high but sometimes they are designed for 30 to 60 years because it is easy to construct additional ones when needed. Consumptions needed are annual average, fire demand, and maximum weekly and maximum hourly.
- **Pipe:** For pipe more than 12 inch diameter, the design period is 20 to 30

years as replacement of smaller pipes is more costly in the long run. For pipes less than 12 inch in diameter, the design period is up to full development because requirements may change fast in the limited areas. Maximum hourly rate of water consumption is needed.

3.11 Conclusion

It is evident from the above discussion that the water consumption and demand is an integrated part of Municipal water supply system and therefore, a sustainable plan and implementation is essential to meet the demand of water of the dwellers.

The next chapter describes different water supply options and its hydraulics.

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