Module 4a: Water Demand

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Approach

- How much water is going to be required?
- Where is the water going to come from?
- How is the water going to be delivered?

How much water is going to be required?

Should be able to answer this question at two levels

Regional Level
- Estimate population growth
- Estimate water requirements for population

Subdivision Level
- Estimate water requirements for planned development

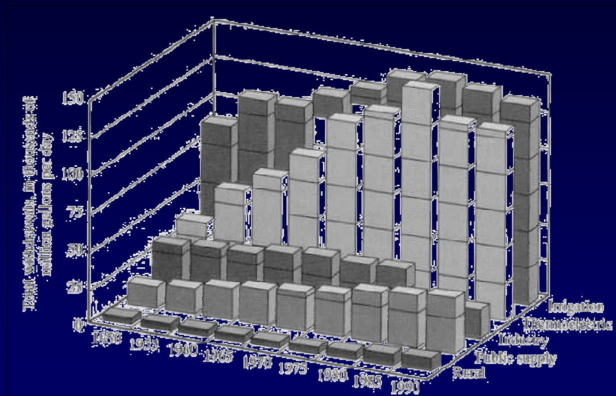
It is very difficult to make an accurate prediction, especially about the future.
Niels Bohr

How much water is going to be required? Water-using Sectors

- Agriculture
  - *Approximately 50% of withdrawn water is consumptively used*
  - *Withdrawals typically are seasonal and may be inversely related to natural water availability*
- Navigation
- Hydroelectric Power/Steam Electric Generation
- Manufacturing
  - *Process Waters*
  - *Cooling Waters*
- Natural Systems
  - *Instream flow requirements*
  - *Lake levels*
  - *Protection of fish and wildlife*
- Cities and Other Communities
  - *Domestic (drinking, cooking, laundry, sanitation)*
  - *Street cleaning*
  - *Fire demand*
  - *Landscaping*
  - *Commercial Use*
- Recreation

How much water is going to be required?

Problem arises in determining allocation of water between sectors.



Trend in Freshwater Withdrawals by Water-Use Category.

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer. Addison-Wesley. 1998.

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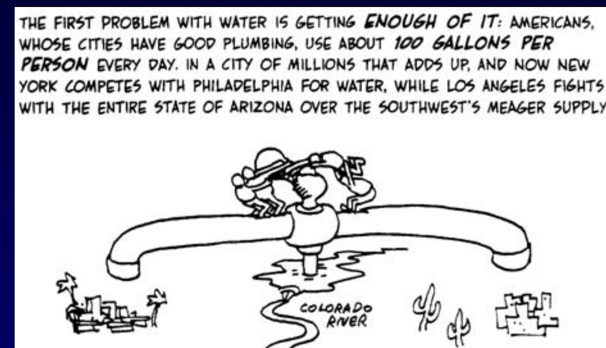


Trend in Freshwater Withdrawals by Water-Use Category.

From: *The Cartoon Guide to the Environment*. Larry Gonick and Alice Outwater. HarperPerennial. New York, NY. 1996.

How much water is going to be required?

How much water do certain water-using sectors need?!

Water Allowance for American Forces Fighting in France in WWI.

- From: *The Story of Man's Quest for Water*. Jasper Owen Draffin. The Garrard Press. 1939.

	Gallons per Man or Animal per day
Advancing Army, Men	0.5
Animal, Drinking	7.5
Army after 3 Days, Men	1.0
Field Hospitals	5.5
Rear Regions	10.0
Base Hospitals	25.0
General Use at Stables	10.0

How much water is going to be required?

How much water do certain water-using sectors need?!

Public Water Supply in Gallons Per Head Per Day

From: *Studies in Ancient Technology, Volume 2*. R.J. Forbes. E.J. Brill Publishers, 1964.

	50 B.C.	A.D. 100	1823	1830	1835	1936
Rome	198	300		250		150
Paris			3			
London			3		10.0	35.5
Manchester					5.5	33
Liverpool					3.5	36.5
Edinburgh					7.5	52
Glasgow					12.0	57
Leipzig						20
Frankfort						40
Munich						55
New York						120

How much water is going to be required?

How much water do certain water-using sectors need?!

Water Use in North American Cities

From: *Environmental Science and Engineering*, J.G. Henry and G.W. Heinke, Prentice-Hall, 1989.

Use	**Average Daily Consumption Per Person***		**Percentage of Total Use (%)**
	Lpcd	**Gpcd**	
Domestic	300	79	45
Commercial	100	26	15
Industrial	160	44	25
Other	100	26	15
TOTAL	660	175	100

Distribution of per capita water demand

Range (liters/day)/person	Number of systems	Percent of systems
190–370	30	7.7
380–560	132	33.7
570–750	133	33.9
760–940	51	13.0
950–1130	19	4.8
> 1140	27	6.9

Source: Reprinted from *1984 Water Utility Operating Data*, by permission. Copyright © 1986 American Water Works Association.

(Chin 2006 Table 2.5)

Regional Level

- **Amount of water needed in a certain area will depend on:**
  - Cost of Water
  - Conservation Regulations
  - Environmental Protection Regulations
  - Cost and Volume of Water Reuse
  - Economic Conditions
    - Availability of Funds
    - Availability of Wastewater Treatment
    - Individual Attitudes towards Conservation, Reuse, Cost

Regional Level

The amount of water used in a locality is directly related to the size of the population. Errors in projecting population changes affect water use projections as well.

Regional Level

- **Population Changes**

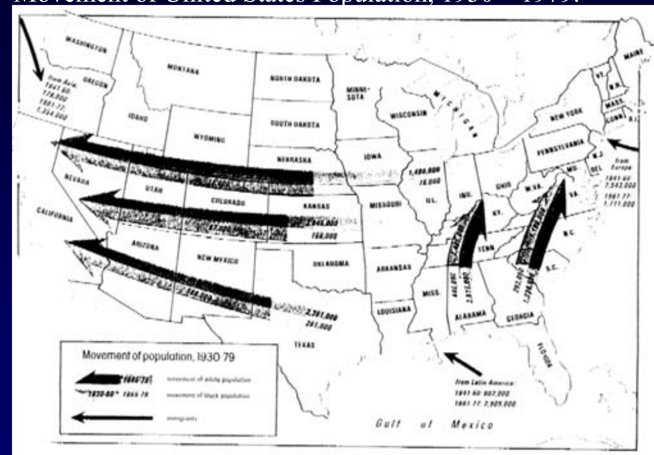
  For any time period:

  Δ Population = Births – Deaths + Immigration – Emigration

Predicted through the use of population projections made by demographers

Review of Past Population Changes

Movement of United States Population, 1930 – 1979.

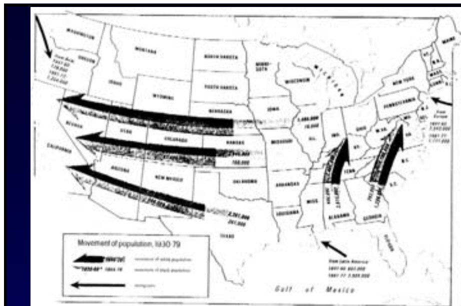


From: *The Times Concise Atlas of World History*. G. Barraclough, editor. Hammond and The London Times. 1982.

Review of Past Population Changes

Movement of United States Population, 1975 – 1980.

From: *Environmental Science, Action for a Sustainable Future, 3rd Edition*. D.D. Chiras. Benjamin/Cummings Publishers. 1990.



Review of Past Population Changes

Estimate population growth

Engineers normally do not conduct these analyses, as this is in the realm of social scientists and economists. Too many uncertainties exist in local and regional social-economic conditions to allow simple extrapolations of past conditions for the future. As an example, many smaller suburban communities actively recruit different types of industries that could have vastly different water demands and impacts on the local population.

Two Growth Models Typically Used: Check past census data to see which is more appropriate:

- Arithmetic Method
  Assumes constant amount of change in the population over time
- Exponential Growth
  Assumes a rate of increase which is proportional to population.

Arithmetic Method

$$P_t = P_0 + Kt$$

$$K = \frac{\Delta P}{\Delta t}$$

P_t = population at time t in future
P_o = present population
Kt = average change in population per unit time period

Exponential Method (Uniform Percentage Method)

$$P_t = P_0 e^{rt}$$

$$OR$$

$$\ln P_t = \ln P_0 + K' \Delta t$$

P_t = population at time t in future
P_o = present population
r = change in population per unit time
K′ = slope of the line of past population vs. time (on semi-log paper)
t = time for which population change is being forecast
Δt = time of population projection

Other Methods: Declining Growth Method

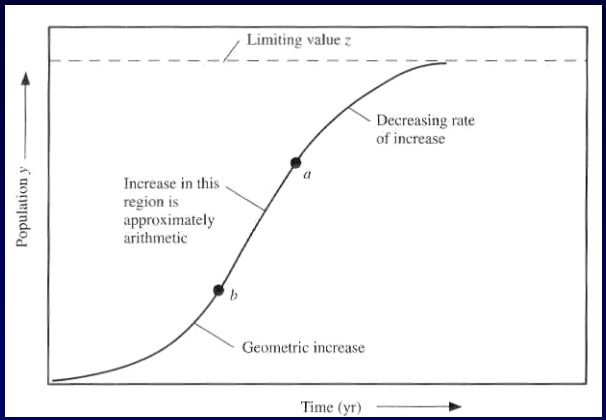
- Assumes city has limiting population
- Assumes that rate of growth is function of population deficit (difference between saturation population and actual population)

$$P = P_0 + (P_{sat} - P_0)(1 - e^{K''\Delta t})$$

$$K'' = -\frac{1}{n}\ln\left(\frac{P_{sat} - P}{P_{sat} - P_0}\right)$$

Where
P_{sat} = saturation population
P = population at future time (or later year when calculating K″)
P_0 = population at base year
n = time interval between successive censuses (time between collection of P_0 and P values for calculating K″)

Other Methods: Declining Growth Method



From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer. Addison-Wesley. 1998.

Other Methods: Ratio Method

- Use population forecasts from professional demographers for the appropriate region and ratio the design area's current population to the current population of the trend line
- Use the ratio calculated above to estimate the future population
- Method assumes that the area's population changes by the same ratio as the region

Other Methods: Curvilinear Method

- Graphically estimate future population based on recorded growths of larger cities (use data for other cites from the point at which they reached the current population of the design city/area)
- For example:
  - City A, the city being studied, is plotted up to 1990, the year in which its population was 51,000. City B reached 51,000 in 1950, and its growth is plotted from 1950 to 1990. Similarly, curves are drawn for cities C, D, and E from the years in which they reached A's 1990 population. A's growth curve is then projected by considering the recorded growth of the comparison cities.

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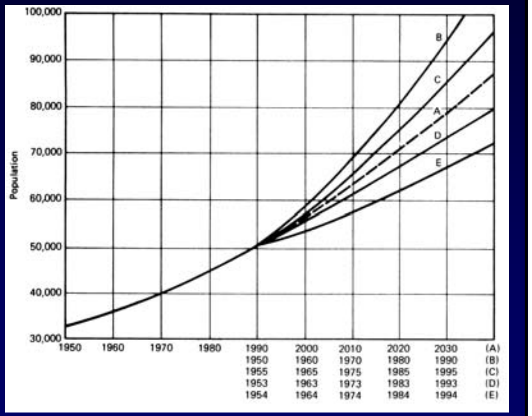
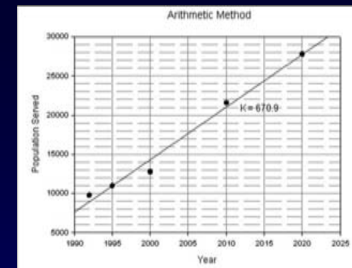
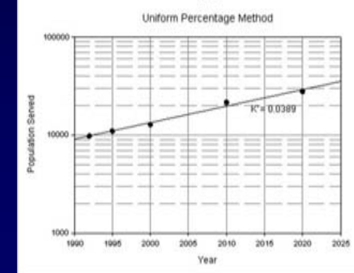


Example using Arithmetic and Uniform Percentage Method

Year	Population Total	Population Served	ln Population Served
1992	11300	9800	9.190
1995	12400	11000	9.306
2000	14200	12800	9.457
2010	22700	21600	9.980
2020	28400	27800	10.233

Example using Arithmetic and Uniform Percentage Method





Estimate water requirements for predicted population size

Varies greatly from city to city

Highly dependent on:

- climate
- economic conditions
- social attitudes toward environmental protection
- local conservation regulations
- tourism
- etc.

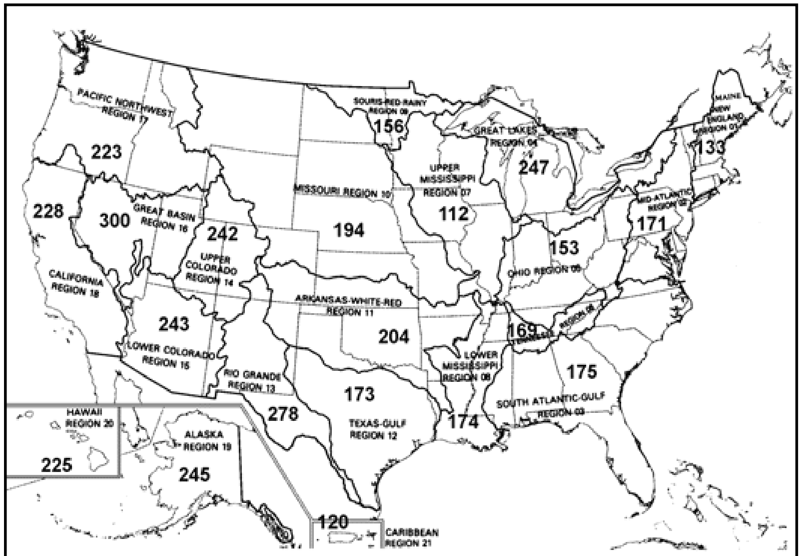
Population Density Estimations

Guide to Population Density

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer. Addison-Wesley. 1998.

Area Type	**Number of Persons Per Acre**
Residential	
Single-Family Units	5 – 35
Multiple-Family Units	30 – 100
Apartments	100 – 1000
Commercial Areas	15 – 30
Industrial Areas	5 – 15

- Average per capita use of public water supplies in the U.S. averages about 183 gallons per day (U.S.EPA, 1990).
- However, this number can vary greatly between regions and between communities



Average use per person (gal/day) of public water in the United States by USGS water region (Solley et al, 1993)

Future Per Capita Estimates of Water Use

Projected Consumption of Water for Various Purposes in the Year 2000

From: *Water Supply and Sewerage, Sixth Edition*. Terence J. McGhee. McGraw-Hill Publishing Company. 1991.

Use	Gallons Per Capita/Day	Percentage of Total
Domestic	79.2	44
Industrial	42.24	24
Commercial	26.4	15
Public	15.84	9
Loss and Waste	13.2	8
TOTAL	176.88	100

Factors Affecting Consumption of Water

- Metering↑ Consumption ↓
- Quality↑ Consumption ↑
- Pressure↑ Consumption ↑
- Rates↑ Consumption ↕
- Sewer Service↑ Consumption ↑
- Income↑ Consumption ↑
- City Size↑ Consumption ↑
- Industries↑ Consumption ↑
- Very cold↑ Consumption ↑
- Very hot↑ Consumption ↑

Table 2. Fate of Water in Public Water Supplies of the U. S., 1990.

Receiving Category	Volume (Mgal/Day)	Percentage of Total
Domestic	21,900	57
Commercial	5,900	15
Public Use Losses	5,460	14
Industrial	5,190	13
Thermoelectric Power	80	<1
Total	**38,530**	**100**

Subdivision Level: Estimate water requirements for planned development

- Many communities have master development plans which establish the allowable uses of various sub-areas: industrial, commercial, public, and residential.
- When such plans exist, they are the best point at which to begin since water consumption can normally be related to land use.

System Design

- Can do estimates based on number and/or types of structures in design area and using existing data.
- Residential:

Residential Water Consumption

From: *On-Site Wastewater Treatment: Educational Materials Handbook*. National Small Flows Clearinghouse. West Virginia University, 1987.

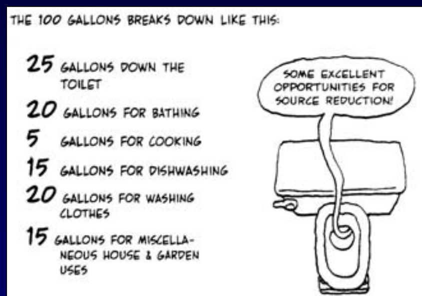
Home Uses	Daily Water Use Per Person	
	Gallons	Percent
Toilet	32	45
Bathing/Personal Hygiene	21	30
Laundry/Dishes	14	20
Drinking/Cooking	3	5
TOTAL	70	100

Residential Areas

- Easier to evaluate areas since anticipated population densities may be established from the residential classification.
- Once an estimate has been made of population density, the average and peak flows can be determined.

Residential System Design

- Water use often assumed to be 100 gallons/person/day.



From: *The Cartoon Guide to the Environment*. Larry Gonick and Alice Outwater. HarperPerennial. New York, NY. 1996.

Residential System Design

- **Residential Water-Use Models**

Winter use (indoor) in metered and sewered areas (single-family)

$$Q_1 = 234 + 1.451\ V - 45.9\ P_a - 2.59\ I_a$$

Where
- Q_1 = estimated water use
- V = market value of residence in \$1000s
- P_a = sum of water and sewer charges in \$/1000 gal
- I_a = effective Nordin/Taylor bill difference evaluated at average indoor use in \$/billing period

Winter use (indoor) in flat rate areas with sewers (apartments)

$$Q_2 = 28.9 + 1.576\ V - 33.6\ D_p$$

Where D_p = number of persons in dwelling unit

Residential System Design

- **Residential Water-Use Models**

Winter use (indoor) in flat-rate areas with septic tanks (multifamily)

$$Q_3 = 30.2 + 39.5\ D_p$$

Summer use (indoor and outdoor) in metered and sewered areas (eastern U.S.)

$$Q_6 = 385.0 + 2.876\ V - 285.8\ P_s - 4.35\ I_s + 157.77(B \bullet MD)$$

Where
- P_s = sum of water and sewer charges that vary with outdoor use in \$/1000 gal
- I_s = effective Nordin/Taylor bill difference applicable to outdoor use in \$/billing period
- B = irrigable landscape per dwelling unit in acres
- MD = summer season moisture deficit in inches

Industrial Areas

- Water use is industry-specific
- Highest industrial users of water usually do not use publicly supplied water
- For water main design, assume equivalent to high-density residential zone
- 20L/m^2-day or 100,000gal/acre-day

Commercial Areas

- Also specific for use – being highest for hotels and hospitals
- Offices and retail sales facilities may range up to 90 L/m^2-day or 1000,000 gal/acre-day for multi-story construction
- A reasonable average value for undefined commercial development is 40L/m^2-day or 45,000 gal/acre-day applied to the land area actually covered by structures, not including parking lots or grassed areas.

Multi-Family Residential and Commercial Water Use (Based on the Residential Water Use Research Project of The Johns Hopkins University and the Office of Technical Studies of the Architectural Standards Division of the Federal Housing Administration, 1963):

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer, Addison-Wesley. 1998.

	Break-down of Water Use	Average Annual Demand (gpd)	Maximum Hourly Demand Rate (gpd)	Ratio, Maximum Hourly to Average Annual	Average Annual Demand Per Unit
Miscellaneous Residential					
Apartment Building	22 units	3,430	11,700	3.41	156 gpd/unit
Motel	166 units	11,400	21,600	1.89	69 gpd/unit
Hotels					
Belvedere	275 rooms	112,000	156,000	1.39	407 gpd/room
Emerson	410 rooms	126,000			307 gpd/room
Office Buildings					
Commer. Credit	490,000 ft^2	41,400	206,000	4.89	0.084 gpd/ft^2

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	Break-down of Water Use	Average Annual Demand (gpd)	Maximum Hourly Demand Rate (gpd)	Ratio, Maximum Hourly to Average Annual	Average Annual Demand Per Unit
Office Buildings					
Internal Revenue	182,000 ft^2	14,900	74,700	5.01	0.082 gpd/ft^2
State Office Building	389,000 ft^2	27,000	71,800	2.58	0.070 gpd/ft^2
Shopping Centers					
Towson Plaza	240,000 ft^2	35,500	89,900	2.50	0.15 gpd/ft^2
Hillendale	145,000 ft^2	26,000			0.18 gpd/ft^2

Multi-Family Residential and Commercial Water Use (Based on the Residential Water Use Research Project of The Johns Hopkins University and the Office of Technical Studies of the Architectural Standards Division of the Federal Housing Administration, 1963):

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer, Addison-Wesley. 1998.

	Break-down of Water Use	Average Annual Demand (gpd)	Maximum Hourly Demand Rate (gpd)	Ratio, Maximum Hourly to Average Annual	Average Annual Demand Per Unit
Miscellaneous Commercial					
Laundries					
Laundromat	Ten 8-lb washers	1,840	12,600	6.85	184 gpd/washer
Commercial	Equal to 10 8-lb washers	2,510	16,200	6.45	251 gpd/ washer equiv.
Car Wash	24 cars/hr capacity	7,930	75,000	9.46	330 gpd/car/hr of capacity
Service Station	1 lift	472	12,500	26.5	472 gpd/lift

From: *Water Resources Engineering, 1st Edition*. Larry W. Mays, John Wiley & Sons, Inc. 2001. (Table 11.1.4 page 346)

	Units	Average Use	Peak Use
Hotels	L/day/m^2	10.4	17.6
Motels	L/day/m^2	9.1	63.1
Barber shops	L/day/barber chair	207	1470
Beauty shops	L/day/station	1020	4050
Restaurants	L/day/seat	91.6	632
Night clubs	L/day/person served	5	5
Hospitals	L/day/bed	1310	3450
Nursing homes	L/day/bed	503	1600
Medical offices	L/day/m^2	25.2	202
Laundry	L/day/m^2	10.3	63.9

From: *Water Resources Engineering, 1st Edition*. Larry W. Mays, John Wiley & Sons, Inc. 2001. (Table 11.1.4 page 346)

	Units	Average Use	Peak Use
Laundromats	L/day/m^2	88.4	265
Retail space	L/day/sales m^2	4.3	11
Elementary schools	L/day/student	20.4	186
High schools	L/day/student	25.1	458
Bus-rail depot	L/day/m^2	136	1020
Car washes	L/day/inside m^2	194.7	1280
Churches	L/day/member	0.5	17.8
Golf-swim clubs	L/day/member	117	84
Bowling alleys	L/day/alley	503	503
Residential colleges	L/day/student	401	946

From: *Water Resources Engineering, 1st Edition*. Larry W. Mays, John Wiley & Sons, Inc. 2001. (Table 11.1.4 page 346)

	Units	Average Use	Peak Use
New office buildings	L/day/m^2	3.8	21.2
Old office buildings	L/day/m^2	5.8	14.4
Theaters	L/day/seat	12.6	12.6
Service stations	L/day/inside m^2	10.2	1280
Apartments	L/day/occupied unit	821	1640
Fast food restaurants	L/day/establishment	6780	20300

From: *Water Resources Engineering, 1st Edition*. Larry W. Mays, John Wiley & Sons, Inc. 2001. (Table 11.1.5 Page 347)

	Units	Average Use
Washing machine	L/load	130 – 270
Standard toilet	L/flush	10 – 30
Ultra volume toilet	L/flush	≤ 6
Silent leak	L/day	≥ 150
Nonstop running toilet	L/minute	≤ 20
Dishwasher	L/load	50 –120
Water-saver dishwasher	L/load	40 –100
Washing dishes with tap running	L/minute	≤ 20
Washing dishes in filled sink	L	20 – 40
Running garbage disposal	L/minute	10 – 20
Bathroom faucet	L/minute	≤ 20

From: *Water Resources Engineering, 1st Edition*. Larry W. Mays, John Wiley & Sons, Inc. 2001. (Table 11.1.5 Page 347)

	Units	Average Use
Brushing teeth	L	8
Shower head	L/minute	20 – 30
Low-flow shower head	L/minute	6 – 11
Filling bathtub	L	100 – 300
Watering 750-m^2 lawn	L/month	7600 – 16000
Standard sprinkler	L/hour	110 – 910
One drip-irrigation emitter	L/hour	1 – 10
½-Inch diameter hose	L/hour	1100
5/8-Inch diameter hose	L/hour	1900
¾-Inch diameter hose	L/hour	2300

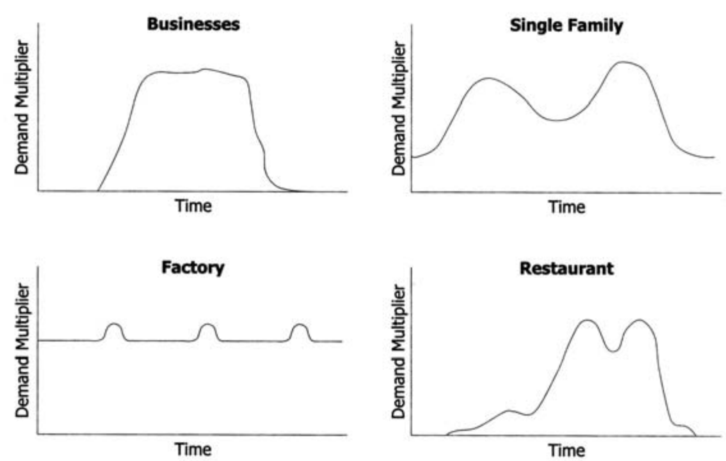
From: *Water Resources Engineering, 1st Edition*. Larry W. Mays, John Wiley & Sons, Inc. 2001. (Table 11.1.5 Page 347)

	Units	Average Use
Washing car with running water	L/20 minutes	400 – 800
Washing car with pistol-grip faucet	L/20 minutes	≥ 60
Uncovered pool	L lost/month	3000 – 11000+
Covered pool	L lost/month	300 – 1200

Given average annual consumption rates, still need to estimate peak demand because

- Water use varies during the day
- Water use varies from day to day
- Water use varies weekly and seasonally

Diurnal curves for different user categories



(Walski, *et al.* 2001 figure 4.8)

Daily Water-Use Patterns in Residential Area: Maximum Day and Minimum Day

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer, Addison-Wesley. 1998.

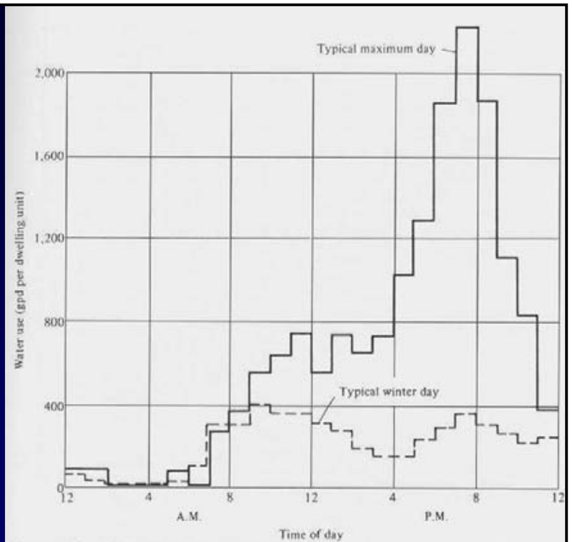


Figure 4.2 Daily water use patterns, maximum day and winter day. (From Residential Water-Use Research Project, Johns Hopkins University and Federal Housing Administration, 1963.)

Daily Water Use Patterns: Maximum Day and Winter Day

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer, Addison-Wesley. 1998.

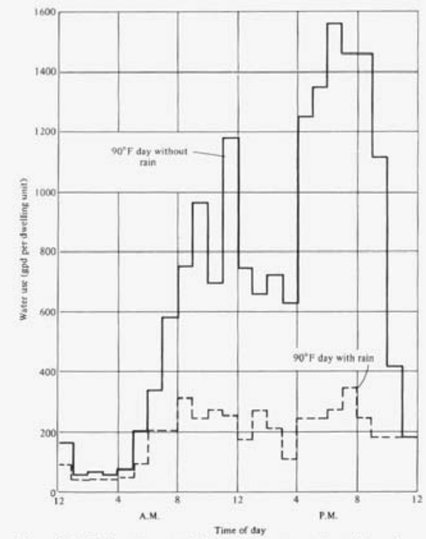
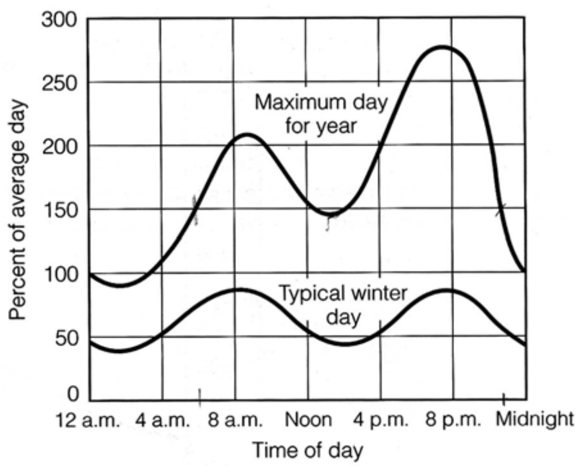


Figure 4.3 Daily water use patterns in R-6 area: maximum day and minimum day. (From Residential Water-Use Research Project, Johns Hopkins University and Federal Housing Administration, 1963.)

Typical daily cycles in water demand



(Chin 2006 Figure 2.24)

Water and Wastewater Flow (No Lawn Irrigation)

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer, Addison-Wesley. 1998.

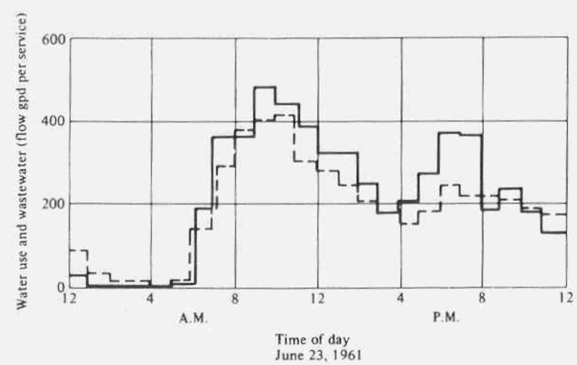


Figure 4.14 Comparison of water use (solid line) and wastewater flow (dashed lines) on days when little sprinkling occurred. (From Residential Water-Use Research Project, Johns Hopkins University and Federal Housing Administration, 1963.)

Peak Water Use Estimation

- Consumption rate for max day = 180% of the annual average daily consumption
- Consumption rate for max week = 148% of the annual average daily consumption
- Consumption rate for max month = 128% of the annual average daily consumption
- Consumption rate for max hour = 150% of the max day,

  or 270% of the annual average daily consumption

Peak Water Use Estimation: Estimation of Average Daily Rate Based on a Maximum Time Period

Goodrich Formula:

- Estimates maximum demand (expressed as daily water demand based on time period for which maximum water demand is desired) for community when given annual average per capita daily water use rate:

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

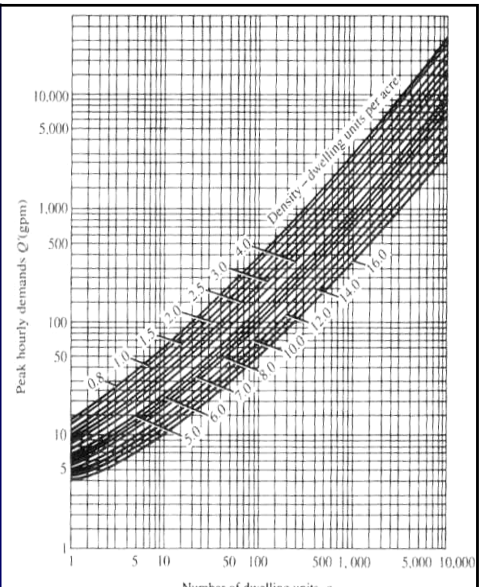
where p = percentage of average annual rate (volume/day) used in period of time of interest

t = length of period for which peak demand is required (days) (valid time periods – 2 hours to 360 days)

- **Daily rate based upon a maximum hour is approximately equal to 150 percent of average annual daily rate.

Peak Hourly Demand vs. Number of Dwelling Units

From: *Water Supply and Pollution Control, Sixth Edition*. Warren Viessman, Jr. and Mark J. Hammer. Addison-Wesley. 1998.



Typical demand factors

Condition	Range of demand factors	Typical value
Daily average in maximum month	1.10–1.50	1.20
Daily average in maximum week	1.20–1.60	1.40
Maximum daily demand	1.50–3.00	1.80
Maximum hourly demand	2.00–4.00	3.25
Minimum hourly demand	0.20–0.60	0.30

Source: Velon and Johnson (1993). Reprinted by permission of The McGraw-Hill Companies.

(Chin 2006 Table 2.6)

Fire Demand
(Equation from the National Board of Fire Underwriters for communities with less than 200,000 people)

$$Q = 1020\sqrt{P}\left(1 - 0.01\sqrt{P}\right)$$

Where Q = demand in gallons/min

P = population in thousands

NOTE: Used when calculating fire demand for sizing reservoirs! This equation is used for the community as a whole (averaged conditions, not for water distribution system pipes!).

Fire Demand: Sizing for Communities

- Community of 175,000 people. Calculate fire demand:

P = 175

$$Q = 1020\sqrt{P}\left(1 - 0.01\sqrt{P}\right)$$
$$Q = 1020\sqrt{175}\left(1 - 0.01\sqrt{175}\right)$$
$$Q = 11{,}708\,gpm = 44{,}314\,L/\min$$

Or rounding to 12,000 gpm or 45,000 L/min

Fire Demand
(from the Insurance Services Office)

$$Q = 18C\sqrt{A}$$

where Q = fire demand in gallons/minute

A = total floor area excluding basements, ft^2

C = coefficient for construction materials

C = 1.5	for wood frame
C = 1.0	for ordinary construction
C = 0.8	for non-combustible construction
C = 0.6	for fire-resistant construction

For this equation, flow should be:

•Greater than 500 gpm, but

•Less than 6,000 gpm (single-story structure); 8,000 gpm (single building); 12,000 gpm (single fire)

Fire Demand
(from the Insurance Services Office)

For example:

- Building is ordinary construction, with an area on each floor of 1000 ft^2 (no basement), and six stories.

$$Q = 18C\sqrt{A}$$
$$Q = 18(1.0)\sqrt{(1000\,ft2/story)(6\,stories)}$$
$$Q = 1{,}394\,gpm = 5{,}276\,L/\min$$

or rounding to 1,400 gpm or 5,300 L/min

In metric units (AWWA 1992):

$$NFF_i = C_i O_i \left(X + P\right)_i$$

C is the construction factor based on the size of the building and its construction,

O is the occupancy factor reflecting the kinds of materials stored in the building (ranging from 0.75 to 1.25), and

(X+P) is the sum of the exposure factor and the communication factor that reflect the proximity and exposure of the other buildings.

$$C_i = 220\, F \sqrt{A_i}$$

C (L/min),

A (m^2) is the effective floor area, typically equal to the area of the largest floor plus 50% of all other floors,

F is a coefficient based on the class of construction

Construction coefficient, F

Class of construction	Description	*F*
1	frame	1.5
2	joisted masonry	1.0
3	noncombustible	0.8
4	masonry, noncombustible	0.8
5	modified fire resistive	0.6
6	fire resistive	0.6

Source: AWWA (1992).

(Chin 2006 Table 2.7)

Occupancy factors, O_i

Combustibility class	Examples	O_i
C-1 Noncombustible	steel or concrete products storage	0.75
C-2 Limited combustible	apartments, churches, offices	0.85
C-3 Combustible	department stores, supermarkets	1.00
C-4 Free burning	auditoriums, warehouses	1.15
C-5 Rapid burning	paint shops, upholstering shops	1.25

Source: Reprinted from *Distribution System Requirements for Fire Protection* (M31), by permission. Copyright © 1992 American Water Works Association.

(Chin 2006 Table 2.8)

Needed fire flow for one- and two-family dwellings

Distance between buildings (m)	Needed fire flow (L/min)
> 30	2,000
9.5–30	3,000
3.5–9.5	4,000
< 3.5	6,000

Source: Reprinted from *Distribution System Requirements for Fire Protection* (M31), by permission. Copyright © 1992 American Water Works Association.

(Chin 2006 Table 2.9)

Table 4.3 Needed fire flow for residences two stories and less

Distance Between Buildings (ft)	Fire Flow (gpm)
More than 100	500
31-100	750
11-30	1000
Less than 11	1500

(Walski, *et al.* 2001)

Required fire flow durations

Required fire flow (L/min)	Duration (h)
< 9000	2
11,000–13,000	3
15,000–17,000	4
19,000–21,000	5
23,000–26,000	6
26,000–30,000	7
30,000–34,000	8
34,000–38,000	9
38,000–45,000	10

Source: Reprinted from *Distribution System Requirements for Fire Protection* (M31), by permission. Copyright © 1992 American Water Works Association.

(Chin 2006 Table 2.10)

Example 2.15 from Chin 2006

Estimate the flowrate and volume required to provide adequate protection to a 10-story noncombustible building with and effective floor area of 8,000 m^2.

$$NFF_i = C_i O_i (X + P)_i \qquad C_i = 220F\sqrt{A_i}$$

The construction factor is calculated as (F=0.8 for class 3 noncombustible construction and the floor area is 8,000 m^2):

$$C_i = 220(0.8)\sqrt{8000m^2} = 16{,}000L/\min$$

The occupancy factor C is 0.75 (C-1 noncombustible) and the (X+P) is estimated using the median value of 1.4. Therefore, the required fire flow is:

$$NFF_i = (16{,}000L/\min)(0.75)(1.4) = 17{,}000\,L/\min$$

The flow must be maintained for a duration of 4 hours, and the required volume is therefore:

$$V = 17{,}000\,L/\min(4\,hours)(60\min/hr) = 4.08x10^6\,L = 4{,}080m^3$$

Fire Demand

Add fire demand to maximum rate

Minimum Flows

- Usually 25 – 50% daily average
- Less important but is considered in the design of pumping plants
- Depends largely on loss and waste, and night industrial use

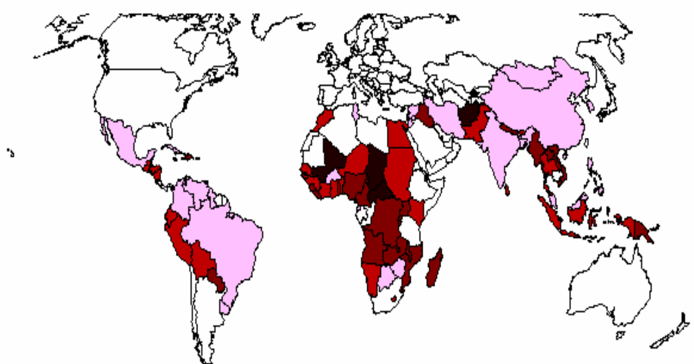
Where is the water going to come from?

Design periods and capacities in water-supply systems

Component	Design period (years)	Design capacity
Sources of supply:		
River	indefinite	maximum daily demand
Wellfield	10–25	maximum daily demand
Reservoir	25–50	average annual demand
Pumps:		
Low-lift	10	maximum daily demand, one reserve unit
High-lift	10	maximum hourly demand, one reserve unit
Water-treatment plant	10–15	maximum daily demand
Service reservoir	20–25	working storage plus fire demand plus emergency storage
Distribution system:		
Supply pipe or conduit	25–50	greater of (1) maximum daily demand plus fire demand, or (2) maximum hourly demand
Distribution grid	full development	same as for supply pipes

Source: Reprinted by permission of Waveland Press, Inc. from R. S. Gupta, *Hydrology and Hydraulic Systems.* (Prospect Heights, IL; Waveland Press, Inc., 1989 [reissued 1995]). All rights reserved.

(Chin 2006 Table 2.11)

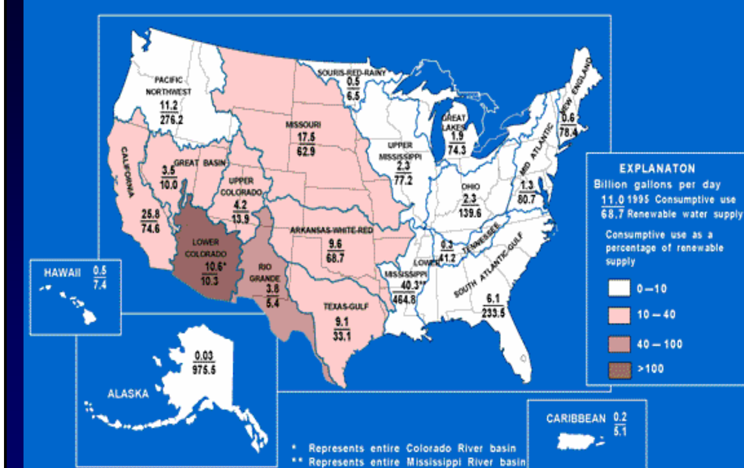


Percent of population without access
- No data
- 1% - 25%
- 26% - 50%
- 51% - 75%
- 76% - 100%

Populations without access to safe drinking water

from The World's Water
The Biennial Report on Freshwater Resources
(Gleick 1998)

CONSUMPTIVE USE AND RENEWABLE WATER SUPPLY, BY WATER-RESOURCES REGION



USGS

Regional Planning Level

- Determine if current sources are adequate based on predicted growth
- Identify potential new sources
- Develop conservation strategies
- (reducing system loss, education, regulations, etc.)

Must consider competing uses of resource

Irrigation for Agriculture
Industry Withdrawals
Sustaining Navigation
Cities Downstream
Sustaining Natural Systems
  in-stream flow requirements
  minimum lake levels
  protection of fish and wildlife
Hydroelectric Power/Steam Electric Generation
Recreation

Subdivision Level

- Check with municipalities or county to determine the water provider for the area in which you are working
- How you proceed will depend on the water provider

Birmingham Water Works Board

- Developer provides development plan to BWWB
- BWWB designs distribution system and determines cost of construction
- Developer pays cost up-front
- BWWB constructs distribution system

Shelby County

- Developer contracts with engineer to design distribution system
- Developer provides design to Shelby county
- Shelby county reviews and approves
- Developer constructs system
- Shelby county inspects along the way
- After completion and final inspection, Shelby county takes over system as part of their own

How is the water going to be delivered?

Designing the distribution system

Methods of Water Distribution

- Gravity
  - Dependable
  - Source of supply must be located well above the city
  - High-pressure demand for fire-fighting may require pumper trucks
- Pumping without Storage
  - Least Desirable
  - Pressures vary substantially with variations in flow
  - Provides no reserve if power failure

Methods of Water Distribution, cont.

- Pumping with Storage
  - Most common
  - Water supplied at approximately uniform rate
  - Flow in excess of consumption stored in elevated tanks
  - Tank water provides flow and pressure when use is high
    - Fire-fighting
    - High-use hours
    - Flow during power failure
  - Storage volume throughout system and for individual service areas should be approximately 15 – 30% of maximum daily rate.

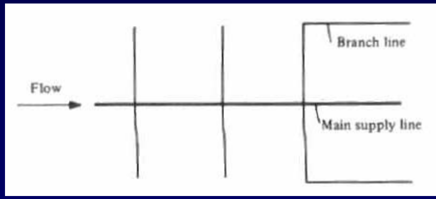
Water Distribution System Components

- Pumping Stations
- Distribution Storage
- Distribution System Piping

Other water system components include water source and water treatment

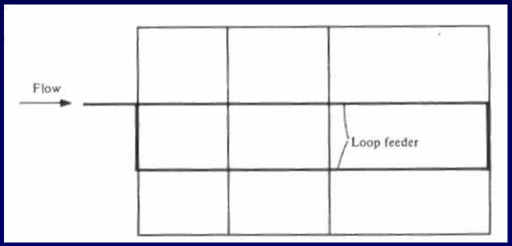
Types of Distribution System

- Branch
  - No circulation
  - Has terminals and dead ends



Types of Distribution System

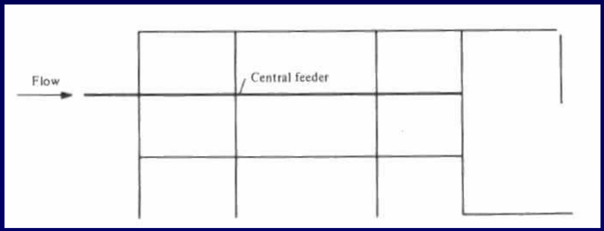
- Grid
  - Furnishes supply from more than one direction
  - In case of water main break, very few people are inconvenienced



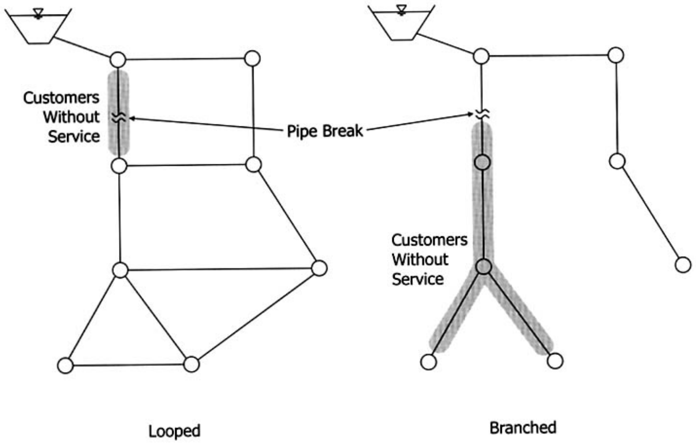
Types of Distribution System, cont.

- Combination
  - Grids cover most of the system
  - Terminals are side streets and houses only

Most common system in urban areas



Looped and branched networks after network failure



(Walski, *et al.* 2001 figure 1.2)

The Pipe System

- Primary Mains (Arterial Mains)
  - Form the basic structure of the system and carry flow from the pumping station to elevated storage tanks and from elevated storage tanks to the various districts of the city
    - Laid out in interlocking loops
    - Mains not more than 1 km (3000 ft) apart
    - Valved at intervals of not more than 1.5 km (1 mile)
    - Smaller lines connecting to them are valved

The Pipe System, Cont.

- Secondary Lines
  - Form smaller loops within the primary main system
  - Run from one primary line to another
  - Spacings of 2 to 4 blocks
  - Provide large amounts of water for fire fighting with out excessive pressure loss

The Pipe System, Cont.

- Small distribution lines
  - Form a grid over the entire service area
  - Supply water to every user and fire hydrants
  - Connected to primary, secondary, or other small mains at both ends
  - Valved so the system can be shut down for repairs
  - Size may be dictated by fire flow except in residential areas with very large lots

Pipe sizes in Municipal Distribution Systems

- Small distribution lines providing only domestic flow may be as small as 4 inches, but:
  - < 1300 ft in length if dead ended, or
  - < 2000 ft if connected to system at both ends.
- Otherwise, small distribution mains > 6 in
- High value districts – minimum size 8 in
- Major streets – minimum size 12 in

- Fire-fighting requirements
  > 150 mm (6 in.)
- National Board of Fire Underwriters
  > 200 mm (8 in.)

Velocity in Municipal Distribution Systems

(McGhee, *Water Supply and Sewerage, 6th Edition*)

- Normal use ≤ 1m/s, (3 ft/s)
- Upper limit = 2 m/s (6 ft/s) (may occur in vicinity of large fires)

(Viessman and Hammer, *Water Supply and Pollution Control, 6th Edition*)

$1 \leq V \leq 1.7$ m/s ($3 \leq V \leq 5$ ft/s)

Pressure in Municipal Distribution Systems (American Water Works Association)

AWWA recommends normal static pressure of 400-500kPa, 60-75lb/in^2

- supplies ordinary uses in building up to 10 stories
- will supply sprinkler sytem in buildings up to 5 stories
- will provide useful fire flow without pumper trucks
- will provide a relatively large margin of safety to offset sudden high demand or closure of part of the system.

Pressure in Municipal Distribution Systems (McGee)

- Pressure in the range of 150 – 400kPa (20 to 40 lb/in^2) are adequate for normal use and may be used for fire supply in small towns where building heights do not exceed 4 stories.

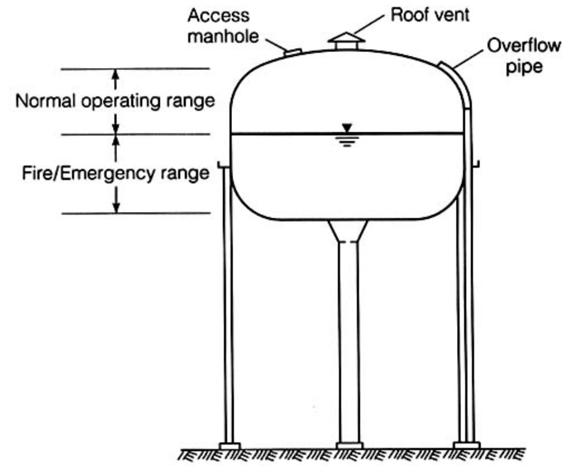
Minimum acceptable pressures in distribution systems

Demand condition	Minimum acceptable pressure (kPa)
Average daily demand	240–410
Maximum daily demand	240–410
Maximum hourly demand	240–410
Fire situation	> 140
Emergency conditions	> 140

Source: GLUMB (1987).

(Chin 2006 Table 2.12)

Typical elevated storage tank



(Chin 2006 Figure 2.27)