Types of Water Resource Systems

- Water Use
  - – Provide specified level of service to meet societal need
  - – Capacity dictated by population of service area, commercial and industrial requirements, economic design life of system
  - – Examples
    - Domestic and industrial water supply
    - Institutional (hospitals, schools, etc.)
    - Recreational (parks, golf courses)
    - Fire control
    - Wastewater collection/treatment
    - Irrigation
    - Hydropower generation
    - In-stream flows for habitat preservation/restoration
    - Leaks (not a use, but a demand that must be considered)

Types of Water Resource Systems

- Water Control
  - – Control spatial and temporal distribution of surface runoff (i.e., flooding)
  - – Capacity dictated by natural variation in flow combined with human alteration of environment and consequences of failure
  - – Examples
    - Storm sewers
    - Detention ponds and flood-control reservoirs

Design of Water Resource Systems

- Always Related to Perceived Risk, Quantified in Terms of Annual Probability or “Return Period” (1/Frequency) of Failure
  - – Frequency-based
    - Return period of event to be protected against is chosen *a priori*
    - Generally applied to minor structures with low costs for failure
  - – Risk-based
    - Design based on attempt to minimize total costs (capital plus cost of failure x probability of failure)
    - Generally applied to larger structures with high costs for failure (human injury or death; substantial societal or ecosystem disruption)
  - – Critical-event-based
    - Design attempts to avoid specified event, regardless of return period or cost
    - Applied to cases where failure would be truly catastrophic

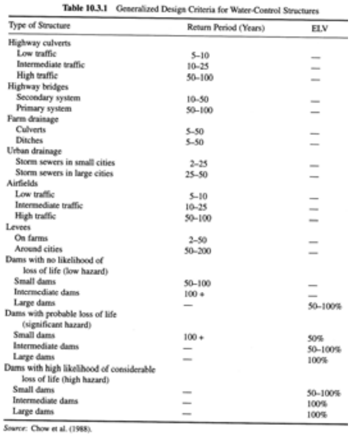
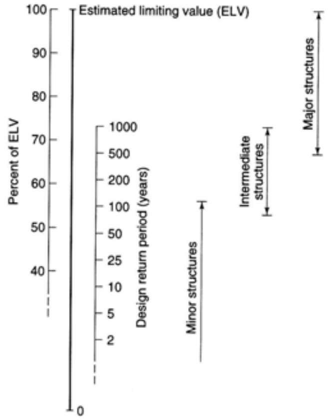


Table 10.3.1 Generalized Design Criteria for Water-Control Structures

Type of Structure	Return Period (Years)	ELV
Highway culverts		
Low traffic	5–10	—
Intermediate traffic	10–25	—
High traffic	50–100	—
Highway bridges		
Secondary system	10–50	—
Primary system	50–100	—
Farm drainage		
Culverts	5–50	—
Ditches	5–50	—
Urban drainage		
Storm sewers in small cities	2–25	—
Storm sewers in large cities	25–50	—
Airfields		
Low traffic	5–10	—
Intermediate traffic	10–25	—
High traffic	50–100	—
Levees		
On farms	2–50	—
Around cities	50–200	—
Dams with no likelihood of loss of life (low hazard)		
Small dams	50–100	—
Intermediate dams	100 +	—
Large dams	—	50–100%
Dams with probable loss of life (significant hazard)		
Small dams	100 +	50%
Intermediate dams	—	50–100%
Large dams	—	100%
Dams with high likelihood of considerable loss of life (high hazard)		
Small dams	—	50–100%
Intermediate dams	—	100%
Large dams	—	100%

Source: Chow et al. (1988).



Design for Public Water-Supply

- Estimate Average Daily Demand (ADD)
  - – Project population or land-use for specified time horizon (usually done by urban or regional planners, not engineers, these days)
  - – Estimate demand for projected conditions
    - Population-based: Vol/person-d (e.g., gpcd or Equivalent Residential Units [ERUs])
    - Land-use-based: Vol/area-d (e.g. gal/acre-d or ERUs); estimates available for low-, medium-, or high-density residential; office commercial; retail; heavy industrial; schools; etc.
    - Usage-unit-based: e.g., Vol/unit-d (e.g., gal/passenger-d for airports; gal/room-d for hotels; or ERUs)

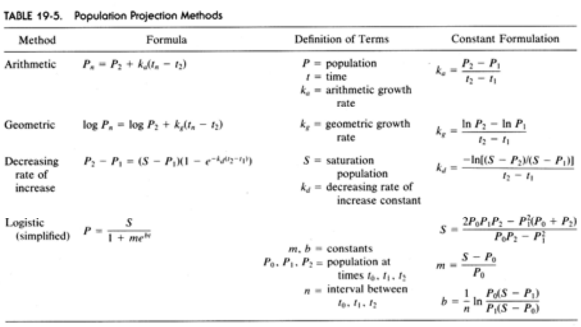


TABLE 19-5. Population Projection Methods

Method	Formula	Definition of Terms	Constant Formulation
Arithmetic	$P_n = P_2 + k_a(t_n - t_2)$	P = population t = time k_a = arithmetic growth rate	$k_a = \frac{P_2 - P_1}{t_2 - t_1}$
Geometric	$\log P_n = \log P_2 + k_g(t_n - t_2)$	k_g = geometric growth rate	$k_g = \frac{\ln P_2 - \ln P_1}{t_2 - t_1}$
Decreasing rate of increase	$P_2 - P_1 = (S - P_1)(1 - e^{-k_d(t_2 - t_1)})$	S = saturation population k_d = decreasing rate of increase constant	$k_d = \frac{-\ln[(S - P_2)/(S - P_1)]}{t_2 - t_1}$
Logistic (simplified)	$P = \frac{S}{1 + me^{bt}}$	m, b = constants P_0, P_1, P_2 = population at times t_0, t_1, t_2 n = interval between t_0, t_1, t_2	$S = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$ $m = \frac{S - P_0}{P_0}$ $b = \frac{1}{n} \ln \frac{P_0(S - P_1)}{P_1(S - P_0)}$

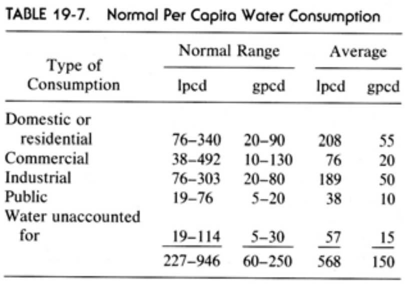


TABLE 19-7. Normal Per Capita Water Consumption

Type of Consumption	Normal Range		Average	
	lpcd	gpcd	lpcd	gpcd
Domestic or residential	76–340	20–90	208	55
Commercial	38–492	10–130	76	20
Industrial	76–303	20–80	189	50
Public	19–76	5–20	38	10
Water unaccounted for	19–114	5–30	57	15
	227–946	60–250	568	150

Note: Much of this kind of data in textbooks is very old

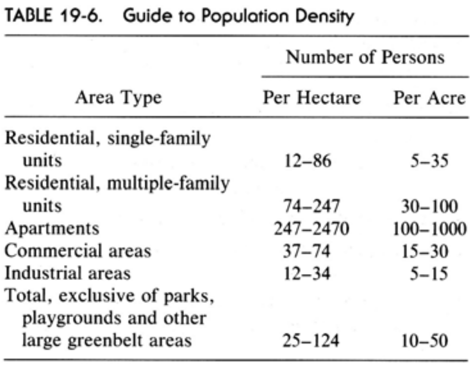


TABLE 19-6. Guide to Population Density

Area Type	Number of Persons	
	Per Hectare	Per Acre
Residential, single-family units	12–86	5–35
Residential, multiple-family units	74–247	30–100
Apartments	247–2470	100–1000
Commercial areas	37–74	15–30
Industrial areas	12–34	5–15
Total, exclusive of parks, playgrounds and other large greenbelt areas	25–124	10–50

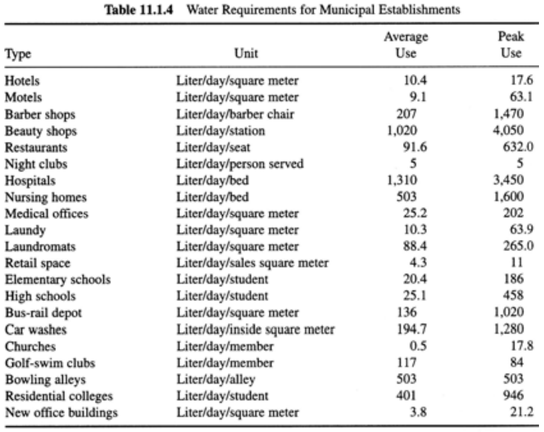


Table 11.1.4 Water Requirements for Municipal Establishments

Type	Unit	Average Use	Peak Use
Hotels	Liter/day/square meter	10.4	17.6
Motels	Liter/day/square meter	9.1	63.1
Barber shops	Liter/day/barber chair	207	1,470
Beauty shops	Liter/day/station	1,020	4,050
Restaurants	Liter/day/seat	91.6	632.0
Night clubs	Liter/day/person served	5	5
Hospitals	Liter/day/bed	1,310	3,450
Nursing homes	Liter/day/bed	503	1,600
Medical offices	Liter/day/square meter	25.2	202
Laundy	Liter/day/square meter	10.3	63.9
Laundromats	Liter/day/square meter	88.4	265.0
Retail space	Liter/day/sales square meter	4.3	11
Elementary schools	Liter/day/student	20.4	186
High schools	Liter/day/student	25.1	458
Bus-rail depot	Liter/day/square meter	136	1,020
Car washes	Liter/day/inside square meter	194.7	1,280
Churches	Liter/day/member	0.5	17.8
Golf-swim clubs	Liter/day/member	117	84
Bowling alleys	Liter/day/alley	503	503
Residential colleges	Liter/day/student	401	946
New office buildings	Liter/day/square meter	3.8	21.2

Example

- A community is planning for a population increase from 50,000 to 75,000. Zoning for the expansion is as follows:

	Area	Typical Water Duty
– Single-family residential	800 ac	2300 gal/ac-d
– Multi-family residential	200 ac	4160 gal/ac-d
– Office commercial	100 ac	2030 gal/ac-d
– Retail commercial	50 ac	2040 gal/ac-d
– Light industrial	10 ac	1620 gal/ac-d

Additional plans include a 2-ac park (2020 gal/ac-d) and an airport for 10,000 passengers per day (4 gal/passenger-d). Estimate the incremental ADD.

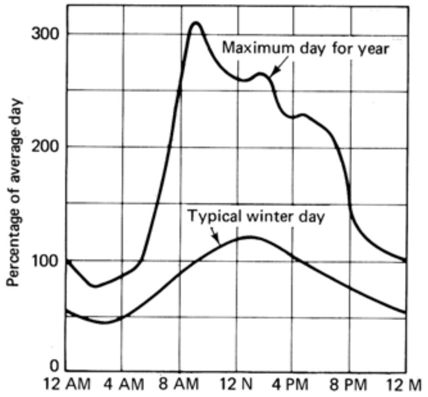
$$\text{Add'l ADD} = (800)(2300) + (200)(4160) + (100)(2030)$$

$$(50)(2040) + (10)(1620) + (10,000)(4) + (2)(2020)$$

$$= 3.04\text{x}10^6 \text{ gal/d} = 3.04 \text{ mgd}$$

Design for Public Water-Supply

- Estimate Extreme Demands from Existing Local Data or Similar Communities
  - Maximum Daily Demand (MDD), 1.5-3.0 (typically ~2) x ADD
  - Peak Hourly Demand (PHD), 2-7 (typically ~4.5) x ADD
  - Fire suppression demand set by National Board of Fire Underwriters
- Per WAC 246-290, hydraulic design must meet:
  - PHD, while maintaining ≥30 psi (210 kPa) throughout system
  - MDD plus fire flow, while maintaining ≥20 psi (140 kPa) throughout system



Example

- For the preceding example community, the fire-flow requirement is:

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

$$Q = \left(0.0643\ \text{m}^3/\text{s}\right)\left(\sqrt{P} - 0.01P\right)$$

where Q is discharge while meeting minimum pressure requirements, and P is population in thousands. Estimate the incremental fire-flow requirement and explore how the population increase could affect the required system hydraulic capacity, assuming MDD/ADD is 1.5 and PHD/ADD is 2.5.

Example

- Population increase is from 50,000 to 75,000, so:

$$Q_{fire,1} = (1020\ \text{gpm})\left(\sqrt{50} - 0.01(50)\right) = 6702\ \text{gpm}$$

$$Q_{fire,2} = (1020\ \text{gpm})\left(\sqrt{75} - 0.01(75)\right) = 8068\ \text{gpm}$$

$$\Delta Q_{fire} = 1366\ \text{gpm} = 1.97\ \text{mgd}$$

- Design flow for system hydraulics is MDD+Fire-flow or PHD, whichever is greater.

$$\Delta\text{MDD} + \Delta Q_{fire} = (1.5*3.04 + 1.97)\text{mgd} = 6.53\ \text{mgd}$$

$$\Delta\text{PHD} = (2.5*3.04)\text{mgd} = 7.60\ \text{mgd}$$

- The increase in PHD is greater than the increase in MDD+fire-flow. These would have to be added to the values for the base condition to determine which one controls the new system hydraulic design.

Meeting Unsteady Demand with a Steady Supply

- Withdrawals from source and treatment processes often operate best if flow is steady
- Demand for water varies during a day and seasonally
- Matching inflow to outflow, when one or both are variable and/or uncertain, arises in many contexts
  - Water supply on daily or seasonal scale (distribution or service reservoir)
  - Storm water mgmt to reduce flooding and improve water quality of discharge (detention basin)
  - Drought mitigation over months to years (impounding or water supply reservoir)
  - Balancing wastewater flows to facilitate smooth operation of treatment processes (equalization basin, or in-pipe equalization)
  - Intermittent, steady pumping at a sewage pump station

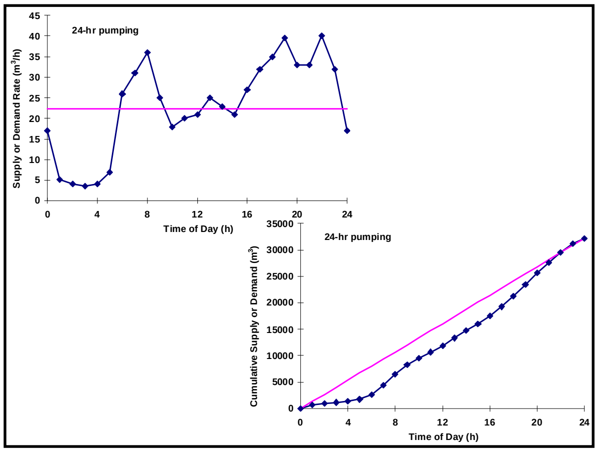
Sizing a Water Distribution Reservoir

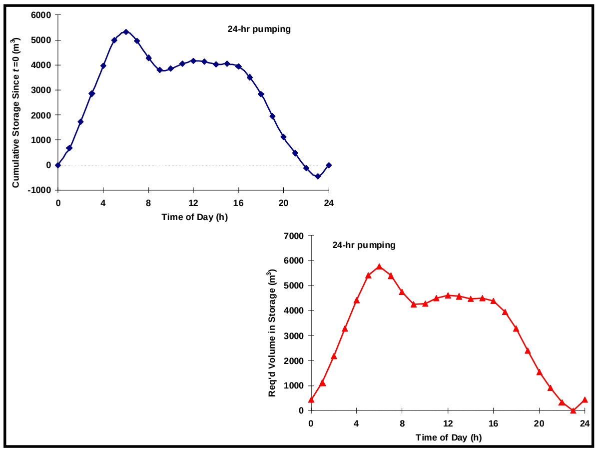
- Choose a demand scenario to be met, based on prior knowledge and cost of failure (e.g., highest demand day on record; probabilistic projection of demand expected no more than once per year)
- Compute supply scenario that meets average demand
- Compute withdrawal from or input to storage during each time increment for design scenario
- Plot cumulative supply and demand
- Sum of largest cumulative excess (supply minus demand) and largest cumulative shortfall is required capacity
- Add any capacity not previously considered – fire-flow requirements, unused or inaccessible storage, safety factor, etc.

Example

- A water supply is to be developed for a new community, with an anticipated ultimate population of 50,000. Based on the pattern in a similar, existing community and an ADD (including commercial demand) of 0.643 m^3/person-d (170 gpcd), the following hourly demand pattern has been chosen as the basis for design. Determine the required storage capacity for continuous pumping and for pumping only 8am-8pm. Assume that 6% of the stored water will be unavailable, and consider fire-flow needs.

TIME hr	Inst.Demand m³/min	TIME hr	Inst.Demand m³/min	TIME hr	Inst.Demand m³/min
1	5.2	9	25.0	17	32.0
2	4.0	10	18.0	18	35.0
3	3.5	11	20.0	19	39.5
4	4.0	12	21.0	20	33.0
5	7.0	13	25.0	21	33.0
6	26.0	14	23.0	22	40.0
7	31.0	15	21.0	23	32.0
8	36.0	16	27.0	24	17.0





Example

- Fire-flow rate:

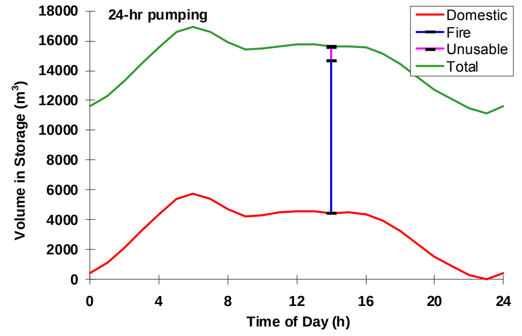
$$Q\left(\text{m}^3/\text{s}\right) = 0.0643\left(\sqrt{P} - 0.01P\right) = 0.423\ \text{m}^3/\text{s}$$

- Duration of fire for design purposes (this estimate very rough; actual estimates based on detailed survey of building and business types):

$$t_{fire}\left(\text{h}\right) = \frac{Q_{fire}\left(\text{in gpm}\right)}{1000} = \frac{Q_{fire}\left(\text{in m}^3/\text{s}\right)}{0.0631} = \frac{0.423}{0.0631} = 6.71\ \text{h}$$

- Fire-flow storage requirement:

$$V_{storage,fire} = Q_{fire}t_{fire} = \left(0.423\frac{\text{m}^3}{\text{s}}\right)\left(6.71\ \text{h}\right)\left(3600\frac{\text{s}}{\text{h}}\right) = 10,200\ \text{m}^3$$



Elements of Water Distribution Systems

- ***Components***
  Pipes
  Pump stations
  Storage facilities
  Fire hydrants
  Service connections
  Meters

- ***Distribution – factors affecting grid configuration***
  Topography and street patterns
  Locations of water treatment system and potential storage
  Grid allows supply to come from more than one direction
  Identify pressure zones to avoid high and low pressures

Water distribution system

Basic Requirements

Pressure
- commercial areas 55- 60 psig
- residential 40-50 psig
- tower buildings
  - storage on top
  - booster pumps

Velocity
- 3-5 fps

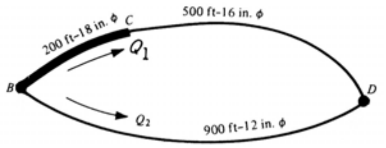
Diameter
- 6-inch minimum for fire flow in grid for connections less than 600 ft; otherwise 8-inch

Hydraulic Design

1. Develop spatial distribution of demand, based on population density, commercial/ industrial use, etc.
2. Evaluate critical demand scenarios
   - Fire plus MDD
   - Peak hourly demand
3. Layout pipe grid
   - Select length and pipe sizes
   - Propose pump locations
   - Identify storage needs
4. Evaluate flow and pressure throughout system
   - Main feeders at 40-75 psi
   - Minimum pressure of 30 psi anywhere; residential 40-50 psi
   - Velocity 3-5 fps
5. Compare capital (pipes, pumps, storage) and operating (pumping) costs

Pipe Network Analysis

1. Equivalent pipe approach
   - Applicable for pipes in simple parallel or series arrangements, with no inputs/withdrawals or pumps in middle;
   - Identifies characteristics of a single pipe with same hydraulic properties (h_L vs Q relationship) as the pipes of interest
   - Applicable if h_L depends only on Q, D, and L
   - For a given set of real pipes, an equivalent pipe with some D exists for each L, and vice versa



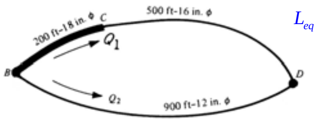
Example

Replace the loop below with a single, equivalent 20″ pipe; assume headloss is given by the Hazen-Williams eqn with $C = 100$

- Assume Q_{BCD}=8 ft³/s. Applying H-W, we find $S_{BC} = 0.0061$ and $S_{CD} = 0.011$

$$h_{L,BCD} = h_{L,BC} + h_{L,CD} = (200')(0.0061) + (500')(0.011) = 6.72'$$

- Identify a single pipe equivalent to BCD; Arbitrarily, choose D=12″ for this pipe. For this diameter and Q=8 ft³/s, H-W indicates S=0.045, so L required to have same h_L as the real pipes BCD is:



$$L_{equiv,BCD} = \frac{h_{L,BCD}}{S_{equiv}} = \frac{6.72'}{0.045} = 153'$$