CE 3372 WATER SYSTEMS DESIGN

LESSON 3: DEMAND ESTIMATION

OUTLINE

- Water Demand(s)

WATER SUPPLY DEMANDS

- Uses
  - Withdrawl
    - Removal from stream, lake, or aquifer to supply user(s) – water is moved to satisfy the use
  - Non-Withdrawl
    - On-site uses for navigation, recreation – water can stay in same location to satisfy use
  - Consumptive
    - Fraction of withdrawl that is no longer available for further use – incorporated into crops and animals (actual biomass); industrial processes (heat exchange)

WATER NEEDS FOR A CITY

- Consider some generic urban area
  - Municipal Requirements
  - Large Industrial Requirements
  - Waste Assimilation Requirements

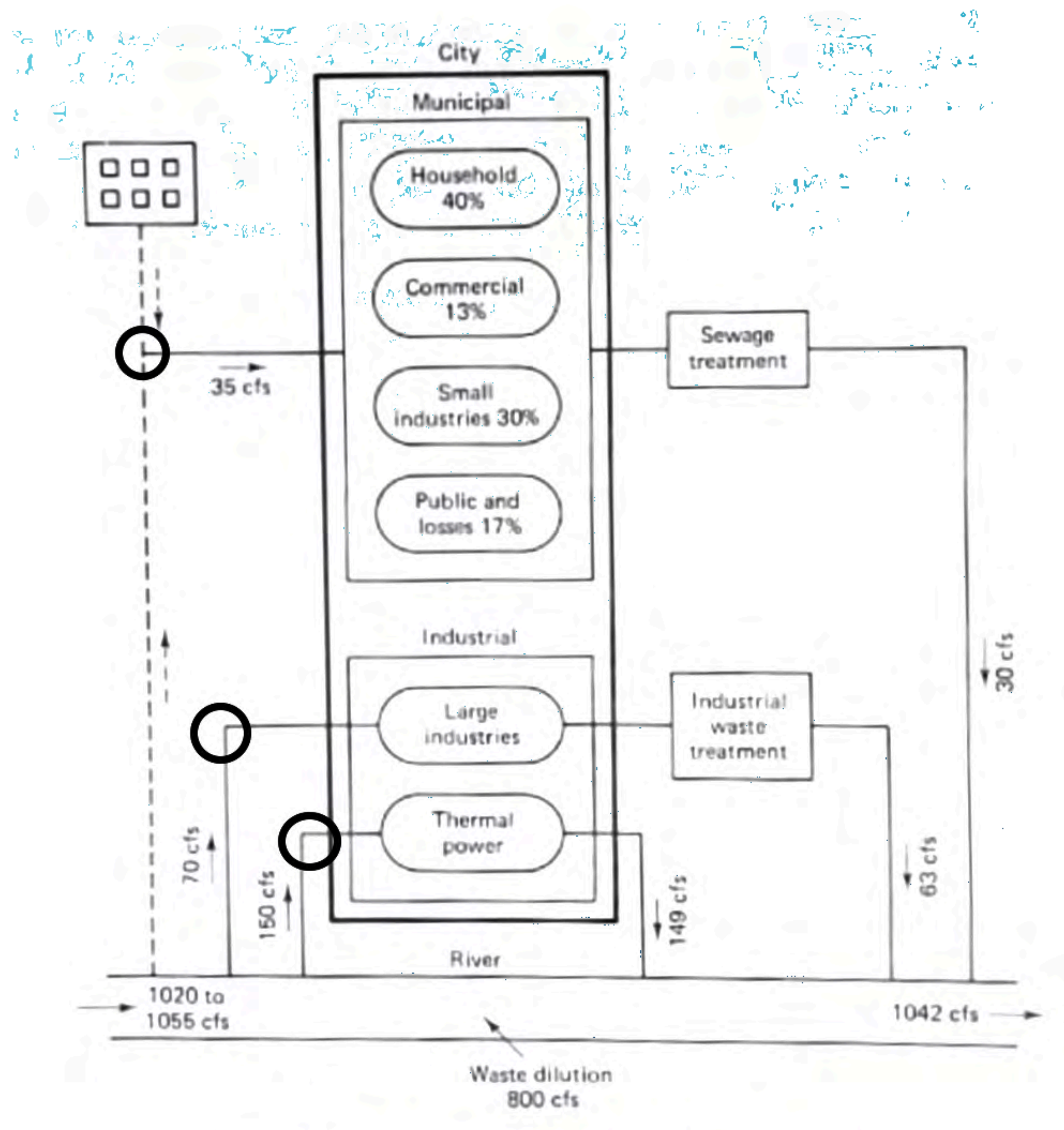


Figure 2.1 Water requirements of a city of 150,000 population

MUNICIPAL REQUIREMENTS

- The municipal requirements are related to the number of users by means of the simple relation:

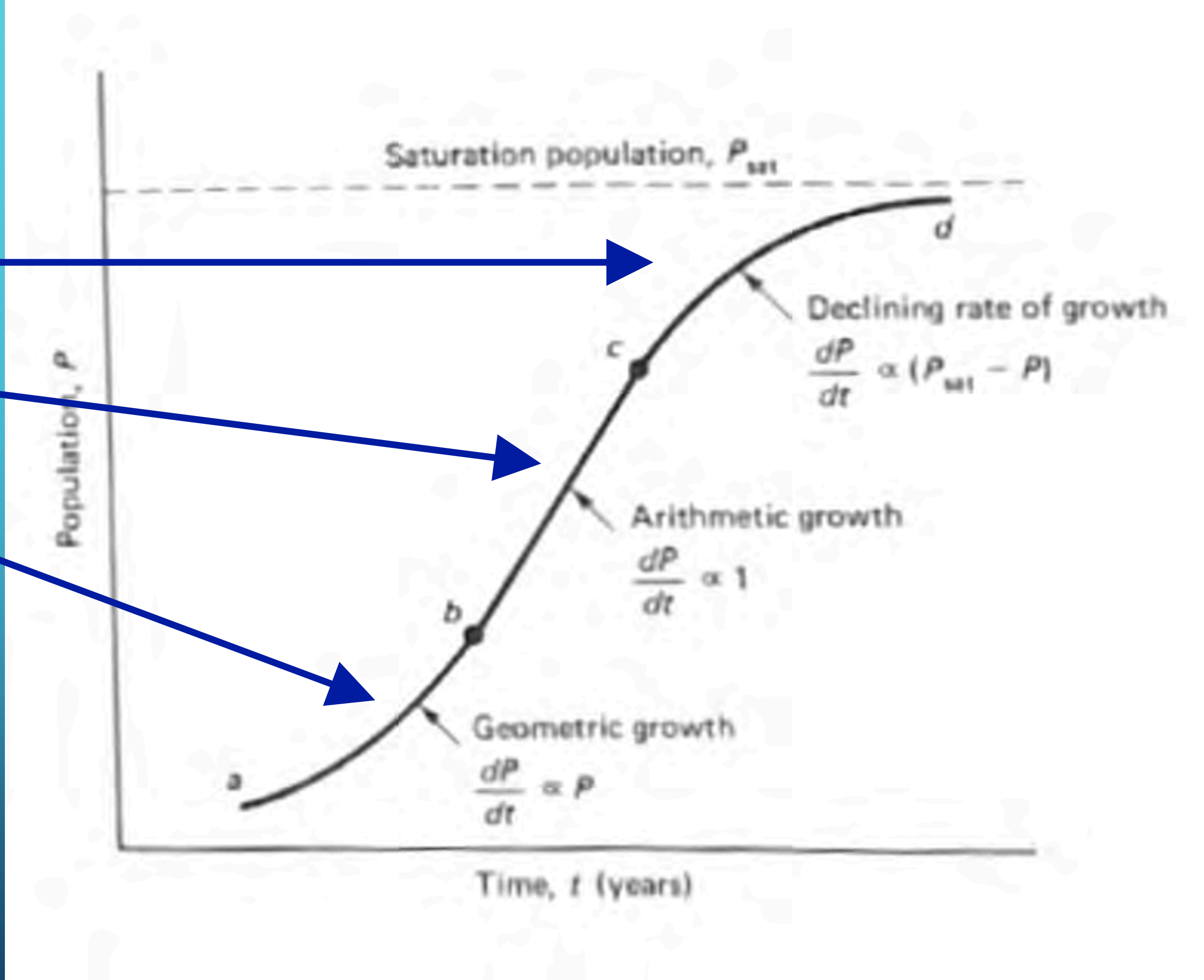
$$V = P \times \left(\frac{V}{P} \right)$$

- Where V=volume, P=population, V/P = volume per person (used).

POPULATION FORECASTING (GRAPHICAL)

- Short-term forecasting
  - Declining growth
  - Arithmetic growth
  - Geometric growth

- Same arithmetic as substrate limited growth that you learn in Envriomental Engineering



GEOMETRIC GROWTH (MATHEMATICAL)

- When the growth curve is in the exponential phase

$$P_2 = P_1 \cdot e^{K_P(t_2 - t_1)}$$

- Where K_P is the exponential growth constant

ARITHMETIC GROWTH (MATHEMATICAL)

- When the growth curve is roughly a straight line, then

$$P_2 = P_1 + K_A(t_2 - t_1)$$

- Where K_A is the slope of the growth curve

DECLINING GROWTH (MATHEMATICAL)

- When the growth curve approaching the carrying capacity of the region

$$P_2 = P_1 + (P_{sat} - P_1)\cdot(1 - e^{-K_D(t_2 - t_1)})$$

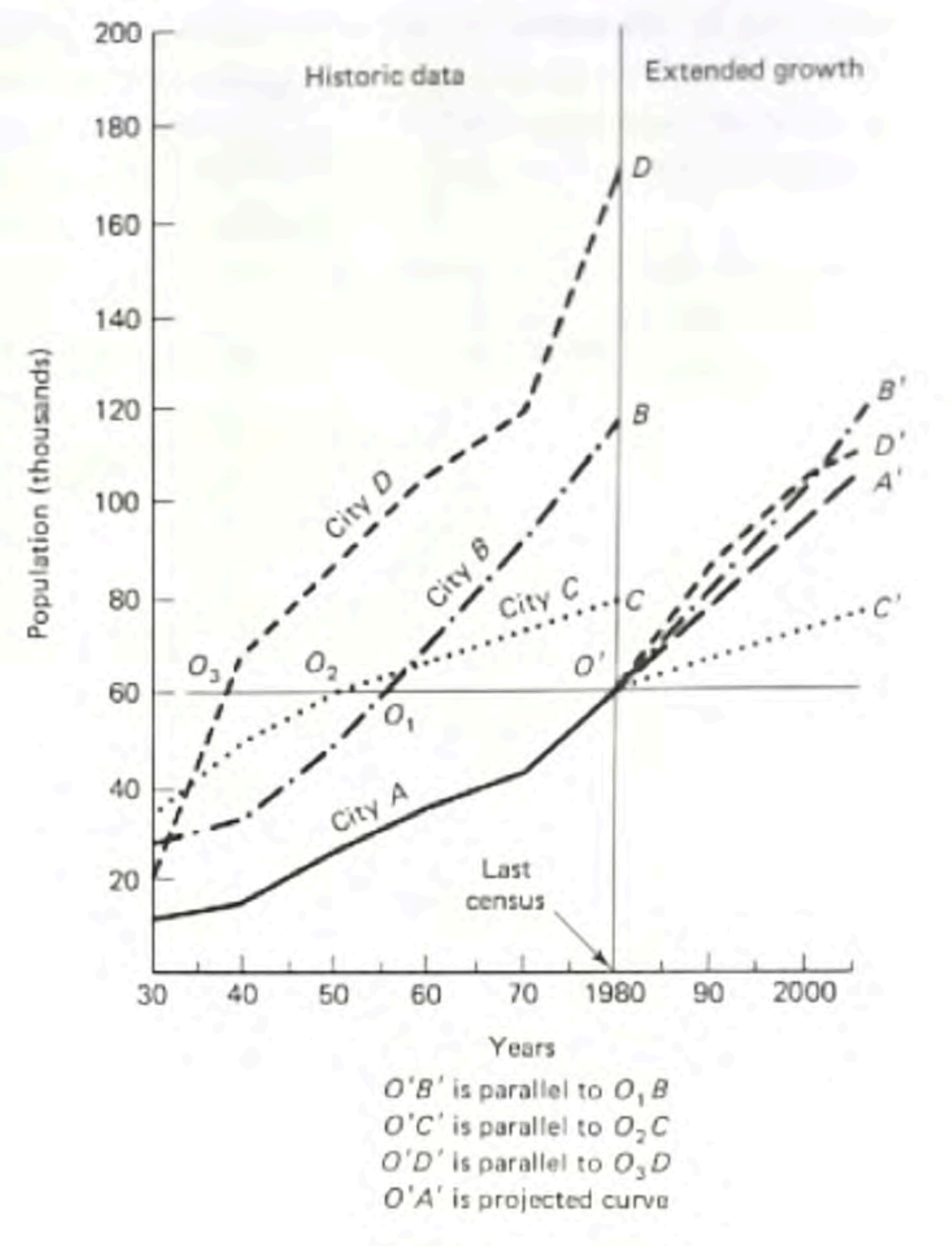
- Where K_D is the declining rate constant

LONGER-TERM FORECASTING

- Naturally, none of the constants are convienently tabulated and historical census data are used both for short term forecasts – the US Census Bureau makes estimates of census values between the every decade census.
- If the region has been around awhile (in the population sense) then the plot might be strightforward to construct.
- Longer term adds the ratio and correlation techniques and component techniques

COMPARISON FORECASTING

- Geographically similar areas are used and projections are made by comparing these growth curves to the area of interest.
- Uncertainty that area of interest may not progress similarily to past growth of comparision areas.



FORECASTING (RATIO/CORRELATION)

- Ratio (transposition) method is based on the ratio of observed populations of two study areas.

$$P_t = \frac{P_0}{P'_0} \cdot P'_t$$

- Correlation method fits (ordinary least squares on the populations or log-populations) to generate a predictive equation based on a reference population.

$$P_t = aP'_t + b$$

FORECASTING (COMPONENT)

- Formal model of a population that considers birth rate (B), death rate (D), net migration rate (M) over a forecasting interval

$$P_t = P_0 + (B - D \pm M)\Delta t$$

- Non-trivial modeling activity
- Nice introduction to the mathematics in:

  Frauenthal, J.C. 1980. Introduction to Population Modeling. Birkhäuser, Boston, Basel, Stuttgart 186p. ISBN 3-7643-3015-5

WATER USAGE

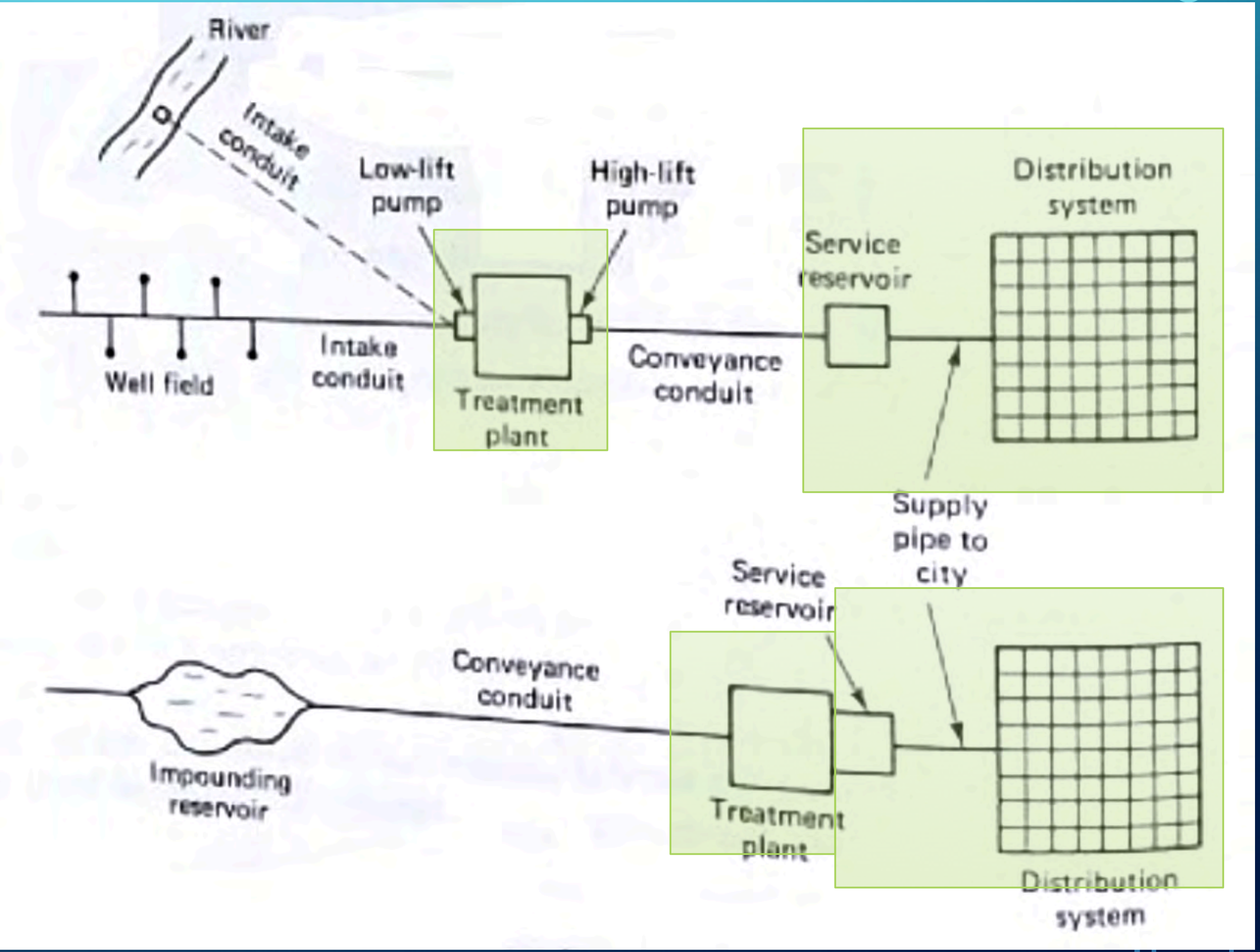
- The forcasting helps establish the target population to be served, next the use per person needs to be established.
- Components include:
  - Avergae Daily Demand (by user category)
  - Hourly Variation
  - Fire Demand

PER CAPITA WATER USAGE – DESIGN LIFE

- Design life varies by system component (or statute).
- Maintenance/replacement needs to be planned for components that will fail within the overall design (service) life

MAJOR COMPONENTS

- Components differ by system type.
- For example consider the two systems in the figure – there are some common components, however each system will have unique components to consider.



Structure	Design Period[a] (years)	Required Capacity
1. Source of supply		
a. River	Indefinite	Maximum daily (requirements)
b. Wellfield	10–25	Maximum daily
c. Reservoir	25–50	Average annual demand
2. Conveyance		
a. Intake conduit	25–50	Maximum daily
b. Conduit to treatment plant	25–50	Maximum daily
3. Pumps		
a. Low-lift	10	Maximum daily plus one reserve unit
b. High-lift	10	Maximum hourly plus one reserve unit
4. Treatment plant	10–15	Maximum daily
5. Service reservoir	20–25	Working storage (from hourly demand and average pumping) plus fire demand plus emergency storage
6. Distribution		
a. Supply pipe or conduit	25–50	Greater of (1) maximum daily plus fire demand or (2) maximum hourly requirement
b. Distribution grid	Full development	Greater of (1) maximum daily plus fire demand or (2) maximum hourly requirement

AVERAGE DAILY USAGE

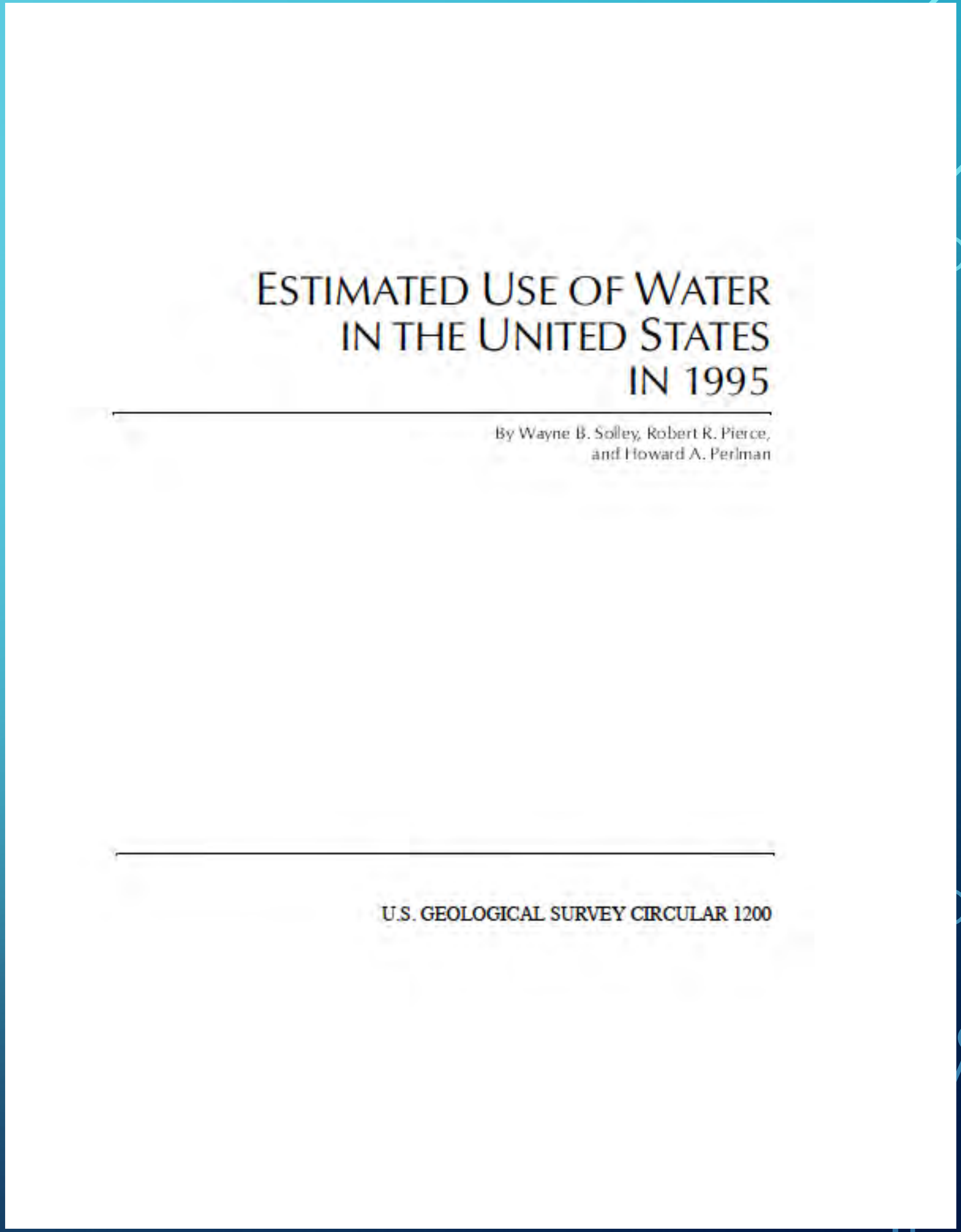
- Residential
  - Water for drinking, landscape, swimming, fires, street cleaning, etc.
  - Usually two demand peaks (morning and evening)

- Commercial
  - Motels, hotels, offices, shopping centers
  - Usually less peak demand and less varied than residential

- Industrial
  - Water for fabrication, cooling, petroleum refining, etc.
  - Water use depends on type of industry

AVERAGE DAILY USAGE

- Estimation tools:
  - USGS Circular 1200
  - Authorative sources
  - Approximation (for preliminary design)
  - Per-connection calculation



ESTIMATED USE OF WATER IN THE UNITED STATES IN 1995

By Wayne B. Solley, Robert R. Pierce, and Howard A. Perlman

U.S. GEOLOGICAL SURVEY CIRCULAR 1200

USGS CIRCULAR 1200

Table 4. Total water withdrawals by water-use category and State, 1995

[Figures may not add to totals because of independent rounding. All values in million gallons per day]

STATE	PUBLIC SUPPLY	DOMESTIC	COMMERCIAL	IRRIGATION	LIVESTOCK	INDUSTRIAL		MINING		THERMOELECTRIC		TOTAL	
	Fresh	Fresh	Fresh	Fresh	Fresh	Fresh	Saline	Fresh	Saline	Fresh	Saline	Fresh	Saline
Alabama	813	62	4.9	139	129	733	0	11	9.1	5,200	0	7,090	9.1
Alaska	81	8.6	11	.6	.5	55	1.8	24	116	31	0	211	117
Arizona	807	39	21	5,670	32	39	0	144	14	62	0	6,820	14
Arkansas	381	38	100	5,940	354	187	0	.1	0	1,770	0	8,800	0
California	5,620	120	385	28,900	459	538	36	76	151	205	9,450	36,300	9,640
Colorado	705	27	8.6	12,700	59	123	0	52	17	114	0	13,800	17
Connecticut	393	55	27	28	1.4	9.6	0	1.7	0	760	3,180	1,280	3,180
Delaware	89	12	2.8	48	4.1	61	3.2	0	0	534	740	752	743
D.C.	0	0	0	0	0	.5	0	0	0	9.7	0	10	0
Florida	2,070	297	50	3,470	56	345	8.0	296	0	636	11,000	7,210	11,000
Georgia	1,150	99	46	722	48	633	32	12	0	3,040	33	5,750	64
Hawaii	214	3.7	46	652	10	19	.9	.5	0	67	903	1,010	922
Idaho	189	65	306	13,000	1,460	47	0	29	0	0	0	15,100	0
Illinois	1,820	129	104	180	56	452	0	50	25	17,100	0	19,900	25
Indiana	669	115	93	116	46	2,270	0	137	0	5,690	0	9,140	0
Iowa	373	45	43	39	110	258	0	43	0	2,120	0	3,030	0
Kansas	370	24	5.2	3,380	109	53	0	24	0	1,270	0	5,240	0
Kentucky	496	25	22	12	46	347	0	28	0	3,440	0	4,420	0
Louisiana	638	39	11	769	325	2,580	0	1.8	0	5,480	0	9,850	0
Maine	100	35	11	27	1.9	11	0	5.0	0	30	105	221	105
Maryland	834	73	24	62	35	65	261	5.2	0	360	6,000	1,460	6,270
Massachusetts	725	34	12	82	10	85	0	3.2	0	196	4,370	1,150	4,370
Michigan	1,300	194	41	227	14	1,850	3.6	58	.8	8,370	0	12,100	4.4
Minnesota	485	88	66	157	62	140	0	298	0	2,090	0	3,390	0
Mississippi	344	33	18	1,740	396	290	0	3.7	0	263	112	3,090	112
Missouri	699	58	14	567	76	39	0	24	0	5,550	0	7,030	0
Montana	143	18	0	8,550	52	60	0	6.6	13	22	0	8,850	13
Nebraska	286	42	.3	7,550	142	30	0	141	4.7	2,350	0	10,500	4.7
Nevada	468	11	21	1,640	5.7	15	0	68	11	27	30	2,260	42
New Hampshire	98	32	30	6.3	.8	43	0	7.0	0	229	877	446	877
New Jersey	1,040	86	18	125	1.5	201	195	90	0	580	3,780	2,140	3,980
New Mexico	311	26	20	2,990	30	8.3	0	61	0	56	0	3,510	0
New York	3,000	144	200	30	34	259	0	45	16	6,570	6,490	10,300	6,500
North Carolina	769	172	7.6	239	297	369	0	16	0	5,860	1,550	7,730	1,560
North Dakota	73	12	.2	117	24	11	0	5.8	0	880	0	1,120	0
Ohio	1,420	140	68	27	27	557	0	93	0	8,190	0	10,500	0
Oklahoma	567	30	23	864	147	21	0	5.4	259	124	0	1,780	259
Oregon	504	68	756	6,170	23	378	0	1.2	0	9.0	0	7,910	0
Pennsylvania	1,550	181	30	16	55	1,680	0	252	0	5,920	0	9,680	0
Rhode Island	114	7.3	1.5	2.3	3.6	1.1	0	6.2	0	0	275	136	275
South Carolina	543	71	1.7	52	25	700	0	2.9	0	4,810	0	6,200	0
South Dakota	88	9.4	10	269	46	5.1	0	27	0	5.4	0	460	0
Tennessee	777	54	20	24	37	863	0	5.5	0	8,300	0	10,100	0
Texas	3,290	130	44	9,450	315	1,300	996	211	409	9,590	3,870	24,300	5,280
Utah	497	9.4	3.8	3,530	108	86	.1	16	150	48	6.7	4,300	157
Vermont	47	19	26	3.9	5.3	9.4	0	3.0	0	453	0	565	0
Virginia	786	125	41	30	36	516	67	39	0	3,890	2,730	5,470	2,800
Washington	1,180	125	24	6,470	34	611	38	3.5	0	376	0	8,820	38
West Virginia	176	41	46	0	18	1,320	0	11	.5	3,010	0	4,620	.5
Wisconsin	600	92	17	169	92	441	0	12	0	5,830	0	7,250	0
Wyoming	90	10	1.6	6,590	25	2.8	0	96	18	220	0	7,040	18
Puerto Rico	431	12	2.7	107	6.3	11	0	4.2	0	2.2	2,260	576	2,260
Virgin Islands	6.5	1.4	.8	0	.1	3.0	17	0	0	0	173	12	190
Total	40,200	3,390	2,890	134,000	5,490	20,700	1,660	2,560	1,210	132,000	57,900	341,000	60,800

- Contains maps and tables by location
- Useful gross estimate tool

AVERAGE DAILY USE (APPROXIMATIONS)

- Water Distribution Systems "Water Distribution Systems" in Land Development Handbook, Ed. S.O. Dewberry, Dewberry Inc., McGraw-Hill -- has tables similar to:

Use	Average Use (gpcd)[a]	Percent of Total
Household	60	40
Commercial	20	13
Industrial	45	30
Public	15	10
Loss	10	7
Total	150	100

PER-CONNECTION (PLUMBER ESTIMATE)

- How Much Water Can You Actually Get?
  - Flow Rates are measured in gallons per minute (gpm).
  - For our purposes, we will talk about the amount of water that you can get through a pipe at a velocity of 8 feet per second (a standard velocity used to engineer a plumbing system).
- Plumbing diameter will limit the flow rate you can get – the larger the pipe, the more water you can get. A home with 1″ plumbing can use substantially more water than a home with 3/4″ plumbing.

Inside home

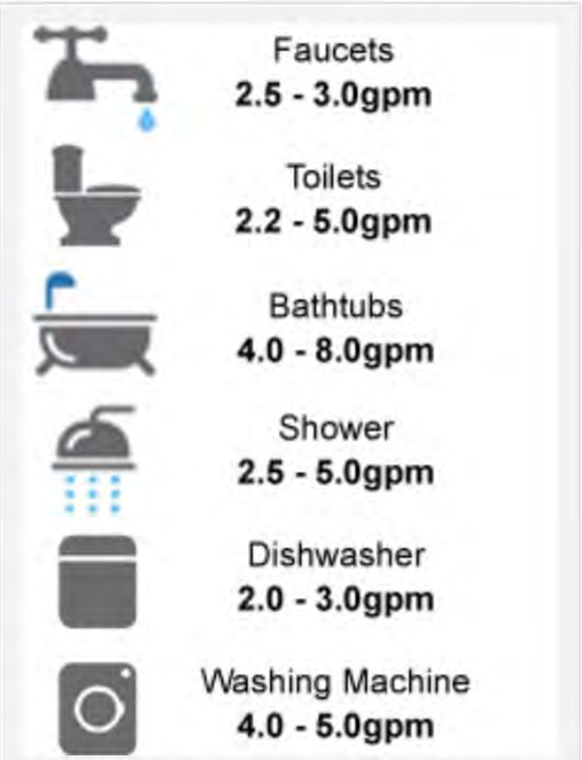
Flow Rates for Type M Copper

1/2"	8.0 gpm
3/4"	13.5 gpm
1"	21.0 gpm
1.25"	32.0 gpm
1.5"	46.0 gpm
2"	80.0 gpm
2.5"	120.0 gpm
3"	175.0 gpm
4"	280.0 gpm
5"	500.0 gpm
6"	700.0 gpm

Meter to hous

PER-CONNECTION (PLUMBER ESTIMATE)

- 1. Think about the maximum number of fixtures and appliances you might operate at the same time.
- 2. Look at the chart to see how many gallons per minute each device requires.
- 3. Add up the flow rates for all the devices you selected.
- You just figured out the PEAK FLOW RATE that you need.
- Now, think about your continual water use, or water use that may run for more than 10 minutes. Add up the fixtures again, and you just calculated your SERVICE FLOW RATE.



Flow Rate Guide

PER-CONNECTION (RURAL ESTIMATE)

Table 2. Minimum flow rates (GPM) for homes based on number of bedrooms and bathrooms. (From Private Water Systems Handbook, 1992.)

# of bedrooms in home	Number of bathrooms in home			
	1	1.5	2	3
2	6 GPM	8 GPM	10 GPM	
3	8 GPM	10 GPM	12 GPM	
4	10 GPM	12 GPM	14 GPM	16 GPM
5		13 GPM	15 GPM	17 GPM
6			16 GPM	18 GPM

- http://extension.psu.edu/natural-resources/water/drinking-water/best-practices/water-system-planning-estimating-water-use

PER-CONNECTION (TCEQ)

§290.45 Minimum Water System Capacity Requirements   TCEQ Publication RG-195

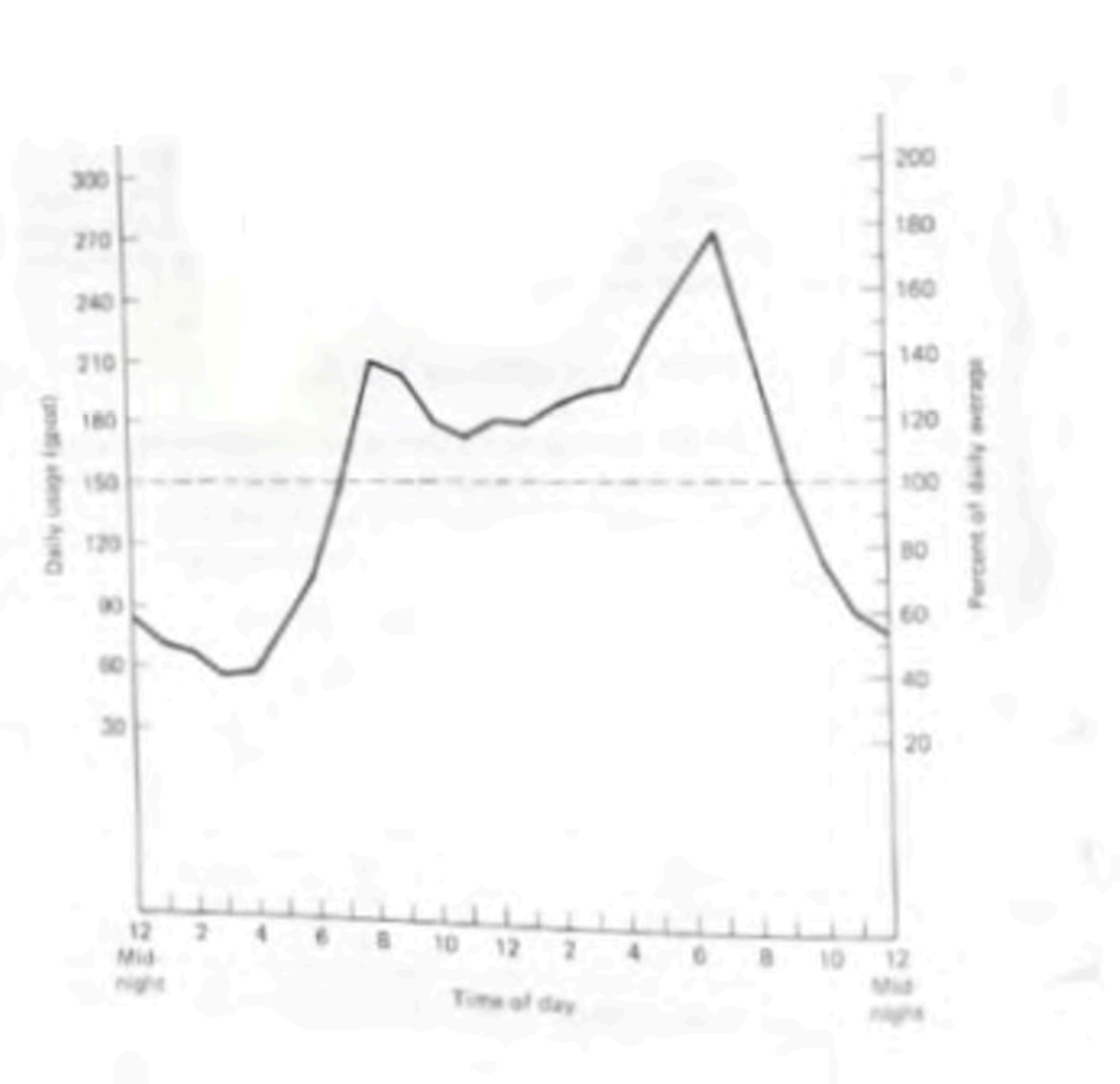
Table A

Type of Establishment	Gallons/Person/Day
Restaurants	18
Schools without cafeterias, gymnasiums, or showers	18
Schools with cafeterias, but no gymnasiums or showers	24
Schools with cafeterias, gymnasiums, and showers	30
Youth camps without flush toilets, showers, or dining halls	6
Youth camps with flush toilets, but no showers or dining halls	24
Youth camps with flush toilets, showers, and dining halls	42
Office buildings	18
Hospitals (based on number of beds)	720
Institutions, other than hospitals	240
Factories (exclusive of industrial processes)	24
Parks	6
Swimming pools	12
Country clubs	120
Airports (per passenger)	6
Self-service laundries	60
Service stations/stores	12

It should be noted that this table is used to determine minimum capacities only and that the overriding criteria will be the ability of the system to maintain a minimum pressure of 35 psi under normal operating conditions. Minimum distribution pressure shall not be less than 20 psi at any time.

USAGE VARIATION (WITHIN A DAY)

- The average estimates are for long-duration (years) usage.
- Use changes with seasons, days within a week, and special cases (the big flush at half-time during the Superbowl)



USAGE VARIATION (WITHIN A DAY)

- In absence of any supporting data one can employ a rule-of-thumb estimate

$$\%U = \frac{180\%}{T^{0.1}}$$

- T is in units of days. The rule-of-thumb is intended for use over a time frame for 1 hours up to 365 days.

FIRE DEMAND

- Fire usage on an annual basis is probably negligible, but when fire demand arises the rate of withdrawl is high.
- Designers are required to design and build the system to be able to provide fire demand (hence service reservoirs will have excess capacity expressly to supply fire flow!)

FIRE DEMAND

- Required flow rates are by:
  - Statute (consider the requirement in the Houston IDM for a fire hydrant)
  - Insurance organizations, for example:

$$Q_{fire,GPM} = 1020\sqrt{P}(1-0.01\sqrt{P})$$

$$P = \text{ population, thousands}$$

INDUSTRIAL DEMAND

- Large industries usually supply their own water
- If the community will supply the industry, then industrial requirements will need to be estimated.

Industry	Average Water Usage
Thermal Power	80 gal/kWh
Steel Production	35,000 gal/ton
Paper Production	50,000 gal/ton
Textile Production	140,000 gal/ton
Carbon (Coke) Production	3,600 gal/ton
Petroleum Refining	770 gal/barrel

WASTE ASSIMILATION DEMAND

- Treated (or even untreated) wastewater is eventually discharged back into the environment and this demand for assimilative capacity needs to be estimated.
- Many methods are employed – TMDL, DO Sag, and similar modeling approaches.
- Preliminary values can be estimated by a simple linear relationship

$$Q_W = \frac{Q_S}{40 - 0.38 \cdot \%T}$$

IRRIGATION DEMAND

- Irrigation (Agricultural) – outside scope of this class but use categories are:
  - Biomass (how much is bound in the actual crop)
  - Evapotranspiration – Consumptive
  - Farm Losses
  - Conveyance Losses

OTHER DEMANDS

- Hydropower
  - Run-of-river
  - Storage release
- Navigation
  - Regulation of river
  - Artificial canal
  - Lock-and-Dam