Sanitary Sewer Design

- Sanitary Sewer Flows
  - Flow sources and quantities
  - Flow variations
  - Infiltration/Inflow
  - Combined versus separate sewers
- System Layout/Elements
  - Manholes
  - Wet wells
  - Pumps and pump stations
  - Pipes
    - Gravity – partial full
    - Force mains
  - Regulators
    - Divert flows
- Hydraulic Design
  - Open channel flow
    - Manning Equation
      - Uniform flow
      - Mild slopes – depth greater critical depth (sub-critical flow)
    - Gradually Varying Flow
      - Backwater analysis -- downstream water deeper than normal depth (depth for uniform flow)
      - Drawdown analysis – downstream water shallower than normal depth, but still greater than critical depth

Wastewater Components and Flows

- Domestic Wastewater
  - Residences, commercial, institutional, etc
- Industrial wastewater
- Infiltration/Inflow (I/I)
  - Infiltration: leakage into wastewater collection system, caused by cracks, corrosion, root intrusion, etc.; EPA estimates ~70% of total infiltration occurs between home/commercial bldg and first lateral
  - Inflow: non-wastewater flow directly into wastewater system, e.g., through manholes
- Storm water

Typical Flows

Domestic Wastewater – 50-100 gal/capita-d

Commercial – site specific

Industrial – site specific

Infiltration – 100 to 100,000 gal/d-inch of diameter-mile (30-3,000 gal/inch of circumference-mile)

– 20 to 3000 gal/acre-d

Infiltration Rates

- **Site specific**
- **Always have some; ≥60,000 gpd/mile is considered excessive**
- **General guidelines**

Pipe (in.)	~minimum achievable gpd/mile
8	3,500 – 5,000
12	4,500 – 6,000
24	10,000 – 12,000

- **Recommended design approach by ASCE**
  - Max flow rate from known sources + 30,000 gpd/mile
- Infiltration/inflow quantification
  - Flow/rainfall monitoring
  - Smoke tests to locate broken pipes
  - Inspect buildings for inflow (e.g., roof or floor drains)

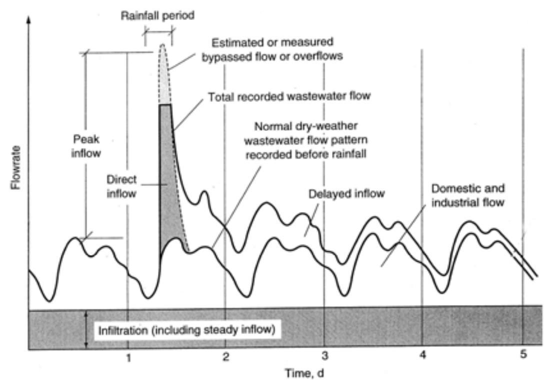
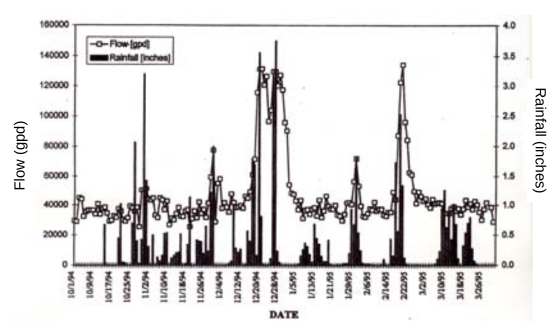


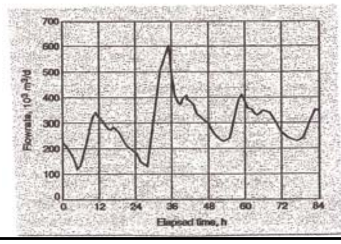
Table G2-1. WA State Design Basis for New Sewage Works

Discharge Facility	Design Units	Flow (gpd)	BOD (lb/day)	SS (lb/day)	Flow Duration (hr)
Dwellings	per person	100	0.2	02	24
Schools with showers and cafeteria	per person	16	.04	.04	8
Schools without showers and with cafeteria	per person	10	.025	.025	8
Motels at 65 gal/person (rooms only)	per room	130	0.26	0.26	24
Trailer courts at 3 persona/trailer	per trailer	300	0-6	0.6	24
Restaurants	per seat	50	0.2	02	16
Interstate or through-highway restaurants	per seat	180	0.7	0.7	16
Interstate rest areas	per person	5	0.01	0.01	24
Service stations	per vehicle serviced	10	0.01	0.01	16
Factories	per person per 8-hr shift	15-35	0.03-0.07	0.03-0.07	Operating period
Shopping centers	per 1,000 ft^2 of floor space	200-300	0-01	0.01	12
Hospitals	per bed	300	0.6	0.6	24
Nursing homes	per bed	200	0.3	0.3	24
Theaters, auditorium type	per seat	5	0.01	0.01	12
Picnic areas	per person	5	0.01	0.01	12

Rainfall and Wastewater Flow During a Wet Weather Season



Example: I/I Evaluation. A large city has high flow rates during the wet season of the year. Flow during the dry period of the year, when infiltration is negligible, averages 120,000 m³/d (31.7 mgd). During wet weather, groundwater levels are elevated, and the flow averages 230,000 m³/d (60.8 mgd), excluding days during and following significant rainfall events. Hourly flows during and for several days following a recent storm are shown in the following figure. Estimate infiltration and inflow, and determine if the infiltration is "excessive", which is defined by the local regulatory agency as >0.75 m³/d-mm-km (8000 gal/d-in-mi). The composite diameter-length of the collection system is 270,000 mm-km (6600 in-mi).



Inflow is difference between total flow during storm and total flow during a similar period without a storm. Consider peak storm flow and assume base flow was the same at the same hour on previous day.

Peak storm flow is 606,000 m³/d at t=35 h. Flow one day earlier (t=11 h) was 340,000 m³/d. Inflow is therefore:

$$\text{Inflow} = (606,000 - 340,000)\ \text{m}^3/\text{d} = 266,000\ \text{m}^3/\text{d}$$

Infiltration is difference between average, daily, non-storm-influenced, wet-weather and dry-weather flow:

$$\text{Infiltration} = \text{ADWF} - \text{ADDF}$$
$$= (230,000 - 120,000)\ \text{m}^3/\text{d} = 110,000\ \text{m}^3/\text{d}$$

Normalize to system geometry:

$$\frac{110,000\ \text{m}^3/\text{d}}{270,000\ \text{mm-km}} = 0.41\frac{\text{m}^3}{\text{d-mm-km}}$$

Normalized infiltration rate does not exceed the rate defined as "excessive."

Peaking factors

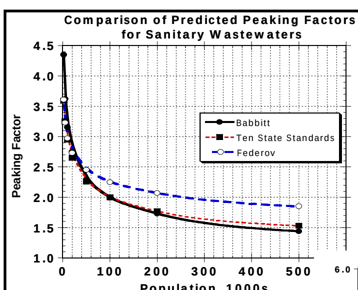
Extreme Peaking Factor (used for hydraulic design): 2 to 4 x ADF
Maximum day flow: 1.2 to 2.0 x ADF
Minimum hour flow: 0.10 to 0.30 x ADF

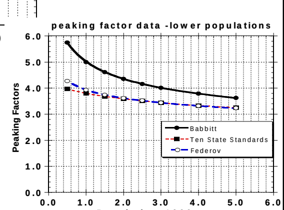
Ten-State Standards (1978): **(most widely used)**
$$\text{PF} = \frac{18 + \sqrt{P/1000}}{4 + \sqrt{P/1000}} \qquad P = \text{population}$$

Harmon (1918):
$$\text{PF} = 1 + \frac{14}{4 + \sqrt{P/1000}}$$

Babbitt (1958):
$$\text{PF} = \frac{5}{(P/1000)^{0.2}}$$

Federov (1975):
$$\text{PF} = \frac{2.69}{Q^{0.121}} \qquad (Q = \text{ADF in L/s})$$





Example: Calculate the design (i.e., peak) flow for a 3-mile long wastewater collection pipe receiving the flows shown below. I/I is estimated to be 500 gpd/mi.

Homes:	**2000 people @ 90 gpcd**
Apartments:	**2000 people @ 80 gpcd**
Commercial:	**500 people-equiv @ 25 gpcd**
Industry:	**8000 gal steadily over one, daily 8-h shift**

ADF from people and commerce:
(2000)(90) + (2000)(80) + (500)(25) = 352,500 gal/d

10-State-Standard PF: $\text{PF} = \frac{18 + \sqrt{P/1000}}{4 + \sqrt{P/1000}} = \frac{18 + \sqrt{4.5}}{4 + \sqrt{4.5}} = 3.29$

$$Q_{design} = \frac{3.29(352,500\ \text{gal/d})}{24\ \text{h/d}} + \frac{8,000\ \text{gal}}{8\ \text{h}} + \frac{(3\ \text{mi})\left(500\,\frac{\text{gal/d}}{\text{mi}}\right)}{24\ \text{h/d}} = 49,324\,\frac{\text{gal}}{\text{h}}$$

Example: Estimate the (a) average dry and wet daily flows, (b) maximum hourly flow, and (c) minimum hourly flow of sewage from a population of 1000, if the average wastewater generation is 80 gpcd. The sewer is 1.5 mi long, and, in wet weather, I/I is 30,000 gal/d-mi. I/I is negligible in dry weather.

(a) AADF: (1000 people)(80 gpcd) = 80,000 gal/d
I/I in wet season: (30,000 gpd/mi)(1.5 mi) = 45,000 gal/d
AAWF: 80,000 gal/d + 45,000 gal/d = 125,000 gal/d

(b) Peak Hour:
10-State-Standard PF: $\mathrm{PF} = \frac{18+\sqrt{1}}{4+\sqrt{1}} = 3.8$

$$Q_{peak} = (3.8)(80,000 \text{ gal/d}) + 45,000 \text{ gal/d} = 349,000 \text{ gal/d}$$

(c) Minimum Hour: (0.20)(80,000 gal/d) = 16,000 gal/d

Example: A 2-ft-diameter sewer line is laid on a slope of 0.0008. How many people can be served by the line with gravity flow, if the input is 100 gpcd? Use Manning's eqn with n =0.011.

Gravity flow implies open channel flow, so the maximum gravity flow corresponds to a full pipe with pressure of zero everywhere. From Flow Master, for the given conditions, the flow when the pipe is full is $4.89\text{x}10^6$ gal/d.

The input flow for design can be expressed as:

Max. Hourly Flow = (Population)(Per Capita Daily Flow)(PF)
= (P)(100 gpcd)(PF)

PF can be computed as function of P from the 10-State Stds. Thus:

$$4.89\text{x}10^6 \text{ gal/d} = P(100 \text{ gpcd})\left(\frac{18+\sqrt{P/1000}}{4+\sqrt{P/1000}}\right)$$

Solving, P = 18,000.

Jargon and Guidelines for Sewer System Design

- Sewer Lingo
  - Building sewers: from buildings to street (laterals)
  - Laterals or branch sewers: First components of public system; usually in streets, connecting building sewers to mains
  - Mains: Collect sewage from several laterals and conveys it to trunk sewers
  - Trunk: Large sewer that connects mains to interceptor or treatment plant
  - Interceptor: Large sewer that connects mains and trunk sewers to treatment plant
  - Invert: bottom, inside of a sewer pipe (or other structure)
  - Crown: top, inside of a sewer pipe

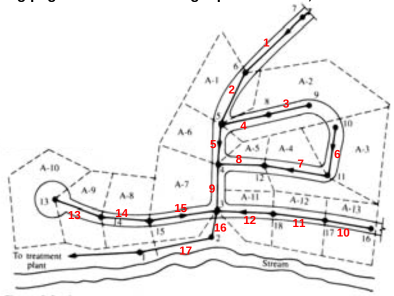
Jargon and Guidelines for Sewer System Design

- Design Criteria/ Considerations
  - Use gravity flow to the extent possible
  - Locate laterals, mains in street right-of-way where possible
  - All pipes at minimum depth, but ≥3 ft and below frost line
  - Velocity preferably $10 \geq v \geq 2$ ft/s
- Manholes
  - Function: Inspections, cleaning
  - Locate at every change in direction, slope, pipe size, intersection of multiple pipes, etc.
  - Maximum separation ~400 ft for laterals, mains, ~600 ft for interceptors
  - Headloss ~0.1 ft
- Standard Pipe Sizes for Sewer Pipes
  - Inches: 4, 5, 6, 8, 10, 12, 14 ,15, 16, 18, 20, 21, 24, 27, 30, 36, 42
  - Millimeters: ~inches x 25

General Approach for Sewer System Design

1. Gather topographic data; sketch plausible collection network, using existing slopes and gravity flow where possible, and pump stations where necessary
2. Estimate design collection flow rates from population and geographic data
3. Compute pipe diameters based on flow through full pipes and regulatory constraints (e.g., minimum diameter for a given type of pipe [lateral vs. main])
4. Increase pipe diameters to closest standard size
5. Check velocities at design flow and average flow
6. Adjust diameters or slopes as needed, and re-check
7. Design pump stations, as needed

Example: The schematic below shows a proposed sewage collection system with 13 collection regions and 18 manholes. By regulation, laterals must have d ≥6 in., and the main (MH 7-6-5-4-3-2-1) must have d ≥8 in. Try to find pipe diameters that meet the regulations and also provide velocities of ≥2 ft/s at design flow. Data for system geometry and flows are on the following pages. Use the Manning eqn for friction, with n = 0.013.



1. **Gather topographic data; sketch plausible collection network, using existing slopes and gravity flow where possible, and pump stations where necessary**

Pipe	From MH	To MH	Length (ft)	Elev'n In	Elev'n Out	Street Slope
P1	7	6	630	116.60	112.19	0.0070
P2	6	5	470	112.19	109.23	0.0063
P3	9	8	390	115.04	112.04	0.0077
P4	8	5	385	112.04	109.23	0.0073
P5	5	4	330	109.23	107.25	0.0060
P6	10	11	410	117.46	113.77	0.0090
P7	11	12	400	113.77	110.29	0.0087
P8	12	4	380	110.29	107.25	0.0080
P9	4	3	370	107.25	105.33	0.0052
P10	16	17	380	116.37	112.57	0.0100
P11	17	18	400	112.57	108.89	0.0092
P12	18	3	405	108.89	105.33	0.0088
P13	13	14	400	115.80	111.92	0.0097
P14	14	15	380	111.92	108.58	0.0088
P15	15	3	411	108.58	105.33	0.0079
P16	3	2	230	105.33	104.18	0.0050
P17	2	1	600	104.18	101.30	0.0048

2. **Estimate design collection flow rates from population and geographic data**

Design criteria for all areas are: population density 40/acre, residential inflow 100 gpcd, infiltration 600 gal/ac-d, PF=3.3. Therefore, design flow per acre is:

$$\frac{Q}{A}=\left(40\frac{\text{people}}{\text{acre}}\right)\left(100\frac{\text{gal}}{\text{person-d}}\right)\left(3.3\frac{\text{gal @ peak}}{\text{gal baseline}}\right)+600\frac{\text{gal}}{\text{ac-d}}$$

$$=13{,}800\frac{\text{gal}}{\text{ac-d}}=0.0138\text{ mgd/ac}$$

2. **Estimate design collection flow rates from population and geographic data**

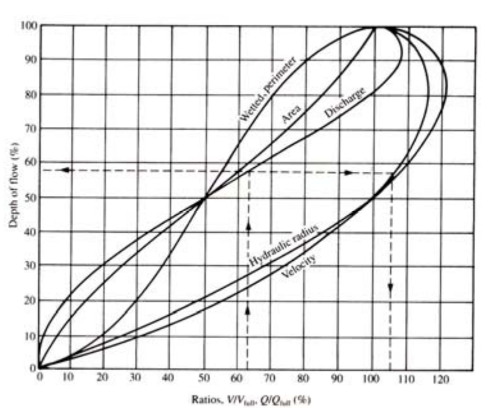
Collection areas, in acres, and corresponding flows are as shown below. Area A10 is undeveloped, so the pipe is closed at MH-13, and A10 has an effective area of 0. On the other hand, the flow in the main as it enters the development (at MH-7) is equivalent to collection from 87 acres.

	Area (ac)	*Q* (mgd)		Area (ac)	*Q* (mgd)		Area (ac)	*Q* (mgd)
A1	5.1	0.070	A6	4.8	0.066	A11	4.3	0.059
A2	12.1	0.167	A7	9.7	0.134	A12	4.9	0.068
A3	8.7	0.120	A8	5.3	0.073	A13	5.0	0.069
A4	6.3	0.087	A9	13.1	0.181			
A5	4.7	0.065	A10	--	0.0			

Flow is then "routed" through the system, as summarized on the following page.

3. **Compute pipe diameters based on flow through full pipes and regulatory constraints**
4. **Increase pipe diameters to closest standard size**

Pipe	Contributions to Flow	Flow (mgd)	Street Slope	*D* (in) for Full Flow	Design *D* (in)
P1	87 ac	1.20	0.0070	10.05	12
P2	P1 + A1	1.27	0.0063	10.47	12
P3	A2	0.17	0.0077	4.74	8
P4	P3	0.17	0.0073	4.79	8
P5	P2 + P4 +A6	1.51	0.0060	11.27	12
P6	A3	0.12	0.0090	4.04	8
P7	P6 + A4	0.21	0.0087	5.02	8
P8	P7 + A5	0.27	0.0080	5.60	6
P9	P5 + P8	1.78	0.0052	12.32	15
P10	A13	0.07	0.0100	3.24	6
P11	P10 + A12	0.14	0.0092	4.27	6
P12	P11 + A11	0.20	0.0088	4.92	6
P13	A9	0.18	0.0097	4.64	6
P14	P13 + A8	0.25	0.0088	5.35	6
P15	P14 + A7	0.38	0.0079	6.38	8
P16	P9 + P12 + P15	2.36	0.0050	13.79	15
P17	P16	2.36	0.0048	13.90	15



Pipe	Q_d (mgd)	D (in)	S (--)	Q_{full} (mgd)	v_{full} (ft/s)	Q_d/Q_{full} (--)	d_d / D (--)	$v@Q_d$ (ft/s)	Q_{avg} (mgd)	$v@Q_{avg}$ (ft/s)
P1	1.20	12	0.0070	1.93	3.80	0.622	0.57	*4.00*	0.400	*2.99*
P2	1.27	12	0.0063	1.83	3.60	0.694	0.61	3.89	0.424	2.93
P3	0.17	8	0.0077	0.69	3.04	0.246	0.34	*2.52*	0.056	*1.83*
P4	0.17	8	0.0073	0.67	2.96	0.254	0.34	*2.47*	0.056	*1.80*
P5	1.51	12	0.0060	1.78	3.51	0.848	0.71	3.94	0.501	*3.02*
P6	0.12	8	0.0090	0.74	3.28	0.162	0.27	*2.41*	0.040	*1.75*
P7	0.21	8	0.0087	0.73	3.23	0.288	0.37	*2.79*	0.069	*2.03*
P8	0.27	6	0.0080	0.32	2.56	0.844	0.70	2.86	0.091	*2.20*
P9	1.78	15	0.0052	3.01	3.80	0.591	0.55	3.95	0.592	2.95
P10	0.07	6	0.0100	0.36	2.86	0.194	0.30	2.11	0.023	*1.60*
P11	0.14	6	0.0092	0.35	2.74	0.400	0.44	*2.59*	0.046	*1.90*
P12	0.20	6	0.0088	0.34	2.68	0.588	0.55	*2.79*	0.065	*2.06*
P13	0.18	6	0.0097	0.36	2.81	0.500	0.50	*2.82*	0.060	*2.09*
P14	0.25	6	0.0088	0.34	2.68	0.736	0.64	2.93	0.085	*2.23*
P15	0.38	8	0.0079	0.69	3.08	0.551	0.53	*3.15*	0.129	*2.35*
P16	2.36	15	0.0050	2.95	3.72	0.800	0.68	4.13	0.787	3.15
P17	2.36	15	0.0048	2.89	3.65	0.817	0.69	4.07	0.787	3.10

Note: Red indicates v < 2 ft/s; *Italicized* indicates supercritical flow