Combined Sewer Design
Part one: sanitary sewage contributions to combined sewers

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One Early Method of Getting Rid of Wastewater

Wastewater treatment has only been around since the late 1800s. People dumped wastes into gutters, ditches, and out open windows.

"Tout-a-la-rue" (all in the streets) described early wastewater disposal (not a rallying cry of the French Revolution!). The expectation was that dogs, pigs, and rain would effectively remove wastes. This was the waste disposal policy in most western cities until the late 1800s.

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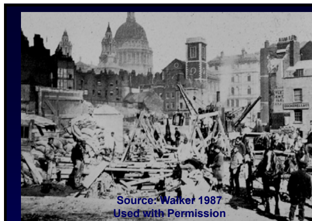

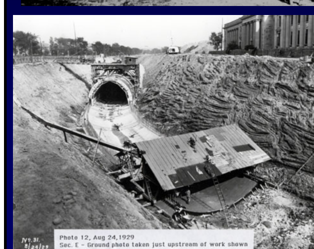

In response to frequent disease outbreaks most large cities undertook massive sewer (both combined and separate) construction projects – the largest public works projects at the time.

Slide by Steve Burion, Univ. of Utah

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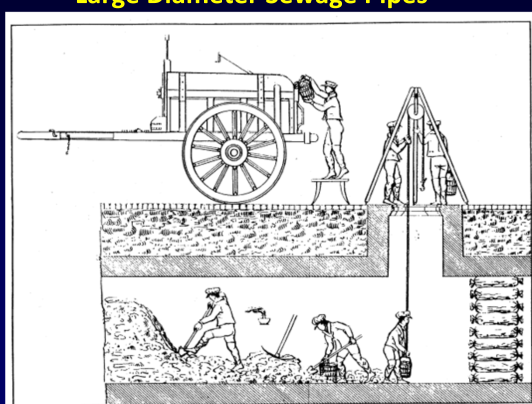
Combined Sewer Systems

- About 15% of communities in the U.S. have a single sewer system that handles both sanitary wastewater and stormwater in the same piping system.
- Most of these are found in older cities with populations of over 100,000.
- Most state regulations now permit the construction of separate sewers only, and expensive projects to separate, or provide partial treatment to combined sewage, is required.
- Combined systems still commonly constructed outside of the US, many include integrated storage and treatment systems

The EPA (1999b) states that combined sewer systems (CSSs) are designed to carry sanitary sewage (consisting of domestic, commercial, and industrial wastewater) and storm water (surface drainage from rainfall or snowmelt) in a single pipe to a treatment facility. In the US, CSSs serve about 43 million people in approximately 950 communities nationwide, most of them located in the Northeast and Great Lakes regions.

Early Sewer Maintenance and the Need for Large Diameter Sewage Pipes



—Clearing drains in Paris, early nineteenth century.

The Historical Development of Sewers Worldwide

G. De Feo, G. Antoniou, H. F. Fardin, F. El-Gohary, X. Y. Zheng, I. Reklaityte, D. Butler, S. Yannopoulos, and A. N. Angelakis. *Sustainability* 6(6):3936-3974, June 2014.

- The use of sewers in China dates back more than 4000 years (10th–15th century BC, in the Shan dynasty), as cities were formed in the mid reach of the Yellow River.
- Need for urban drainage including wastewater from the residential areas, especially in the royal palaces.
- The earliest sewer facility was discovered in the old town Pingliangtai of Henan province. Earthenware was used to build the sewer inside the town.
- Urban drainage 800 m length from the East Gate to the palace. Inside the palace, there were branch sewers for draining of rainwater and wastewater. The underground raceway was 1.3 m in breadth and 1.4 m in height and led water from the palace and town into the moat.

- After the Song dynasty (960–1206 AD), sewers were usually built of brick or stone blocks. The walls of the sewer were built of bricks and covered by a flagstone.
- From this period, two types of sewer construction were common. One was a raceway built underground to collect wastewater or rainwater. The other type was built along the street, usually constructed along the two sides of the street or inside the street. The walls were built of brick and covered with flagstones, still common in many cities until the 1950s. The photograph shows this example in the old town of Huai'an. Finally, the wastewater and rainwater were channeled into the river.

De Feo, *et al.* 2014

Example Relationship between Water and Wastewater Flows

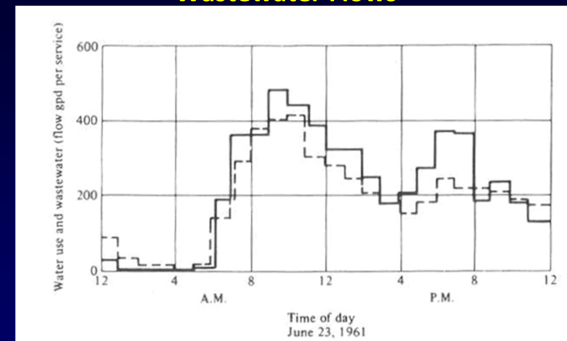


Figure 4.14 Comparison of water use (solid line) and wastewater flow (dashed lines) on days when little sprinkling occurred. (From Residential Water-Use Research Project, Johns Hopkins University and Federal Housing Administration, 1963.)

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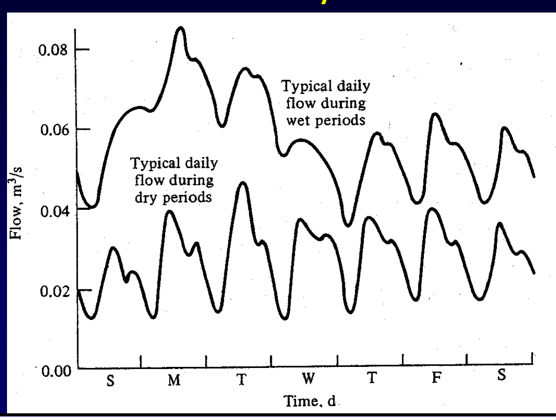
Example Daily/Weekly Variations in Residential Wastewater Flows for Dry and Wet Periods



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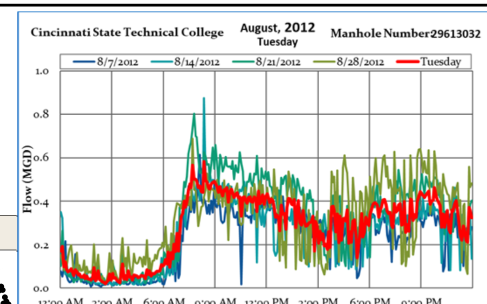
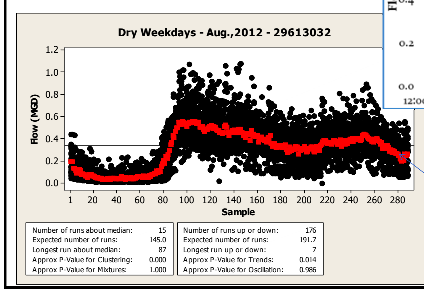
Base Flow Analysis

Separating dry weather flows by days and months





Trend Analysis

Base flow

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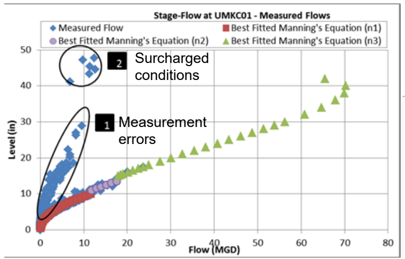
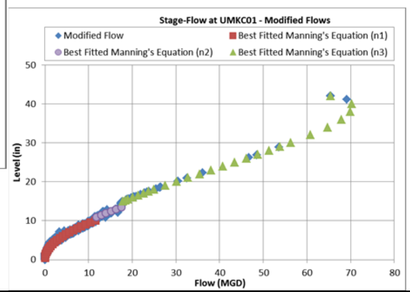
Quality Assurance and Quality Control Examinations of Monitored Runoff and Rainfall Data





These data were obtained from an area-velocity sensor that reports the discharge (flow) directly, using a calculated flow cross-sectional area based on the stage value multiplied by the measured velocity value.

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Design of Gravity-Flow Sanitary Sewers

- Conduct preliminary investigations
- Review design considerations and select basic design data and criteria
- Design the sewer

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Preliminary Investigations

- Obtain pertinent maps
- Describe existing structures and utilities
- Determine groundwater conditions
- Determine character of the soil (and subsurface obstructions) in which sewers are to be constructed

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Map Sources

- Site map prepared by land developer
- GIS information from city or county
- Municipal and county engineers and surveyors
- Regional planning agencies
- Local planning boards
- Land-title and insurance companies
- Public utility officials

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Information from maps

- Location of streets, alleys, drainage ditches, public parks and railways
- Location of buildings
- Location of ponds and streams with surface water elevations
- Land elevation and contours
- Geologic conditions (sinkholes, bedrock, soil chemistry/acidity)

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Information on existing structures and utilities

- Elevations of the sills of buildings and depths of their basements
- Character, age, and condition of the pavements of streets in which sewers will be laid
- Location of water and gas mains, electric conduits, drain lines, and other underground structures

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Sanitary and Combined Sewer: Basic Design Considerations

- Wastewater flow
- Design wet weather flow (next lectures)
- Hydraulic-design equation
- Sewer pipe materials
- Minimum pipe sizes
- Minimum and maximum velocities
- Slopes and cover
- Evaluation of alternative alignments or designs
- Selection of appropriate sewer appurtenances

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Hydraulic Design Equation

- The Manning equation is commonly used
- Manning n value not less than 0.013 recommended for new sewers
  - Assumes first class construction
  - Pipe sections not less than 5 feet long
  - True and smooth inside surfaces
  - Manholes, building connections, other flow-disturbing appurtenances
  - Uncertainties inherent in sewer design and construction

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Pipe Sizes

- Minimum size 8 inches (200 mm)
- Smallest sewers should be larger than the building sewer connections in general use in the area
- Most common size of building connection is 6 inches
- Connections of 5 and 4 inches have been used successfully in some areas

Velocities

- Minimum velocity of 2.0 ft/sec (0.6 m/sec) with flow at ½ full or full depth
- Maximum average velocities of 8-10 ft/sec (2.5-3.0 m/sec) at design depth of flow
- Minimum and maximum velocities may be specified in state and local standards

Sewer Pipe Slopes

- Sewers with flat slopes may be required to avoid excessive excavation where surface slopes are flat or the changes in elevation are small.
- In such cases, the sewer sizes and slopes should be designed so that the velocity of flow will increase progressively, or at least will be steady throughout the length of the sewer.

Gravity Sewer Minimum Pipe Slopes

	Slope, m/m[a]	
Size inches (mm)	n=0.013	n=0.015
8 (200)	0.0033	0.0044
10 (250)	0.0025	0.0033
12 (300)	0.0019	0.0026
15 (375)	0.0014	0.0019
18 (450)	0.0011	0.0015
21 (525)	0.0009	0.0012
24 (600)	0.0008	0.0010
27 (675)	0.0007[b]	0.0009
30 (750)	0.0006[b]	0.0008[b]
36 (900)	0.0004[b]	0.0006[b]

a. Based on Manning's equation with a minimum velocity of 0.6 m/s. Where practicable, steeper slopes should be used

b. The minimum practicable slope for construction is about 0.0008

Steps in the Design of a Sanitary Component of a Combined Sewer System (these are the minimum values, to be expanded due to additional wet weather flows)

1. Estimate the wastewater flow rates for the design period and any local conditions that may affect the hydraulic operation of the system.
   - Design for the expected peak flows (peak hourly flows from residential, commercial, institutional and industrial sources from the entire service area and add the peak infiltration and inflow allowance for the entire service area).

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Steps in the Design of a Sanitary Sewer System (cont.)

2. Select the hydraulic design equation, sewer-pipe materials and minimum sizes, minimum and maximum velocities, slopes, and covers.
   1. Manning's n of 0.013 recommended when analyzing well-constructed new sewers and 0.015 for most older existing sewers. This value is based on the use of individual pipe sections (not less than 1.5 m, 5 ft long) with true and smooth inside surfaces, and on the assumption that only first-class construction procedures are used.
      - Minimum allowable velocity = 2 ft/sec (0.6 m/sec) at one-half full or full depth. If access for cleaning is difficult, the minimum velocity should be 3 ft/sec (1 m/sec).
      - Maximum allowable velocity = 8 to 10 ft/sec (2.5 to 3.0 m/sec) to prevent damage to the sewer.

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Steps in the Design of a Sanitary Sewer System (cont.)

2. ASCE guidance specifies that sanitary sewers up to 375 mm (15 in) be designed to flow half full at the design flow rate, with larger sewers designed to flow three-quarters full. These guidelines reflect that small wastewater flows are much more uncertain than larger flows.
3. Minimum sanitary sewer pipe sizes are usually specified as 205 mm (8 in), laid on a 1% slope. Service connections are usually 150 mm (6 in) or 205 mm (8 in) pipes at a 2% slope.

- Evaluate alternative alignments or designs.
- Select the appropriate sewer appurtenances.
- Review the need for sewer ventilation to minimize H_2S formation.

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Preliminary/Tentative Layout

- Locate lines along streets or utility easements (must be in front of all buildings!)
- Use arrows to show direction of flow (normally direction of ground slope)
- Should have sewer system leaving area at its lowest point (with flow coming to that point from areas with higher elevations)
- In flat areas, sewers should be sloped to common collection point
- WATCH OUT FOR PRE-EXISTING UTILITY LINES!!

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Vertical Location

- Note where basement/below-ground service connections are required
- Want to have sewer below basement points so you don't have to pump!
- Also must have minimum required cover:
  - 3 m (10 ft) required in northern states
  - 0.75 m (2.5 ft) or more required in southern states

Manhole Locations

- Sewer intersections
- Abrupt changes in horizontal direction or slope
- Pipe size change locations
- Regular intervals along straight runs (for maintenance)
  - Less than, or equal to 100 m (300 ft) – general rule
  - 500 ft – maximum spacing
  - Exception: sewers that can be walked through
- Number manholes and use manhole numbers to identify sewers pipes

Vertical Profile

- Prepared for each sewer line
- Horizontal scale of 1:500 or 1:1000
- Vertical scale of 1:50 or 1:100
- Show following items:
  - Ground surface
  - Street surface (where applicable)
  - Tentative manhole locations
  - Elevations of important subsurface strata such as rock
  - Boring locations
  - Underground structures
  - Basement elevations
  - Cross streets
  - Plan of the sewer line

Design Principles Review

- Changes in direction in small sewers ALWAYS made at a manhole
- Head loss in manhole due to change in direction assumed to be 30 mm (0.1 ft). Drop down-gradient invert by this amount across manhole.
- Losses due to pipe size increases:
  - Provided for by matching the crowns or 0.8 depth points for sewer pipes on each side of manhole.
  - Drop in invert due to matching crowns greater than 30 mm, so head loss due to change in direction can be ignored.
  - Dropping invert of lower sewer (by matching crowns) also ensures that smaller sewer pipe not flowing full unless larger pipe is also full.
- Assume hydraulic grade line parallels invert if sewer line is fairly long and not surcharged (assume uniform flow).

Typical Sewer Design Problem

- Given:
  - Flow
  - Velocity
  - Minimum pipe size
  - Ground elevations and slope
  - Pipe material and roughness
  - Minimum pipe cover
- Calculate:
  - Pipe slope
  - Pipe size
  - Pipe alignment
- WATCH COST OF EXCAVATION (slope of pipe versus slope of land)

Sanitary and Combined Sewer Layout Design Example

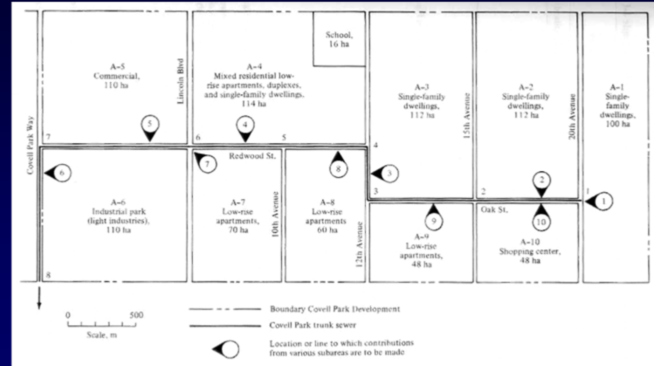

Figure 4-4 Location map for the design of the Covell Park trunk sewer for Example 4-1. (Only major streets are shown.) Note: ha × 2.4711 = acre: m × 3.2808 = ft.

Information for Sanitary Sewer Component

- Given:
  - Wastewater saturation densities and wastewater flows for the area.
  - Average wastewater flow from industrial areas = 30 m^3/ha-day (3200 gal/ac-day)
  - Peaking factor for wastewater flow from industrial areas = 2.1

Zoning	Type of development	Saturation population density		Wastewater flows	
		Persons/ha	Persons/ac	L/capita-day	Gal/capita-day
Resid.	Single-family houses	38	15	300	80
Resid.	Duplexes	60	24	280	75
Resid.	Low-rise apartments	124	50	225	60

Information for Sanitary Sewer Component (cont.)

- Average wastewater flow from commercial areas = 20 m^3/ha-day (2100 gal/ac-day)
- Peaking factor for wastewater flow from commercial areas = 1.8
- Average wastewater flow from the school = 75 L/student-day (20 gal/student-day)
- Peaking factor for wastewater flow from the school = 4.0
- Anticipated population of the school = 2000 students

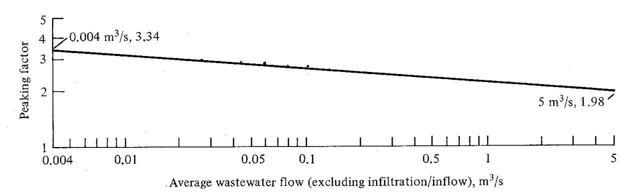

Figure 3-4 Peaking factor for domestic wastewater flows. Note: $m^3/s \times 22.8245$ = Mgal/d.

Calculation of average daily sanitary wastewater flows

Area Design.	Development type	Area (ha)	Sat. pop. density (persons/ha)	WW flows (L/cap.-day)	Average WW flow (m^3/day)
A-1	S-Family	100	38	300	1140
A-2	S-Family	112	38	300	1276.8
A-3	S-Family	112	38	300	1276.8
A-4	Mix Resid.	114	(38+60+124)/3 = 74	(300+280+225)/ 3 = 268.3	2263.7
A-4	School	16	2000	75	150
A-5	Comm.	110		20 m^3/ha-day	2200
A-6	Ind.	110		30 m^3/ha-day	3300
A-7	Low-rise Apart.	70	124	225	1953
A-8	Low-rise Apart.	60	124	225	1674
A-9	Low-rise Apart.	48	124	225	1339.2
A-10	Shopping Center	48		20 m^3/ha-day	960

Calculation of average daily sanitary wastewater flows (cont.)

Start at most upgradient location and work downgradient until intersection with another pipe, then go to upper end of that pipe and work down to intersection, then work down until next pipe intersection, etc. This example only has one main line, with no branching. More complex situations require care in setting up the calculation sheet.

Calculation of average daily sanitary wastewater flows (cont.)

Line Number	Up-stream Manhole	Down-stream Manhole	Feeder Areas	Cum. Av. WW Flow (Land Use) (m^3/day)	Peaking Factor	Peak WW Flow (Land Use) (m^3/day)
1	1	2	A-1 A-2 A-10	Res. 2417 Com. 960	2.9 1.8	R: 7009 C: 1728 Total: 8737
2	2	3	A-9	Res. 1339	3.0	4017
3	3	4	A-3	Res. 1277	3.0	3831
4	4	5	A-8	Res. 1674	3.0	5022
5	5	6	A-4	Res. 2264 School 150	2.9 4.0	R:6566 S: 600 Total: 7166
6	6	7	A-7 A-5	Res. 1953 Com. 2200	2.9 1.8	R: 5664 C: 3960 Total: 9624
7	7	8	A-6	Ind. 3300	2.1	6930

Infiltration and Inflow Allowances for Separate Sanitary System

- Use the new sewer curve to determine infiltration and inflow allowances. Assumption: Since industrial, commercial and institutional areas typically have a smaller density of sewer pipes, can assume that only a part of the area is contributing to infiltration.
- Assume 50% of area used for infiltration area for finding the infiltration allowance (which is assumed to include inflow) from the curve.

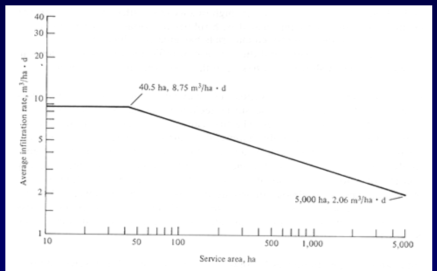

Figure 3-1 Average infiltration rate allowance for new sewers. Note: ha × 2.4711 = acre; m^3/ha·d × 106.9 = gal/acre·d

Calculate Peak Daily Flows Entering Each Pipe Segment (with I&I)

Line #	Feeder Areas	Infiltration Area (ha)	Infiltration Allowance (m^3/ha-day)	Infilt. (m^3/day)	Peak WW Flow (m^3/day)	Peak Flow (m^3/day)
1	A-1 A-2 A-10	100 112 (0.5)48 Total: 236	5.4	1274	8737	10011
2	A-9	(0.5)48 Total: 24	8.75	210	4017	4227
3	A-3	112	7.6	8512	3831	12343
4	A-8	60	8.0	480	5022	5502
5	A-4	R: 114 S: (0.5)16 Total: 122	7.6	927	7166	8093
6	A-7 A-5	70 (0.5)110 Total: 125	7.6	950	9624	10574
7	A-6	(0.5)110	8.0	440	6930	7370

Calculate cumulative flows in each pipe segment

Line Number	Feeder Line	In-Pipe Flow (m^3/day)	Entering Flow (m^3/day)	Cumulative Flow (m^3/day)	Cumulative Flow (m^3/sec)
1	None	0	10011	10011	0.116
2	1	10011	4227	14238	0.165
3	2	14238	12343	26581	0.308
4	3	26581	5502	32083	0.371
5	4	32083	8093	40176	0.465
6	5	40176	10574	50750	0.587
7	6	50750	7370	58120	0.673

Pipe Diameter Calculations only Considering Separate Sanitary Flows

- Calculate the pipe diameters assuming these peak flows are 'sewer flowing full conditions.' Assume Manning's n of 0.015 and slopes as shown in the table (slopes are typically determined from post-grading topographic maps of the area).

Example for line 1, using Manning's equation to solve for pipe diameter:

$$D = 1.548\left[\frac{nQ}{S^{0.5}}\right]^{0.375} = 1.548\left[\frac{(0.015)(0.116 m^3/\sec)}{(0.0019)^{0.5}}\right]^{0.375} = 0.462m$$

The next larger commercial pipe size is 525 mm, which has a full flowing capacity of 13,995 m^3/day with this slope and roughness.

Pipe Diameter Calculations

- Calculate the pipe diameter assuming these peak flows are 'sewer flowing full conditions.' Assume Manning's n of 0.015 and slopes as shown in the table (slopes are typically determined from post-grading topographic maps of an area).

Line Number	Cumulative Flow (m^3/sec)	Slope (m/m)	Exact Diameter (m)	Pipe Diameter (mm)	Full Flow (m^3/day)
1	0.116	0.0019	0.462	525	13995
2	0.165	0.0015	0.528	600	17803
3	0.308	0.0012	0.667	675	26581
4	0.371	0.0011	0.716	750	32083
5	0.465	0.0010	0.779	900	40176
6	0.587	0.0007	0.849	900	50750
7	0.673	0.0009	0.894	900	58120

Velocity of Flowing Sewage

- Need to calculate the full-flowing velocities at the actual diameters (V_{full}) and the velocities at design flow (using the cumulative flow) through the partial-flow diagram.
  - If the velocity at design flow is greater than 0.6 m/sec (2 ft/sec), the design should be sufficient to regularly achieve self-cleansing velocity. If not, increase the slope of the pipe, or anticipate increased maintenance.
  - If V > 10 ft/sec, need to lessen the slope to prevent erosion of the pipe interior.

Example for first pipe:

$$V_{full} = \frac{1}{n}\left(\frac{D}{4}\right)^{2/3} S^{0.5} = \frac{1}{0.015}\left(\frac{0.525m}{4}\right)^{2/3}(0.0019)^{0.5} = 0.75m/\sec = 2.5\,ft/\sec$$

$$\frac{Q}{Q_{full}} = \frac{(0.116m^3/\sec)(86{,}400\sec/day)}{13{,}995m^3/day} = 0.716$$

$$d/D = 0.72 \text{ from hydraulic elements figure}$$

$$\frac{V}{V_{full}} = 0.96 \text{ from hydraulic elements figure}$$

$$\text{therefore}, V = 0.96(2.5\,ft/\sec) = 2.4\,ft/\sec$$

Since this is greater than the minimum 2 ft/sec requirement, the pipe diameter is suitable for this slope. If the velocity was less than desired, then the slope should be increased (resulting in an increased trench depth at the lower end of the pipe) and the pipe size and resulting velocities re-calculated. This trial-and-error process would be repeated until the desired velocity outcome is achieved. This problem with velocity is most common for the upper pipe segments in residential areas that have little slope, and the minimum pipe diameter is used. In those cases, the slope may have to be significantly increased, which would result in unreasonable trench depths. Anticipated increased maintenance is usually a more reasonable solution.

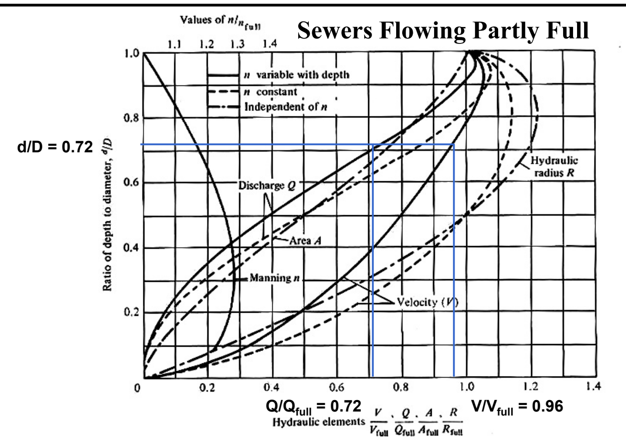

Figure 2-16 Hydraulic elements for circular sewers [10].

Metcalf and Eddy 1981

Example Sewer Profile

Once the final design is complete, need to draw profile maps of the sewer. An example profile map is shown here (it is not the same sewer as this example problem).

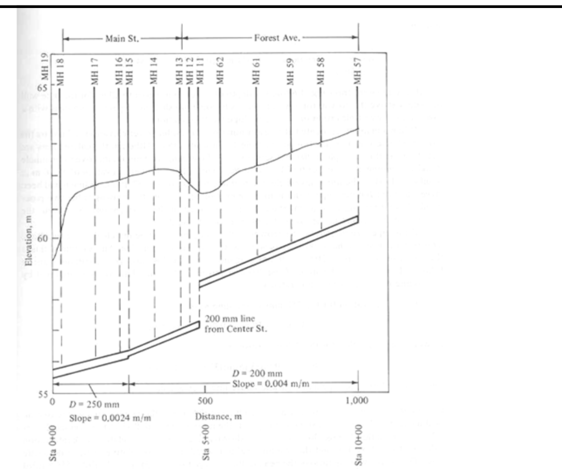

Figure 4-6 Sewer profile work sheet for Example 4-2. Note: m × 3.2808 = ft; mm × 0.03937 = in

Sewer Profile Example (Construction Drawings)

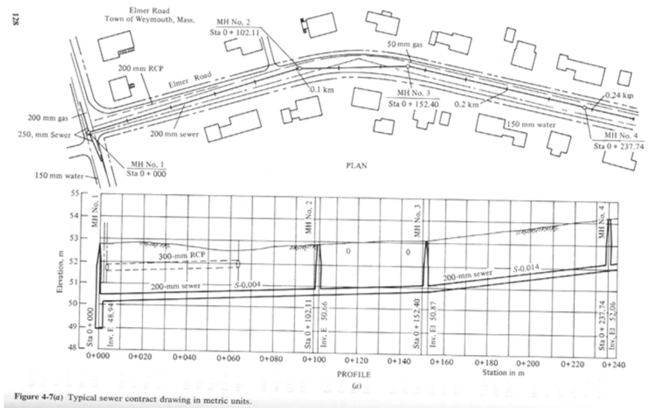

Figure 4-7(a) Typical sewer contract drawing in metric units.

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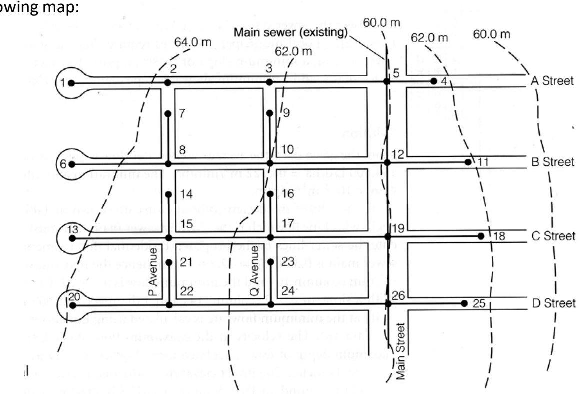
Example 3.32 (Chin 2006) Separate Sanitary Sewer

A sewer system is to be designed to service the residential area shown on the following map:



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The average per-capita wastewater flowrate is estimated to be 800 L/D/capita, and the I&I is estimated to be 70 m^3/d/km. This new sewer is to join an existing system at manhole #5, where the average wastewater flow is 0.37 m^3/sec, representing the contribution of about 100,000 people. The existing sewer at MH#5 is 1,065 mm in diameter, has an invert elevation of 55.35 m, and is laid on a slope of 0.9%. The flow will be along Main Street from MH#5 to MH#26. The following table lists the pipe lengths, contributing areas, and ground surface elevations. Design a sewer system between A Street and C Street for a saturation density of 130 persons/ha. Local regulations require:

-minimum pipe cover of 2 m,
-minimum slope of 0.08%,
-peak flow factor of 3.0,
-minimum flow factor of 0.5, and
-minimum allowable pipe diameter of 150 mm.
-the wastewater depth at peak flow must be less than half of the pipe diameter for pipes smaller than 375 mm and less than three-fourths full for larger pipes

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Example 3.32 Sewer System Data (Chin 2006)

Line no. (1)	Location (2)	Manhole no. From (3)	Manhole no. To (4)	Length (m) (5)	Contributing area (ha) (6)	Ground surface elevation Upper end (m) (28)	Ground surface elevation Lower end (m) (29)
0	Main Street	—	5	—	—	—	60.04
1	A Street	1	2	53	0.47	65.00	63.80
2	A Street	2	3	91	0.50	63.80	62.40
3	A Street	3	5	100	0.44	62.40	60.04
4	A Street	4	5	89	0.90	61.88	60.04
5	Main Street	5	12	69	0.17	60.04	60.04
6	B Street	6	8	58	0.43	65.08	63.20
7	P Avenue	7	8	50	0.48	63.60	63.20
8	B Street	8	10	91	0.39	63.20	62.04
9	Q Avenue	9	10	56	0.88	62.72	62.04
10	B Street	10	12	97	0.45	62.04	60.04
11	B Street	11	12	125	0.90	61.88	60.04
12	Main Street	12	19	75	0.28	60.04	60.20
13	C Street	13	15	57	0.60	64.40	62.84
14	P Avenue	14	15	53	0.76	63.24	62.84
15	C Street	15	17	97	0.51	62.84	61.60
16	Q Avenue	16	17	63	0.94	62.12	61.60
17	C Street	17	19	100	0.46	61.60	60.20
18	C Street	18	19	138	1.41	61.92	60.20
19	Main Street	19	26	78	0.30	60.20	60.08

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1) The average wastewater flow is 800 L/D/person x 130 persons/ha = 104,000 L/D/ha = 0.0722 m^3/min/ha. The I&I is 70 m^3/d/km = 4.86x10^{-5} m^3/min/m.

2) Computations begin with the existing line #0 which must be extended to accommodate the sewer lines in the new area. The average flow in the sewer main is 0.37 m^3/sec = 22.2 m^3/min. The maximum flow is 3x this flow, or 66.6 m^3/min, and the minimum flow is 0.5x this flow, or 11.1 m^3/min. With a slope of 0.009 and a diameter of 1,065 mm, the velocity at the minimum flow rate is calculated to be 1.75 m/s. The velocity at the maximum flow rate is calculated to be 2.88 m/sec, with a maximum depth of flow of 476 mm, or 45% of the pipe diameter. The velocity and depth values are acceptable (between 0.6 and 3.5 m/sec, and less than three-quarters full).

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3) The design of the sewer system begins with line 1 (between MH#1 and 2) on A Street, and is 53 m long.

- The area contributing wastewater flow is 0.47 ha, and the average flow is 0.47 ha x 0.0722 m^3/min/ha = 0.0339 m^3/min
- The I&I is 4.86x10^{-5} m^3/min/m x 53 m = 0.0026 m^3/min.
- The peak wastewater flow is 3 x 0.0339 m^3/min = 0.102 m^3/min. Adding the I&I results in a total peak flow of 0.102 m^3/min + 0.0026 m^3/min = 0.105 m^3/min.
- The minimum wastewater flow is 0.5 x 0.0339 m^3/min = 0.0170 m^3/min. Adding the I&I results in a total minimum flow of 0.0170 m^3/min + 0.0026 m^3/min = 0.0196 m^3/min.
- Using the minimum pipe diameter of 150 mm and the ground slope of 0.047, the velocity at the minimum flow is 0.60 m/s, which is equal to the minimum acceptable velocity. If the velocity was less than this value, the slope would need to be increased, or permission obtained from the regulatory agency if an unusually deep pipe depth would result at the down-gradient manhole location.

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- At the peak flow, the calculated velocity would be 0.99 m/sec, and the depth of flow is 23 mm. The velocity is less than the maximum permissible value of 3.5 m/sec and the depth is less than the half full goal.
- With a slope of 0.047 and a length of 53 m, the drop in elevation between the inverts at the ends of the pipes (in MH#1 to MH#2) would be 2.49 m. The elevation of the down-gradient invert is the elevation of the up-gradient invert minus this drop.

4) The designs of lines 2 and 3 are done in a similar manner, except that the flows are determined from the cumulative areas of all upslope pipes, plus the pipe being designed.

5) The crowns of the joining pipes must match, and the inverts must have a 30 mm drop, at least, when pipes are joined in a manhole at different directions.

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6) Along Main Street (flat, with no ground slope), using the smallest pipe slope (0.001) that meets the depth of flow and velocity criteria minimizes excavation depths.

Table 4.27 Sewer Design Calculations

		Manhole No.			Area		Maximum Flow			Minimum Flow										Sewer Invert Elevation		Ground Surface Elevation	
Line No. (1)	Location (2)	From (3)	To (4)	Length (m) (5)	Increment (ha) (6)	Total (ha) (7)	I/I (m^3/min) (8)	Sewage (m^3/min) (9)	Total (m^3/min) (10)	I/I (m^3/min) (11)	Sewage (m^3/min) (12)	Total (m^3/min) (13)	Slope of Sewer (14)	Diam (mm) (15)	Min Velocity (m/s) (16)	Max Velocity (m/s) (17)	Max Depth (mm) (18)	Invert Drop (m) (19)	Fall in Sewer (m) (20)	Upper End (m) (21)	Lower End (m) (22)	Upper End (m) (23)	Lower End (m) (24)
0	Main Street	–	5	–	–	–	–	–	66.6	–	–	11.1	0.009	1065	1.75	2.88	476	–	–	–	55.35	–	60.04
1	A Street	1	2	53	0.47	0.47	0.0026	0.102	0.105	0.0026	0.0170	0.0196	0.047	150	0.60	0.99	23	–	2.49	62.74	60.25	65.00	63.80
2	A Street	2	3	91	0.50	0.97	0.0070	0.210	0.217	0.0070	0.0350	0.0420	0.024	150	0.60	0.97	40	–	2.18	60.25	58.07	63.80	62.40
3	A Street	3	5	100	0.44	1.41	0.0120	0.305	0.317	0.0120	0.0509	0.0629	0.018	150	0.61	0.97	52	–	1.80	58.07	56.27	62.40	60.04
4	A Street	4	5	89	0.90	0.90	0.0043	0.195	0.199	0.0043	0.0325	0.0368	0.027	150	0.60	0.98	37	–	2.40	58.67	56.27	61.88	60.04
5	Main Street	5	12	69	0.17	309.96	0.0197	67.14	67.16	0.0197	11.19	11.21	0.001	1220	0.78	1.24	879	0.155	0.07	55.20	55.13	60.04	60.04
6	B Street	6	8	58	0.43	0.43	0.0028	0.0932	0.0960	0.0028	0.0155	0.0183	0.050	150	0.60	0.99	22	–	2.90	62.90	60.00	65.08	63.20
7	P Avenue	7	8	50	0.48	0.48	0.0024	0.104	0.106	0.0024	0.0173	0.0197	0.048	150	0.60	1.00	23	–	2.40	61.34	58.99	63.60	63.20
8	B Street	8	10	91	0.39	1.30	0.0097	0.282	0.292	0.0097	0.0469	0.0566	0.019	150	0.60	0.97	49	–	1.73	58.99	57.26	63.20	62.04
9	Q Avenue	9	10	56	0.88	0.88	0.0027	0.191	0.194	0.0027	0.0318	0.0345	0.029	150	0.60	1.00	36	–	1.62	60.44	58.82	62.72	62.04
10	B Street	10	12	97	0.45	2.67	0.0171	0.578	0.595	0.0171	0.0964	0.114	0.011	205	0.61	0.95	86	0.055	1.07	57.21	56.14	62.04	60.04
11	B Street	11	12	125	0.90	0.90	0.0061	0.195	0.201	0.0061	0.0325	0.0386	0.026	150	0.60	0.97	37	–	3.25	59.45	56.20	61.88	60.04
12	Main Street	12	19	75	0.28	313.81	0.0465	67.97	68.02	0.0465	11.33	11.38	0.001	1220	0.79	1.24	887	–	0.08	55.13	55.06	60.04	60.20
13	C Street	13	15	57	0.60	0.60	0.0028	0.130	0.133	0.0028	0.0217	0.0245	0.040	150	0.60	1.00	27	–	2.28	62.20	59.92	64.40	62.84
14	P Avenue	14	15	53	0.76	0.76	0.0026	0.165	0.168	0.0026	0.0274	0.0300	0.034	150	0.61	1.02	32	–	1.80	60.38	58.58	63.24	62.84
15	C Street	15	17	97	0.51	1.87	0.0101	0.405	0.415	0.0101	0.0675	0.0776	0.015	150	0.61	0.98	63	–	1.46	58.58	57.12	62.84	61.60
16	Q Avenue	16	17	63	0.94	0.94	0.0031	0.204	0.207	0.0031	0.0339	0.0370	0.028	150	0.60	1.01	37	–	1.76	59.90	58.21	62.12	61.60
17	C Street	17	19	100	0.48	3.27	0.0180	0.708	0.726	0.0180	0.1180	0.1360	0.010	205	0.60	0.96	83	0.055	1.00	57.07	56.07	61.60	60.20
18	C Street	18	19	138	1.41	1.41	0.0067	0.305	0.312	0.0067	0.0509	0.0576	0.019	150	0.60	0.99	51	–	2.62	58.75	56.13	61.92	60.20
19	Main Street	19	26	78	0.30	318.79	0.0750	69.05	69.13	0.0750	11.51	11.59	0.001	1220	0.79	1.25	900	–	0.08	55.06	54.98	60.20	60.08

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