Sewer system- Design Criteria
Design of W.W. Collection System

DETERMINATION OF DESIGN FLOW

The design of sanitary sewers, including new construction and replacement sewers, must consider minimum, average, and peak flows. Normally, ADWF is determined or selected, and a factor is applied to determine the peak dry weather flow. The PDWF is the design flow used to select the pipe size. Minimum flows are used to determine if specified velocities can be maintained to prevent deposition of solids. The ratio of PDWF to ADWF will range from less than 130% for some large diameter sanitary sewers to more that 260% for smaller sewers.

HYDRAULICS

Sewers shall be designed to accommodate future tributary flows, in addition to those from the project. Gravity sewer capacities shall be determined for peak flow rates by Manning’s Formula using an “n” value of 0.013 for all pipelines, according to pipe material.
Design of W.W. Collection System

**Design criteria:**

**Waste water flow:** Flow varies according to:
- The season (monthly variations)
- Weather conditions
- Week of the month, day of the week, time of the day.

**Estimation of the design flow \( Q_{des} \): Data needed:**
- Average daily water consumption per capita for domestic areas (L/c/d), \( Q_{avg} \).
- Average daily water consumption per capita for institution (school, offices, ….etc.), \( Q_{avg} \).
- Average daily water consumption for commercial and industrial areas.

**Infiltration, inflow:**
- \( Q_{infil} \) is taken as \([24-95 \text{ m}^3/\text{day/km}] \) or \([0.5 \text{ m}^3/\text{day/diameter (cm)}]\), take the bigger value of the two.
- \( Q_{inflo} \) is taken as \([0.2-30 \text{ m}^3/\text{ha/day}]\). (hectare = 10,000 m\(^2\))

\[
Q_{des} = Q_{max} + Q_{I/I} \ (\text{if found})
\]

\[
Q_{I/I} = Q_{infil} + Q_{inflo}
\]

\[
Q_{max} = [0.80 * Q_{avg}] * P_f \ (0.8 > 80\% \text{ return from water supply}).
\]

This equation is for domestic users only. \( Q_{max} \) for institutions, commercial activities, and industries are calculated according to the type of industry, and cannot be calculated from this equation. Each industry has its specific average wastewater production and peaking factor that can be taken from published references or from the records of these industries or institutions.
Sewage flow diagram for a small town

- **Peak coefficient**
- **Average day flow**
- **Average 24 hr flow**
- **Average night flow**

Flow coefficients and flow rates for different times of the day are shown in the diagram. The x-axis represents the hour of the day, while the y-axis represents the flow coefficient and flow rate (L/s).
- \( P_f \): peak factor for domestic wastewater can be calculated from one of the following formulas:

\[
P_f = 1 + \frac{14}{4 + \sqrt{P}}, \quad (P: \text{population in thousands})
\]

Or \( P_f = \frac{5}{P \cdot 0.167} \)

The minimum domestic wastewater flow \((Q_{min})\) is necessary to check for the minimum velocity in the sanitary sewers, it is estimated from the following formula:

\[
Q_{min} = 0.2 P^{\frac{1}{6}} \cdot \left[ Q_{avg} \right]_W
\]

**Note:** \([Q_{avg}]_W = 0.8 Q_{avg}\), which is the average domestic wastewater production, while \(Q_{avg}\) is the average water consumption.

A typical value of \( Q_{min} = \frac{1}{3} \left[ Q_{avg} \right]_W \)
<table>
<thead>
<tr>
<th>Upstream Population</th>
<th>Peaking Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>3.62</td>
</tr>
<tr>
<td>200</td>
<td>3.14</td>
</tr>
<tr>
<td>300</td>
<td>2.90</td>
</tr>
<tr>
<td>400</td>
<td>2.74</td>
</tr>
<tr>
<td>500</td>
<td>2.64</td>
</tr>
<tr>
<td>600</td>
<td>2.56</td>
</tr>
<tr>
<td>700</td>
<td>2.50</td>
</tr>
<tr>
<td>800</td>
<td>2.46</td>
</tr>
<tr>
<td>900</td>
<td>2.42</td>
</tr>
<tr>
<td>1000</td>
<td>2.38</td>
</tr>
<tr>
<td>1001 to 10,000</td>
<td>(PF = (6.330 \times p - 0.231) + 1.094)</td>
</tr>
<tr>
<td>10,001 to 100,000</td>
<td>(PF = (6.177 \times p - 0.233) + 1.128)</td>
</tr>
<tr>
<td>More than 100,000</td>
<td>(PF = (4.500 \times p - 0.174) + 0.945)</td>
</tr>
</tbody>
</table>

PF = Peaking Factor  
P = Upstream Population
Example

A gravity pipe serving a community of 50,000 inh. The length of the pipe is 200 m, and the average water consumption is 120 L/c.d. Use an infiltration rate of 30 m$^3$/day.km, and a wastewater production rate of 80% of the water supply. Neglect the inflow for this example. Calculate $Q_{des}$ and $Q_{min}$.

**Solution**

a. **Calculate the average domestic WW flow:**

$$[Q_{avg}]_{w} = 0.8 \times Q_{avg} = 0.80 \times 120 \text{ L/c/d} \times 50,000 \text{ capita} \times 10^{-3} = 4800 \text{ m}^3/\text{d}$$

b. **Calculate the peak factor:**

$$P_f = 1 + \frac{14}{4 + \sqrt{P}} = 1 + \frac{14}{4 + \sqrt{50}} = 2.26$$
a. Calculate the maximum wastewater flow:

\[ Q_{\text{max}} = [Q_{\text{avg}}]_w \times P_f = 2.26 \times 4800 = 10848 \text{ m}^3/\text{d} \]

b. Calculate the minimum wastewater flow:

\[ Q_{\text{min}} = \frac{1}{0.2 P^6} \times \left[ Q_{\text{avg}} \right]_W \times \frac{1}{50^6} \times 4800 = 1845 \text{ m}^3/\text{d} \]

c. Calculate the infiltration flow:

\[ Q_{\text{infil}} = 30 \times 0.20 = 6 \text{ m}^3/\text{d} \]

d. Calculate the design flow:

\[ Q_{\text{des}} = Q_{\text{max}} + Q_{\text{I/I}} = 10848 + 6 = 10854 \text{ m}^3/\text{d} \]
Peak hour sewer flow rates do not include infiltration or inflow (I/I). Infiltration is defined as the addition of groundwater into the sewer collection system and inflow is the addition of storm water into the sewer collection system.

Because sewer collection system I/I is dependent on a number of factors including season, age of system, type of pipe material and joints, root intrusion, and presence of storm water system, the I/I flow rates will vary from system to system.
**Maximum and minimum velocities:**
Minimum velocity of 0.6 m/s should be maintained to prevent solids settling, it is called self cleansing velocity.
Maximum velocity should not be greater than 3 m/s to prevent erosion of pipes and manholes.

**Minimum size of pipes:**
Minimum diameter is 8 inches (20 cm).

**Minimum Slope and maximum slope of sanitary sewers:**
Minimum slope is a function of the minimum velocity of 0.60 m/s. The maximum slope is related to the maximum velocity (3 m/s or any other velocity selected by the designer) according to the pipe material and the expected amount of sand carried with the wastewater.

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### Minimum slopes for gravity flow sewers

<table>
<thead>
<tr>
<th>Diameter</th>
<th>Slope m/m</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n=0.013</td>
</tr>
<tr>
<td>mm</td>
<td>inch</td>
</tr>
<tr>
<td>200</td>
<td>8</td>
</tr>
<tr>
<td>250</td>
<td>10</td>
</tr>
<tr>
<td>300</td>
<td>12</td>
</tr>
<tr>
<td>375</td>
<td>15</td>
</tr>
<tr>
<td>450</td>
<td>18</td>
</tr>
<tr>
<td>525</td>
<td>21</td>
</tr>
<tr>
<td>600</td>
<td>24</td>
</tr>
<tr>
<td>675</td>
<td>27</td>
</tr>
<tr>
<td>750</td>
<td>30</td>
</tr>
<tr>
<td>900</td>
<td>36</td>
</tr>
</tbody>
</table>

Based on Manning equation with a velocity of 0.6 m/s
Minimum slopes for gravity flow sewers

<table>
<thead>
<tr>
<th>Pipe Sizes</th>
<th>Min. Slope (ft/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6”</td>
<td>0.0060</td>
</tr>
<tr>
<td>8”</td>
<td>0.0040</td>
</tr>
<tr>
<td>10”</td>
<td>0.0028</td>
</tr>
<tr>
<td>12”</td>
<td>0.0022</td>
</tr>
<tr>
<td>15”</td>
<td>0.0015</td>
</tr>
<tr>
<td>18”</td>
<td>0.0010</td>
</tr>
<tr>
<td>21”</td>
<td>0.0008</td>
</tr>
<tr>
<td>24”</td>
<td>0.0007</td>
</tr>
</tbody>
</table>
**Depth of excavation:**
Minimum cover on the top of sewers
Depth of excavation depends on:
- water table
- topography
- lowest point to be served
- other factors

<table>
<thead>
<tr>
<th>D (inch)</th>
<th>Depth below design level (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.7</td>
</tr>
<tr>
<td>6</td>
<td>0.8</td>
</tr>
<tr>
<td>8</td>
<td>1.0</td>
</tr>
<tr>
<td>10</td>
<td>1.0</td>
</tr>
<tr>
<td>12</td>
<td>1.0</td>
</tr>
<tr>
<td>14</td>
<td>1.2</td>
</tr>
<tr>
<td>16</td>
<td>1.3</td>
</tr>
</tbody>
</table>
Manhole Location:

Install manholes at all changes of slope

Install manholes at all changes in horizontal direction

Install manholes at all intersections of mains.

Install manholes at changes of pipe sizes.

Install manholes at the end of all sewer mains

Maximum spacing of manholes shall be based on maintenance capacity of the city
Lay-out plan

1. Find the intermediate points of collection from topographic maps.
2. Assign the final points of collection.
3. Draw lines indicating the flow of sewage by gravity (different alternatives).
4. The pipes can be considered as:
   - Building sewers.
   - Lateral sewers.
   - Sub main sewers.
   - Main sewers.
   - Trunk sewers.
   - Intercepting sewers.
5. The contributory area for each pipe is defined by drawing lines depending on topography and points of connection to manholes.
6. Manholes and pipes are given numbers to facilitate the design of each pipe.
Alternative Lay-outs for main sewer
Lay-out of sewer Scheme

TOWN A
Extension B

P₁ number of heavy sewage producer

A = nr. of area (hectare)
B = area in hectare
C = class of sewage production

E = nr. of manhole
F = ground level
G = invert level

5 = number of manhole
9.20 = ground level
7.07 = invert of upstream sewer
7.02 = invert of downstream sewer (this indicates a drop of 5 cm)
Sanitary Sewers Appurtenances
Manholes

**Manholes**: Manholes are constructed in the following cases:
- when pipes change in diameter
- change of direction
- change of slope
- intersection of pipes
- at interval, (20-100 m)

The following table gives the allowable intervals of manholes relative to the diameter:

<table>
<thead>
<tr>
<th>Pipe diameter (inch)</th>
<th>Max. distance between manholes (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>30</td>
</tr>
<tr>
<td>8-10</td>
<td>40</td>
</tr>
<tr>
<td>10-12</td>
<td>50</td>
</tr>
<tr>
<td>12-16</td>
<td>60</td>
</tr>
<tr>
<td>16-36</td>
<td>100</td>
</tr>
<tr>
<td>≥ 36</td>
<td>150</td>
</tr>
</tbody>
</table>

Note: The distance depends on the maintenance equipments available.
Manhole dimensions
The diameter of the manhole or its side's dimensions depends on the depth of excavation. The following table gives their relation.

<table>
<thead>
<tr>
<th>Depth of manhole</th>
<th>Manhole dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Depth ≤ 0.90 m</td>
<td>0.60 x 0.60 m</td>
</tr>
<tr>
<td></td>
<td>Φ 0.60 m</td>
</tr>
<tr>
<td>≥ 2.00 m</td>
<td>Φ 1.50 m</td>
</tr>
</tbody>
</table>

- The cover of the manhole should be strong enough to withstand the loads of traffic.
- It is usually made of cast iron to carry a minimum concentrated load of 25 ton.
- The manhole should be supplied with steps to allow for maintenance access.
- The floor of the manhole should be lined with cement mortar which is called benching.
**Drop manhole:** are used when the difference of elevation between the inlet pipe and the outlet pipe is ≥ 60cm. The drop manhole has a vertical pipe to prevent turbulence in the manhole and to allow the maintenance works to enter the manholes safely.

**Grease and oil traps:** For the institutions, commercial units, restaurants and other places which produce oil and grease in their effluent, a grease and oil trap should be used to remove oil and grease before they enter the sewage pipes. Grease and oil affect the sewers and the treatment plant equipments that is why they should be removed. In case of the pipes, grease sticks to the walls and collects sand and other solids leading eventually to the decrease in the pipe diameter and some times to complete clogging.
Inverted siphon: When an obstacle such as railway or a river obstructs the sewer line the sewers can be lowered below these obstacles.

- For the inverted siphon: Minimum velocity = 0.9 m/s
- Pipes flow full (under pressure).

More than one pipe is used to overcome these variations. Usually Three pipes are used.

- The first pipe is used to carry the minimum wastewater flow ($Q_{\text{min}}$),
- The second carry the difference between the average flow and the minimum flow ($Q_{\text{avg}} - Q_{\text{min}}$)
- The third carries the difference between the average and the maximum flow ($Q_{\text{max}} - Q_{\text{avg}}$)
Example
An inverted siphon composed of three pipes is to be used to convey wastewater from one side of a river to the other side. The invert level of the upstream manhole is + 100 above the sea level. The length of each of the three pipes is 250 m. The average flow interring the upper manhole is 0.25 m³/s. Find the diameter of each of the three pipes, and the invert of each pipe at the down stream manhole.

Assume the following:
peak factor = 2.5
minimum flow factor = 0.30
minimum velocity when flowing full = 0.90 m/s

Solution
Qaverage = 0.25 m³/s, Qmin= 0.3 X 0.25= 0.075 m³/s, Qmax = 2.5 X 0.25 = 0.625 m³/s

- Flow in the first pipe= Qmin= 0.075 m³/s
- Flow in the second pipe = Qaverage – Qmin = 0.25- 0.075= 0.175 m³/s
- Flow in the third pipe = Qmax- Qaverage = 0.625- 0.25 = 0.375m³/s

Design of minimum flow pipe
Q=VA  0.075= 0.9 \(\frac{3.14 \ D^2}{4}\)  D= 0.32 m
Headless in the first pipe

\[ V = \frac{1}{n} R \left( \frac{2}{3} \right) S^\frac{1}{2} \] \hspace{1cm} \text{..........................................................} \hspace{1cm} \text{(1)}

\[ Q = \frac{0.312}{n} D \left( \frac{8}{3} \right) S^\frac{1}{2} \] \hspace{1cm} \text{..........................................................} \hspace{1cm} \text{(2)}

0.9 = \left( \frac{1}{0.013} \right) \left\{ \frac{0.32}{4} \right\}^{2/3} S^{1/2}

S = 4.0 \times 10^{-3}

S = H/L = 4.0 \times 10^{-3} = H/250 \quad H = \text{Head loss} = 0.99 \; m = 1.0 \; m

The invert level of the outlet should be at 99 above sea level.

The same procedure for the second and the third pipes.