Example

**Forecasting Design Flowrates**  A residential community with a current population of 15,000 is planning to expand its wastewater-treatment plant. In 20 years, the population is estimated to increase to 25,000 residents and 2000 day students are expected to attend a proposed junior college. A new industry will also move in and contribute an average flowrate of 840 m$^3$/d and a peak flowrate of 1260 m$^3$/d. The plant will operate 8 h/d and will shut down one day per week. The present average daily wastewater flowrate is 6500 m$^3$/d and the infiltration/inflow has been determined to be nonexcessive. Infiltration is estimated to be 100 L/capita-d at average flow and 150 L/capita-d at peak flow. Residential water use in the new homes is expected to be 10 percent less than the existing residences because of the installation of water-saving appliances and fixtures. Compute the future average, peak, and minimum design flowrates. For peak residential flowrates, use a peaking factor of 2.75 and assume the ratio of minimum to average flowrate is 0.35.

1. **Compute the present and future per capita wastewater flowrates**
   a. **For present conditions, compute the average domestic flowrate excluding infiltration**
      i. **Compute infiltration**
         \[
         \text{Infiltration} = 15,000 \text{ persons} \times 1 \text{ L/capita-d} \times \frac{1 \text{ m}^3}{1000 \text{ L}} = 1500 \text{ m}^3/\text{d}
         \]
      ii. **Compute average domestic flowrate**
         \[
         \text{Domestic flow, m}^3/\text{d} = \text{total average flow} - \text{infiltration}
         = 6500 - 1500 = 5000 \text{ m}^3/\text{d}
         \]
   b. **Compute present per capita flowrate by dividing the existing domestic flowrate by the present population**
      \[
      \text{Per capita flowrate} = \frac{(5000 \text{ m}^3/\text{d})}{15,000 \text{ persons}} = 0.33 \text{ m}^3/\text{capita-d}
      \]
   c. **For future conditions, reduce existing per capita flowrate by 10%**
      \[
      \text{Future per capita flowrate} = 0.33 \times 0.9 = 0.297 \text{ m}^3/\text{capita-d}
      \]
2. Compute future average flowrate
   a. Existing residents =
      Flowrate, m³/d
      5,000
   b. Future residents = 10,000 × 0.297 m³/capita·d =
      2,970
   c. Day students (assume 95 L/capita·d from
      Table 3–3) = 2000 × 0.095 m³/capita·d
      190
      Subtotal residential
      8,160
   d. Industrial flowrate =
      840
   e. Infiltration = (25,000)(100 L/capita·d)(1 m³/10³ L) =
      2,500
   f. Total future average flowrate =
      11,500

3. Compute future peak flowrate
   a. Residential peak flowrate = 8160 × 2.75 =
      22,440
   b. Industrial peak flowrate =
      1,260
   c. Infiltration = (25,000)(150 L/capita·d)(1 m³/10³ L) =
      3,750
   d. Total future peak flowrate =
      27,450

4. Compute the minimum flowrate
   a. Residential: As indicated on Fig. 3–4, the low flowrate
      usually occurs in the early morning hours. The future
      minimum flowrate, excluding mere day
      students = 0.35 × (20% × 2970) =
      2,780
   b. Industrial facilities are shut down at night =
      0
   c. Infiltration = (25,000)(100 L/capita·d)(1 m³/10³ L) =
      2,500
   d. Total minimum flowrate =
      5,280

Comment  In this example, infiltration/inflow contributes nearly 50 percent of the minimum flowrate
and over 20 percent of the average flowrate; an illustration of the influence of extraneous
flows on treatment plant design. If wastewater flow records are not adequate or are unavailable,
future average daily flow may be calculated based on the future population and unit
wastewater flowrates, similar to those given in Tables 3–1 to 3–5. Appropriate adjustments
should be made in the calculations to account for any special conditions such as flow
reduction, infiltration/inflow allowances, and industrial flows. When peak flowrates for
more than one flow component are calculated, some adjustment in the total peak flowrate
should be made if the peaks from the components do not occur simultaneously.
with all measurements closely grouped about the wrong value, while another may be accurate but imprecise, with all measurements widely scattered about the correct value. The accuracy and precision of the various test methods are presented below, but it must be recognized that these values refer only to the laboratory determination. Additional uncertainty is introduced by the inherent variability of wastewater and the difficulty of obtaining truly representative samples.

Generally, composition of sewage may be broken into three major areas. These areas are the physical, chemical, and biological characteristics of wastewater.

**PHYSICAL CHARACTERISTICS**

Sewage is over 99.9 percent water, but the remaining material has very significant effects upon the nature of the mixture. Fresh domestic sewage has a slightly soapy or oily odour, is cloudy, and contains recognizable solids, often of considerable size. As the waste ages, its character changes as a result of biological and chemical phenomena. Stale sewage has a pronounced odour of hydrogen sulphide, is dark grey, and contains smaller but occasionally recognizable solids.

The change from fresh to stale requires 2 to 6 hours at a temperature of 20°C with the time depending primarily on the concentration of organic matter. The concentration varies with per capita water use, infiltration, and the quantity of industrial waste which enters the collection system. The quantity of domestic waste produced per person is relatively invariant on a dry solids basis, but the quantity of carriage water is not.

The physical characteristics of wastewater include those items that can be detected using the physical senses. They are temperature, colour, odour, and solids.

**TEMPERATURE**

The temperature of wastewater is commonly higher than that of the water supply because of the addition of warm water from households and industrial activities. The temperature of water is a very important parameter because of its effect on the aquatic life, the chemical reactions and reaction rates and the suitability of the water for beneficial uses.

Increased temperature, for example, can cause a change in the species of fish that can exist in the receiving water body. Industrial establishments that use surface water for cooling-water purposes are particularly concerned with the temperature of the intake water.

In addition, oxygen is less soluble in warm water than in cold water. The increase in the rate of biochemical reactions that accompanies an increase in temperature, combined with the decrease in the quantity of oxygen present in surface waters, can often cause serious depletion in dissolved oxygen concentration in the summer months. When significantly large quantities of heated water are discharged to natural receiving waters, these effects are magnified. A sudden change in temperature can result in a high rate of mortality of aquatic life. Abnormally high temperature can foster the growth of undesirable water plants and wastewater fungus.

**COLOUR**

Fresh wastewater is usually grey; however, as organic compounds are broken down by bacteria, the dissolved oxygen in the wastewater is reduced to zero and the colour changes to black. In this condition the wastewater is said to be septic (or stale). Some industrial wastewater may also add colour to domestic wastewater.

Significance of Colour in Wastewater
change in DO is an indirect measure of the organic substances in the bottle. Through this process we see that biodegradable organic materials have associated with them a potential demand for oxygen when they are degraded (hence the name biochemical oxygen "demand").

Organic matter is typically measured as either Biochemical Oxygen Demand (BOD) or Chemical Oxygen Demand (COD). BOD is the most widely used parameter to quantify organic pollution of water. BOD is the measurement of the dissolved oxygen that is used by microbes in the biochemical oxidation of organic matter.

\[
\text{Dissolved } O_2 + \text{ organic Matter} \rightarrow CO_2 + \text{ Biological Growth}
\]

BOD measurements are used to:

- Determine the approximate quantity of oxygen required to react with organic matter
- Determine the sizing of the wastewater treatment works
- Measure the efficiency of some treatment process
- Determine compliance with wastewater discharge permits or consents

The steps in the laboratory method to measure BOD are:

- Measure a portion of wastewater sample into a 300 ml BOD bottle
- Add seed organisms, if required
- Fill the bottle with aerated dilution water
- Measure the initial dissolved oxygen (DO)
- Incubate the bottle at 20°C for 5 days in the dark (to determine BOD₅)
- Measure the final DO
- Calculate BOD₅

The initial depletion of DO is due to carbonaceous demand (Figure ??). The reproduction of nitrifying bacteria is low, and it usually takes them 6-10 days to reach significant enough numbers to cause measurable oxygen demand. The later oxygen demand is mainly due to nitrification, i.e. the conversion of ammonium nitrogen to nitrate and nitrite.
**Strength and bedding of sewers**

Since sewers are ordinarily not pressurized, they are often deeply buried than water mains and are made of brittle, rather weak materials, the effect of soil and other external loads is quite important.

The static load produced on buried pipe may be calculated from marstons equation:-

\[ W = C w B^2 \]

Where: \( W \) = load on the pipe per unit length  
\( w \) = weight of fill material per unit volume  
\( B \) = width of trench just below top of pipe  
\( C \) = coefficient that depends on the depth of trench, character of construction and fill material.

For ordinary trench construction, \( C \) may be calculated from:

\[ C = 1 - e^{-2k\mu'H/B} / 2K\mu' \]

Where:- \( H \) = depth of fill above pipe  
\( B \) = width of trench just below top of pipe  
\( K \) = ratio of active lateral pressure to vertical pressure  
\( \mu' \) = Coefficient of sliding friction between fill material and sides of trench.

The product of \( K\mu' \) ranges from 0.1 to 0.16 for most soils. Value of the product \( K\mu' \)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Maximum value of ( K\mu' )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohesion-less granitic material</td>
<td>0.192</td>
</tr>
<tr>
<td>Sand and gravel</td>
<td>0.165</td>
</tr>
<tr>
<td>Saturated top soil</td>
<td>0.150</td>
</tr>
<tr>
<td>Clay</td>
<td>0.130</td>
</tr>
<tr>
<td>Saturated clay</td>
<td>0.110</td>
</tr>
</tbody>
</table>

Unit weight of back fill material

<table>
<thead>
<tr>
<th>Material</th>
<th>Unit weight(kg/m3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry sand</td>
<td>1600</td>
</tr>
<tr>
<td>Ordinary sand</td>
<td>1840</td>
</tr>
<tr>
<td>Wet sand</td>
<td>1920</td>
</tr>
<tr>
<td>Damp clay</td>
<td>1920</td>
</tr>
<tr>
<td>Saturated clay</td>
<td>2080</td>
</tr>
<tr>
<td>Saturated top soil</td>
<td>1840</td>
</tr>
<tr>
<td>Sand and damp top soil</td>
<td>1600</td>
</tr>
</tbody>
</table>
Example:- A 610 mm clay sewer is to be placed in an ordinary trench 3.66m deep and 1.22m wide which will be filled with wet clay. Determine the load on the pipe and the type of bedding required if the installation is to have a factor of safety of 1.5

Solution

\[ C = 1 - e^{-0.110(2)(3.66/1.22)} = 2.20 \]

\[ W = 2.20(1920)(1.22)^2 = 6290 kg/m \]

- Other Fabricated Sewers

**Plastic truss pipe**: It is a pipe in which the space between the inner and outer surfaces is filled with light weight concrete, which increases the pipe stiffness. Truss pipe can be subjected to rather large differential settlements without failure and is thus particularly useful in areas with poor soil conditions. This pipe is available only in sizes of 200 to 380 mm hence its application is limited to laterals and sub mains.

**Solid wall plastic pipe** is manufactured of PVC i.e polyvinyl chloride in Diameters from 100-380mm. The smaller sizes are used for household plumbing.

**Corrugated metal pipe** is sometimes used for storm sewers, although its primary application is in highway drainage. The pipe may be galvanized or provided with other protective coatings (such as asphalt) to increase its life. Corrugated pipe is available in a large variety of cross section and wall thickness. Like truss pipe, it derives a large part of its strength from its ability to deform and develop lateral support.

**Iron pipe** it may be used in conveying sewage in circumstances in which other less expensive materials are unsuitable. eg. lines installed under very high external loads.

- Flow in gravity sewers

**Minimum Velocity**: The flow velocity in the sewers should be such that the suspended materials in sewage do not get silted up; i.e. the velocity should be such as to cause automatic self-cleansing effect. The generation of such a minimum *self-cleansing velocity* in the sewer, at least once a day, is important, because if certain deposition takes place and is not removed, it will obstruct free flow, causing further deposition and finally leading to the complete blocking of the sewer.

**Maximum Velocity**: The smooth interior surface of a sewer pipe gets scoured due to continuous abrasion caused by the suspended solids present in sewage. It is, therefore, necessary to limit the maximum velocity in the sewer pipe. This limiting or non-scouring velocity will mainly depend upon the material of the sewer.

**Effects of Flow Variation on Velocity in a Sewer**: Due to variation in discharge, the depth of flow varies, and hence the hydraulic mean depth \( r \) varies. Due to the change in the hydraulic mean depth, the flow velocity (which depends directly on \( r^{2/3} \)) gets affected from time to time. It is necessary to check the sewer for maintaining a minimum velocity of about 0.45 m/s at the time of minimum flow (assumed to be \( 1/3 \)rd of average flow). The designer should also ensure that a velocity of 0.9 m/s is developed at least at the time of maximum flow and preferably during the
slowed just enough to permit the grit to settle. Grit chambers are designed with a linear flow velocity of 30 cm/s with a detention time of 1 minute. These conditions allow the grit to settle out on the bottom of the chamber where it is collected for disposal. The settled grit is mechanically removed from these tanks and taken to landfills.

The wastewater may then flow into a comminuting device which shreds any material not removed by the previous two operations. Generally, the comminutor consists of slotted cylinder with rotating cutting members which shear the material to a size small enough to pass through the slots. Usually the slots are approximately 0.5 cm (¼ in). In this operation, the shredded solids remain in the wastewater and are subsequently removed in the following operations.

**Primary Treatment (Removal of Particulate Organic Material)**

After Preliminary Treatment, the water moves on to primary treatment, that consists chiefly of primary sedimentation operation. The wastewater flows very slowly (≈ 2 m/hr) through large tanks (called Primary Clarifier) because it flows slowly through these tanks. The water is nearly motionless for several hours. The particulate organic material (about 30% to 50% of the organic material) settles to the bottom, from where it can be removed. At the same time, fatty material floats on the top, where it is skimmed from the surface. All the material removed, both particulate organic and fatty materials is combined into what is referred to as raw sludge.

This operation is the most important in primary treatment operations for which the previous preparation has been carried out. Sedimentation tanks are designed to provide relatively quiescent conditions with a detention time of 1-2 hours. The remaining relatively uniform-sized solids will therefore settle to the bottom of the tank where they are pushed by moving scrapers into a sludge hopper for collection and disposal. These conditions permit a removal of 50-75% of suspended solids which may account for 40-50% of the biodegradable pollution in the wastewater.

**Secondary Treatment (Removal of Colloidal and Dissolved Organic Material)**

This is also called biological treatment, because it makes use of organisms – natural decomposers and detritus feeders. Basically, an environment is created to enable these organisms to feed on the colloidal and dissolved organic material and break them down to carbon dioxide and water via their cellular respiration. The sewage water from primary treatment is the food and water rich medium. The only thing that needs to be added is oxygen to enhance the organisms’ respiration and growth. The amount of dissolved oxygen needed by these aerobic decomposers to break down organic materials in a given volume of water at certain temperature over specific time period is referred to as the biological oxygen demand (BOD).

The activated-sludge system may be used as the major process for removal of biodegradable organic matter. In this system, wastewater from primary treatment enters a long tank that is equipped with an air bubbling system. A mixture of detritus-feeding organisms, referred to activated-sludge is added to the water as it enters the tank, and the water is vigorously aerated as it moves through the tank. Organisms in this well-aerated environment reduce the biomass of organic material, including pathogens, as they feed. As organisms feed on each other, they tend to form clumps referred to as floc that settles readily when the water is motionless. Thus from the aeration tank the water is passed into a secondary clarifier tank where the organisms settle out. The wastewater is now is cleaner as 90% of the organic material has been removed. The settled
Components of a Secondary Treatment Process

Components of a secondary treatment process can be listed as follows:

- Microorganisms,
- Oxygen supply (aeration)
- Wastewater, and
- Mixing to bring all the other components together.

Classification of Secondary Treatment Process

Classification of secondary treatment processes is often based on the nature of microbial growth. Organisms can be suspended in wastewater, or they can be attached to an inert surface.

**Suspended Growth Processes:** Activated Sludge (most common);

1) Conventional (tapered aeration),
2) Step aeration,
3) Contact stabilization,
4) Extended aeration,
5) Oxidation ditch.

**Attached Growth Processes:** Attached growth processes can be listed as follows;

1) Trickling filters,
2) Rotating biological contactors,
3) Biological towers.

**Lagoons:** Lagoons can be listed as follows; (1) Mechanically aerated and (2) Waste stabilization ponds

**ACTIVATED SLUDGE PROCESS**

The most common suspended growth process used for municipal wastewater treatment is the activated sludge process.

Activated sludge plant involves:
destruction will result. These coliforms pose a hazard to soil and groundwater purity if the lagoon leaks. Common conversion efficiency reaches up to 95%

Pond systems, in which oxygen is provided through mechanical aeration rather than algal photosynthesis, are called aerated. There are generally 2 to 6 meters in depth with detention times of 3 to 10 days and they are advantageous because they require very little land area.

The oxidation ditch is a modified form of extended aeration of activated sludge process. The ditch consists of a long continuous channel oval in shape with two surface rotors placed across the channel.

**Facultative (aerobic-anaerobic) ponds**

In facultative ponds, stabilisation of waste is achieved by combination of aerobic, anaerobic and facultative bacteria. The functioning of a facultative stabilization pond and symbiotic relationship in the pond are shown below. Sewage organics are stabilized by both aerobic and anaerobic reactions. In the top aerobic layer, where oxygen is supplied through algal photosynthesis, the non-settleable and dissolved organic matter is oxidized to CO₂ and water. In addition, some of the end products of partial anaerobic decomposition such as volatile acids and alcohols, which may permeate to upper layers are also oxidized periodically. The settled sludge mass at the bottom, originating from raw waste and microbial synthesis in the aerobic layer and dissolved and suspended organics in the lower layer, undergo stabilization through anaerobic conversion to methane which escapes a pond in form of bubbles. In the intermediate zone, that is partly aerobic and anaerobic, decomposition of organic wastes is carried out by facultative bacteria.
**Natural Evaporation**

The process involves large impoundments with no discharge. Depending on the climatic conditions large impoundments may be necessary if precipitation exceeds evaporation. Therefore, considerations must be given to net evaporation, storage requirements, and possible percolation and groundwater pollution. This method is particularly beneficial where recovery of residues is desirable such as for disposal of brines.

**Groundwater Recharge**

Methods for groundwater recharge include rapid infiltration by effluent application or impoundment, intermittent percolation, and direct injection. In all cases risks for groundwater pollution exists. Furthermore, direct injection implies high costs of treating effluent and injection facilities.

**Irrigation**

Irrigation has been practiced primarily as a substitute for scarce natural waters or sparse rainfall in arid areas. In most cases food chain crops (i.e. crops consumed by humans and animals whose products are consumed by humans) may not be irrigated by effluent. However, field crops such as cotton, sugar beets, and crops for seed production are grown with wastewater effluent.

Wastewater effluent has been used for watering parks, golf courses, and highway medians.

**Recreational Lakes**

The effluent from the secondary treatment facility is stored in a lagoon for approximately 30 days. The effluent from the lagoon is chlorinated and then percolated through an area of sand and gravel, through which it travels for approximately 0.5 km and is collected in an interceptor trench. It is discharged into a series of lakes used for swimming, boating and fishing.

**Aquaculture**

Aquaculture, or the production of aquatic organisms (both flora and fauna), has been practiced for centuries primarily for production of food, fiber and fertilizer. Lagoons are used for aquaculture, although artificial and natural wetlands are also being considered. However, the uncontrolled spread of water hyacinths is itself a great concern because the flora can clog waterways and ruin water bodies.

**Municipal Uses**

Technology is now available to treat wastewater to the extent that it will meet drinking water quality standards. However, direct reuse of treated wastewater is practicable only on an emergency basis. Many natural bodies of water that are used for municipal water supply are also used for effluent disposal which is done to supplement the natural water resources by reusing the effluent many times before it finally flows to the sea.