Learning objectives

Upon successful completion of this lecture, the participants will be able to describe:

- Components of urban drainage systems
- Fundamental stages of urban drainage system design procedures
- Preliminary design considerations
- Data requirements for designing urban drainage systems
- System layout of urban drainage systems and factors affecting drainage system layouts
- Rainfall analysis for urban drainage system network designs
System components

- **Sewers**
  - **Material** - Must be durable and strong
    - cast and ductile iron,
    - PVC (polyvinyl chloride),
    - concrete, asbestos cement,
    - HDPE (high density polyethylene),
    - brick, and
    - vitrified clay
  - **Shape**
System components

- **Vertical alignment**

![Diagram of vertical alignment with labels:
- $a =$ invert level (IL)
- $b =$ Soffit level
- $c =$ Crown level
- $d =$ Ground level
- $D =$ internal diameter of pipe
- $t =$ pipe wall thickness
- $b = a + D$
- $c = b + t$]
System components

- **Manholes**
  - means of access for inspection, repair and cleaning
  - placed at changes in
    - direction,
    - pipe size,
    - grade and elevation, and
  - at junctions, and
  - at intervals of 90-120 m
System components

- **Inlets**
  - an opening into sewer for entrance of storm runoff
  - placed at intersections and at intervals of 20 to 100 m
  - consist of a grating and an underlying sump to collect heavy material in the flow

![Inlet Diagrams](image)
System components

- **Ventilation**
  - to ensure that aerobic conditions are maintained within the pipe, and to avoid the possibility of build-up of toxic or explosive gases
  - above-ground ventilation shafts
  - ventilated manhole covers
  - soil stacks on individual buildings
System components

- Sand, oil and grease trap
  - To prevent sand, oil and grease from entering the sewers
Design stages

- Fundamental stages to design urban drainage system
- Stage 1 - Data collection and analysis
  - Identify the area(s) to be served
  - Set system design criteria
  - Collect topographic map, geologic and geographic data
  - Add location and level of existing or proposed details
  - Undertake field investigations
  - Identify the natural drainages, streets, wastewater inflow points at the boundaries of the area to be sewered
  - Locate all proposed sources of wastewater
Design

- Stage 2 - Preliminary horizontal layout
  - Design the horizontal layout of the sewer, including manholes and possible pumping station locations.
  - Prepare alternate layouts

- Stage 3 - Preliminary sewer sizing
  - Divide the total area into logical subareas and develop design flow rates for each section in the system
  - Select pipe sizes, slopes, and inverts
    - Perform the hydraulic design of the system
    - Revise selections until the design criteria are met
  - Draw preliminary longitudinal profiles (vertical alignment):
    - ensure pipes are deep enough so all users can connect into the system
    - try to locate pipes parallel to the ground surface
    - ensure pipes arrive above outfall level
    - avoid pumping if possible
Design

- **Stage 4 - Cost estimate**
  - Complete cost estimate(s) for the design and alternate designs

- **Stage 5 - Revise design**
  - Carefully review all designs, along with assumptions, alternates, and costs
  - Complete the plan and profile drawings and prepare specification and other bid documents
Initial Planning

- An initial planning study
  - whether to provide drainage service,
  - the type of conveyance (gravity and/or pressure), and
  - the pros and cons of different types of systems

- A preliminary investigation to determine
  - the potential area to be served,
  - the consequences of not serving the area,
  - how the area will be served, and
  - the economic feasibility of such a project
Types of Conveyance

- Sewer systems use one or combination of the following conveyance systems
  - gravity,
  - pressure,
  - vacuum

- In most cases gravity sewers have lower total life-cycle costs over pressure or vacuum systems
Separate versus Combined Systems

- In the past, combined sewers made economic sense.
- Today, separate sewer systems are favoured due to expensive mandatory treatment requirements.
- In the future, combined sewer system may again be the more economical solution.
  - Treatment requirements for urban storm waters may become so stringent.
Initial System Layout

- Sewer systems
  - almost always laid out in a dendritic (treelike) pattern
  - normally allow flow in only one direction and are rarely looped
- Their layout is affected by many factors
  - political boundaries
  - street patterns,
  - alignment of existing underground services,
  - land topography, and geology
Initial System Layout

- The layout of a gravity sewer system
  - topographic map of the service area
  - locations of the sewer outlet(s) and elevations of the highest services
  - follow streets at the flattest acceptable slope
  - the line ends at a connection to
    - a trunk sewer,
    - a wastewater treatment facility,
    - a pumping station, or
    - a receiving water
Initial System Layout

- System lay outs should consider
  - Economy
  - Budget limitation vs the desire to provide ultimate capacity

- Location of Pumping Facilities
  - placed at low points to collect gravity flow from an area and pump it to a desired point
  - best placed on public land
Initial System Layout

- **Pipe Slopes**
  - A minimum velocity must be maintained to prevent solids build-up during low flows
  - Determined by either the tractive force method or self cleansing velocity requirement
  - Usually it is recommended that flow velocities be less than 3m/s at peak flow
Initial System Layout

- Curved Sewer Alignment
  - to avoid obstructions or
  - give future access for lateral connections or repair

- Minimum Depth of Cover
  - as shallow as possible while still being located
  - Deep enough to provide gravity service whenever feasible
  - Below the frost
  - A reasonable distance below other utilities,
  - Deep enough to adequately distribute traffic and surface loads
Initial System Layout

- Special Installations
  - Sewers in Steep Terrain
  - Sewers along Streams
  - Elevated Crossings
  - Inverted Siphons (Depressed Sewers)
Hydraulic Design - steps

- Drainage networks
  - connect inlet points to a discharge point or outfall by a series of pipes
  - Flow into the sewer from
    - rainfall-runoff process and
    - wastewater discharge

- Designing a storm drainage network involves
  - Choosing a suitable design storm
  - Quantifying physical properties of contributing area
  - Computing design runoff (discharge)
  - Determining
    - diameters,
    - slopes, and
    - crown or invert elevations for each pipe in the system
Hydraulic Design – design storm

- design storm
  - give statistically representative rainfall
  - can be applied to the contributing area and converted into runoff flows
- design storm return period determines the degree of protection
- protection should be related to the cost of any damage or disruption
Hydraulic Design – design storm

- Assumption: frequency of rainfall ≈ frequency of runoff
- Reality: rainfall frequency ≠ runoff frequency due to
  - antecedent soil moisture conditions
  - areal distribution of the rainfall
  - movement of rain
- Storm runoff data is less common than rainfall records
- Reasonable approach is to assume
  - rainfall frequency is equivalent to runoff frequency
Rainfall Analysis

- Rain data expressed either as depth in mm or intensity in mm/h
- Rainfall depth can be related statistically to *duration* and *frequency*
- Rainfall duration refers to the time period over which the rain falls
- Frequency or probability of the rainfall usually expressed as a return period
Steps for IDF analysis

- IDF relationships
  - A convenient form of rainfall information
  - For a particular return period, rainfall intensity and duration are inversely related
  - IDF curves can be developed using frequency analysis
- Steps for IDF analysis are:
  - gathering time series records of different duration. (eg. 5, 10, 15, 20, 30, 60, 90, and 120 min)
  - Extract annual extremes from the record of each duration
  - Fit the annual extreme data to a probability distribution in order to estimate rainfall depth for different return periods
Steps for IDF analysis are

\[ X_T = \mu + K_T \sigma \]

where

- \( X_T \) represents the magnitude of the \( T \)-year event,
- \( \mu \) and \( \sigma \) are the mean and standard deviation of the annual maximum series and
- \( K_T \) is frequency factor depending on the return period \( T \). Note that the frequency factor is distribution-specific
- For example \( K_T \) for Gumbel’s extreme value distribution is given by

\[ K_T = \frac{-\sqrt{6}}{\pi} \left[ 0.5772 + \ln \left( \ln \left( \frac{T}{T-1} \right) \right) \right] \]
Steps for IDF analysis are

- Calculate the average intensity

\[ \bar{i}_T(D) = \frac{X_T}{D} \]

- Construct the IDF curves (plot rainfall intensity versus duration for different return periods)
Steps for IDF analysis are

- **Annual maximum series for different durations**

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<th>Year</th>
<th>5min</th>
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$\mu$, $\sigma$, $X_T$
Steps for IDF analysis are

- **IDF**

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<th>Duration (min)</th>
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IDF curves

IDF curves usually represented by an empirical formula which has one of the following different forms

\[ i = \frac{aT^m}{(t_d + c)} \]

\[ i = \frac{aT^m}{(t_d + c)^e} \]

Where

- \( i \) = intensity in mm/hr
- \( T \) = return period in years
- \( t_d \) = rainfall duration in minutes
- \( a, m \) and \( e \) are coefficients representing local condition
The alternating block method is a simple way of developing a design storm from an IDF curve.

The design storm produced by this method specifies the precipitation depth occurring in $n$ successive time intervals of duration $\Delta t$ over a total duration $T_d = n \times \Delta t$.

Steps:
- Select the design return period,
- Read the intensity from the IDF curve/relation for each of the durations,
- Calculate the corresponding precipitation depth as the product of the intensity and duration.
Design storm from IDF curves

Steps

- Differences between successive precipitation depth values give the amount of precipitation to be added for each additional unit of time.
- These increments, or blocks, are recorded into a time sequence with the maximum intensity occurring at the centre of the required duration.
- And the remaining blocks arranged in descending order alternately to the right and left of the central block to form the design hyetograph.
Design storm from IDF curves

- Design storm hyetograph