• Sewers are underground conduits for conveying wastewaters from urban areas to treatment facilities
  – The earliest drainage systems were constructed in 16th- and 17th-century cities

• Combined sewers were constructed in many U.S. cities prior to 1900
  – Without recognizing the need for segregation and treatment of domestic and industrial wastewaters

• Although combined sewers still exist in older municipalities, separate sewers are now required
• Sewer outlets that terminate in channels subject to tides or high water levels are equipped with flap gates
  – To prevent backflooding into the sewer system

• Storm sewers are assumed to surcharge & overflow periodically—differing from sanitary sewers
  – Sanitary sewers are designed & constructed to prevent surcharging

• Circular concrete pipe is commonly in storm sewers
  – Elliptically shaped and arch-type concrete pipe are also manufactured for special applications
• Stormwater management programs are designed to keep pollutants in drainage from entering waterways
  – Sediment, trash, metals, organics, pesticides, nutrients, oil & grease

• Source control measures include:
  – Sweeping and cleaning; controlling litter and erosion
  – Spill, leak, and overflow control
  – Limits on use of chemicals; monitoring for illegal dumping
Stormwater retention ponds are used to attenuate storm flow rate and provide a quiescent reservoir for pollutant retention.
• The goal for stormwater management is to generate no more runoff after development than before

• For green projects, at least 15% of rain from a design-case storm must be prevented from running off site

• Some stormwater management strategies include:
  – Run-off retention & storage
  – Pervious asphalt; subsurface perforated piping
• Sanitary sewers transport domestic and industrial wastewaters by gravity flow to treatment facilities.

• A force main is a sewer through which wastewater is pumped under pressure rather than by gravity flow.

• Design flows for sewer systems are based on population served using specific per capita quantities.
• Sewer slopes should be sufficient to maintain self-cleansing velocities

• Where velocities exceed 10 ft/sec, special provision must be made to protect the pipe and manholes
  – Against erosion and shock hydraulic loadings

• Sanitary sewers are placed deep enough to prevent freezing and to receive wastewater from basements

• Ease of maintenance dictates many of the design criteria for wastewater collection systems
• Pumping stations are used in a collection system only when continuing flow by gravity is impractical
  – Due to high cost and potential maintenance problems
• A plan view is drawn over the profile & an aerial photo or survey topography can be included (Fig. 10–2)

• New sewer lines & water mains must be installed so as to prevent any possible passage of polluted water from the sewer into the potable water supply

• If separation cannot be maintained or the water line crosses under the sewer, the Health Department must determine alternative construction methods
• A siphon is a depressed sewer that drops below the hydraulic gradient to avoid an obstruction
  – Such as a stream, railway cut, or depressed highway

• Velocity of flow in the pipes should be greater than 3 ft/sec to prevent deposition of solids
Where a waterway, railroad, road, or other structures do not allow an open-cut trench pipe may be installed using trenchless technologies (Fig. 10–3)
• Horizontal auger boring uses an auger machine to turn an auger within a carrier pipe (Fig. 10–4)

• As the casing is pushed into the soil, a cutting head and flighted auger remove the soil and hollow out the hole

• Auger boring machines are capable of installing pipe from 8 to 60 in
• Microtunneling machines use a cutting-style tunneling face to lead the pipe through the hole
  – Simultaneously tunneling and installing the pipe

• Machines are specific to each pipe size
  – Ranging from 48” to 120”

• A variety of pipe materials may be installed
  – Including steel, concrete, and clay
• Tunnel boring machines have a single rotating disc tunneling face with directional control

• Cuttings are removed dry and automatically loaded on a conveyor belt for removal

• Because work must be done within the tunnel, the minimum diameter is 96”

• In poor geologic conditions where water is present or rock is highly fractured, sealed concrete segments are installed by hand as the machine cuts the tunnel
• Most manholes are circular in shape with an inside diameter of 4 ft. (Fig. 10–5)
  – Sufficient to perform sewer inspection and cleaning

• Solid covers are used on sanitary sewers, and open-type covers are common on storm sewers
  – Steps or ladder rungs are placed for access

• Walls may be constructed of precast concrete rings, concrete block, brick, or poured

• Manholes constructed in high groundwater should be waterproofed to prevent excessive infiltration
• A drop manhole is used when it is necessary to lower the elevation of a sewer in a manhole more than 24”
  – Protects men entering the structure & eliminates the nuisance created by solids splashed onto the walls

• Vortex manhole inserts reduce the velocity during the drop and reduce corrosion and odor
• Manholes should be placed:
  – At all changes in sewer grade, pipe size, or alignment
  – At all intersections; at the end of each line
  – Distances not greater than:
    • 400 ft. for sewers 15” or less
    • 500 ft. for sewers 18” - 30”
• House sewers are laid on a straight line and grade using 4” or 6” pipe (Fig. 10–6)
  – Preferred minimum slope is 2%, or 1/4 in/ft

• In some housing developments, the dwelling setback from the street dictates the slope of the connection

• Good workmanship, high-quality pipe & watertight joints minimize infiltration and root penetration
• Building vents to sewer drains provide a connection between the air in sewer pipes and the atmosphere.

• Where natural aeration is not sufficient, forced ventilation is installed to draw air out of the sewer:
  – Exhausting it to a high stack or some deodorizing process.
Monitoring sewer use requires measuring flow and composite sampling at critical points in the system.

Estimated flow can be computed from the measured depth of flow using the Manning formula:

$$Q = \frac{1.49}{n} AR^{2/3} S^{1/2}$$

where
- $Q =$ quantity of flow, cubic feet per second
- $n =$ coefficient of roughness depending on material
- $A =$ cross-sectional area of flow, square feet
- $R =$ hydraulic radius, feet (cross-sectional area divided by the wetted perimeter)
- $S =$ slope of the hydraulic gradient, feet per foot
• Installation of a flume is necessary for accurate flow measurement and automatic composite sampling.

• A Palmer-Bowlus flume with a trapezoidal throat cross section can be used in a sewer with adequate slope (Fig. 10–7)
  – They are constructed for temporary installation in the half section of a sewer in a manhole.

• Open-channel flow meters use an ultrasonic sensor, submerged probe, or bubbler to measure water level or depth (Fig. 10–8).
• A portable wastewater sampler can be programmed for sampling, and uses an attached peristaltic pump (Fig. 10–9)

• Sampling can be at uniform or nonuniform intervals
  – Single-bottle sequential collection
  – Multiple- or single-bottle compositing
  – Split sampling, or flow-paced collection

• Sampling stations range from a standard manhole to a separate chamber large enough for flow-recording and automatic-sampling equipment (Fig. 10–10)
• Circular sewer pipe is manufactured with inside diameters from 4” to 144”
  – Maximum sizes vary with materials

• The most important chemical characteristics of a pipe are resistance to dissolution in water and to corrosion (Fig. 10–11)

• Vitrified clay is the most common material used in sanitary sewer pipe
  – Bell-and-spigot vitrified clay pipes are connected by compression joints with seals of flexible plastic
• Plastic pipe used most frequently in sewer systems is made of polyvinyl chloride (PVC) or polyethylene (PE)

• PVC pipe is produced in two strength classifications in sizes from 4” to 12”
  – PVC pipe sections have a deep-socket bell end to accommodate a chemical weld joint

• PE pipe is joined by softening aligned end and pressing them together under controlled pressure
• Precast concrete sewer pipe may be obtained in many sizes with several kinds of joints
  – The choice of type of pipe & joint depends on application, location, and conditions for installation

• Concrete pipe is used extensively in storm sewers
  – Abrasion resistance and availability in large sizes
  – High crushing strength and generally lower cost

• Concrete is an alkaline material subject to acid attack
  – It should not be used for sewers where hydrogen sulfide production can cause internal corrosion
• Ductile-iron pipe is used…
  – For inverted siphons and force
  – Inside pumping stations and treatment plants
  – Where proper separation from water mains cannot be maintained
  – Where poor sewer foundation conditions exist

• Other pipe materials for special applications in wastewater collection systems:
  – Smooth-wall and corrugated steel pipe
  – Bituminized fiber; reinforced resin pipe
• Bedding & backfill varies with native soil conditions, pipe material, local conditions, and with bury depth

• The materials must be able to be placed in a readily compacted state under, around, and over the pipe

• Bedding is critical to pipe integrity—in the bottom of the trench, it is a level compacted surface for pipe support (Fig. 10–13)

• Backfill must be capable of flowing under the pipe in a compacted state
Warning tape and tracer lines may be installed in the trench on the backfill above the pipe to warn future excavators of the buried pipeline.
• Sewer installation requires knowledge of appropriate excavation, installation and compaction requirements

• Considerations include environmental requirements, shoring, dewatering & field testing of placed material

• Safety plans & trench requirements are specified by the U.S. Department of Labor, OSHA and state and local agencies
  – OSHA classifies materials and defines a maximum allowable slope
• The most accurate method of soil classification is to submit samples to a laboratory (Fig. 10–14)
  – To determine of gradation, plasticity, and unconfined compressive strength

• Pipe section alignment is done by laser (Fig. 10–14)
  – Each pipe joint is tested for tightness immediately after placement, with compressed air
• Dewatering is necessary to prevent excessive groundwater from entering the trench
  – Disturbing the pipe bedding & weakening the trench walls

• To reduce water migration through the porous trench material, seepage barriers are used along the pipeline
  – At about 1000-ft intervals

• Environmental considerations apply to excavation in environmentally sensitive areas, protection of excavated material, and runoff control
• Testing of cohesive materials in the excavation verifies compaction & limit future soil settlement

• Laboratory tests are used to determine the optimum water content and maximum density for a given soil

• The most popular laboratory test is ASTM D1557, often called the Modified Proctor Test (Fig. 10–16
- Field measurements evaluate effectiveness of the contractor use of compaction equipment (Fig. 10–17)

- The field measurement is compared to the lab results of the Modified Proctor Test
  - The percentage of maximum density or the relative density of the compacted soil is calculated

- Bedding and backfill is placed in layers, or lifts of up to 12", and compacted (Fig. 10–18)

- Limiting the backfill layer depth ensures complete compaction throughout the vertical trench profile
• New sewers are tested for watertightness by monitoring infiltration & exfiltration and air testing

• Exfiltration testing, the reverse of measuring actual infiltration, is used mainly in dry areas
  – Maximum allowable exfiltration varies between pipe sizes

• A well-constructed sewer will exhibit some loss of air pressure even if watertight
  – Significant air loss is caused by damaged pipe or defective joints
• In an air test, a section of sewer between manholes is isolated by plugging both ends & capping any service connections (Fig. 10–19)
  – Air pressure is applied & held while plugs are checked for leakage and the temperature of the air stabilizes
  – The air supply is disconnected and the time required for the pressure to drop from is measured

• Manholes are tested using a vacuum test after completion of pipe testing
Lift stations elevate and transport wastewater in collection systems when gravity flow is not feasible.

A pumping station can lift the wastewater to an intercepting sewer at a higher level (Fig. 10–20)
- Or the pumps can discharge to a force main.

Pumping stations are expensive to install, and require periodic inspection/maintenance
- And strain public relations if they malfunction.

They are avoided when possible by including sewer planning into municipal land-use zoning and planning.