Municipal Wastewater Treatment Systems

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Module 1: Primer for Municipal Wastewater Treatment Systems

Learning Objectives

By the end of this section, you will be able to:

- **Identify** the physical, biological, and chemical processes used in centralized and decentralized treatment.
- **Evaluate** the impact of various pollutants, such as BOD and nutrients, on water quality and aquatic ecosystems.
- **Select** appropriate disinfection and biosolids management strategies based on regulatory and environmental constraints.

Executive Summary: As population and industrial growth increase demands on natural resources, modern wastewater treatment must employ a combination of physical, biological, and chemical processes to remove complex contaminants and residuals, ensuring the protection of public health and the restoration of the nation's water bodies.

The Need for Wastewater Treatment

Wastewater treatment is essential to ensure that rivers and streams remain viable for fishing, swimming, and drinking water. Historical pollution led to low dissolved oxygen, fish kills, and bacterial contamination. While early efforts were local, modern water pollution issues now dominate national concerns regarding healthy ecosystems.

Key Challenges for Professionals

- **Aging Infrastructure**: Many collection and treatment facilities require significant repair or replacement.
- **Complex Contaminants**: Modern contaminants are far more complex than those faced in the past.
- **Population Growth**: Expanding populations tax existing systems and necessitate new plant construction.
- **Uncontrolled Runoff**: Agricultural runoff and urbanization provide pollution sources not captured by traditional treatment.
- **Decentralized Migration**: One-third of new developments rely on septic or cluster systems.

Effects of Wastewater on Water Quality

The primary function of a treatment plant is to accelerate the natural purification processes of water. Failure to treat wastewater properly introduces various pollutants into the environment.

Pollutant Type	Impact and Characteristics
Oxygen-Demanding Substances	Measured as Biochemical Oxygen Demand (BOD); substances like organic matter and ammonia deplete dissolved oxygen needed for fish.
Pathogens	Infectious micro-organisms like those causing typhoid and cholera; modern disinfection has largely eliminated these in the U.S.
Nutrients	Carbon, nitrogen, and phosphorus; excess leads to algae blooms and eutrophication, which chokes aquatic life.
Synthetic Chemicals	Detergents, heavy metals, and pesticides; many are toxic to humans and aquatic life and are difficult to remove.
Thermal	Waste heat reduces water's oxygen-retaining capacity and alters ecosystem ecology.

Collecting and Treating Wastewater

Centralized systems use a network of sewers to deliver waste to treatment facilities.

- **Combined Sewer Systems**: Designed to collect both sanitary wastewater and storm water runoff in a single pipe; these can overflow during heavy rains, releasing pollutants.
- **Sanitary Sewer Systems**: Designed strictly for domestic and industrial wastewater, utilizing smaller pipes and reducing treatment costs compared to combined systems.

The Multi-Stage Treatment Process

Preliminary and Primary Treatment

1. **Preliminary**: Uses screens to remove large objects like rags and cans that could clog pumps. Grit chambers allow sand and stones to settle.
2. **Primary Sedimentation**: Wastewater slows down in tanks, allowing suspended organic solids to settle to the bottom as **primary sludge**.

Secondary Treatment

This stage uses biological processes to remove up to **90 percent** of organic matter.

- **Attached Growth**: Microorganisms grow on media (rocks or plastic). Trickling filters and biotowers are common examples.
- **Suspended Growth**: Microorganisms are suspended in aerated water. The **activated sludge process** is a common, though energy-intensive, method.
- **Lagoons**: Scientifically constructed ponds (3-5 feet deep) that use sunlight, algae, and bacteria for purification.

Land Treatment and Constructed Wetlands

- **Slow Rate Infiltration**: The most common land technique; wastewater is applied to crops where soil filters contaminants.
- **Overland Flow**: Wastewater flows down vegetated slopes, suited for heavy clay soils.
- **Constructed Wetlands**: Engineered areas that recreate natural wetland processes to treat industrial or storm runoff.

Advanced Treatment

Used to reach higher purification levels for reuse in irrigation or industrial cooling.

- **Nitrogen Control**: **Nitrification** converts ammonia to nitrate; **denitrification** converts nitrate to harmless nitrogen gas.
- **Phosphorus Control**: Achieved through chemical addition (alum or lime) to "floc" particles together for sedimentation.
- **Carbon Adsorption**: Uses activated carbon to remove resistant trace organic substances.

Disinfection Methods

⚠️ **Safety Constraint**: Trace amounts of free chlorine are highly toxic to aquatic life; **dechlorination** is often required before discharge.

- **Chlorine**: Most widely used; can be gas, liquid, or solid.
- **Ozone**: Highly effective against viruses and bacteria; leaves no harmful byproducts but is energy-intensive.
- **Ultraviolet (UV) Radiation**: A physical process that damages the genetic material of microbes; leaves no chemical residue.

Management of Residuals and Biosolids

Biosolids are processed wastewater solids that meet standards for beneficial reuse.

- **Land Application**: Used as a soil conditioner or fertilizer; provides nutrients and improves soil structure.
- **Incineration**: Burning dried solids to ash; can include heat recovery for energy.

🧮 **Calculation Note**: To utilize the fuel potential of biosolids for incineration, water content must be significantly reduced through dewatering or pressure filtration.

Decentralized (Onsite) Systems

Decentralized systems treat sewage from individual homes or small clusters not connected to central plants.

- **Septic Tanks**: Anaerobic chambers where solids settle and bacteria break down organic matter.
- **Absorption Fields**: Perforated pipes in gravel trenches that disperse effluent into the soil for further natural treatment.
- **Mound Systems**: Used when soil is poorly permeable or groundwater is high; the system is built above the original ground level.

Checkpoint Quiz

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1. **Which process is primarily used in Secondary Treatment to remove organic matter?**
   a) Grit removal in a grit chamber.
   b) Biological metabolism by microorganisms.
   c) Carbon adsorption of trace organics.
   d) Physical screening of large objects.

Answer: (b). Secondary treatment relies on attached or suspended growth biological processes to consume organic matter.

2. **What is the primary difference between a combined sewer and a sanitary sewer?**
   a) Sanitary sewers carry both storm water and domestic waste.
   b) Combined sewers are strictly for industrial waste.
   c) Sanitary sewers are designed only for wastewater, not storm water.
   d) Combined sewers utilize smaller pipes to save on construction costs.

Answer: (c). Sanitary sewers are built for domestic/industrial sources and exclude storm water to maintain smaller volumes.

3. **Why is dechlorination often required when using chlorine as a disinfectant?**
   a) To reduce the energy cost of the treatment plant.
   b) Because free chlorine is highly toxic to beneficial aquatic life.
   c) To allow the water to be reused for industrial cooling.
   d) To prevent the growth of algae in the receiving water body.

Answer: (b). Even low concentrations of free chlorine can kill fish and other aquatic organisms, necessitating its removal.

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