Wastewater Management and Resource Recovery Briefing

Executive Summary

This document provides a comprehensive overview of modern wastewater management, synthesizing key principles from watershed-level planning to advanced technological applications. The core themes revolve around a holistic approach to water environment protection, the implementation of stringent, data-driven water quality standards, and the increasing focus on resource recovery through grey water reuse and biosolids management.

New Jersey serves as a critical case study, demonstrating a structured approach to classifying surface waters, setting precise nutrient criteria for pollutants like phosphorus, and utilizing Total Maximum Daily Load (TMDL) models to restore impaired water bodies such as the Passaic River. The TMDL process exemplifies a quantitative, cost-effective strategy for allocating pollutant load reductions among various sources.

Pollution control is addressed through a multi-pronged strategy targeting point, nonpoint, and internal sources. Advanced point source controls include innovative biological processes for nutrient removal and energy generation from sludge, as seen in Washington D.C.'s high-tech facilities. Nonpoint source control is highlighted by the Barnegat Bay watershed rules, which mandate specific land use practices and green infrastructure like subsurface gravel wetlands.

The paradigm is shifting from simple disposal to resource recovery. Grey water reuse for non-potable applications is an increasingly vital tool for combating water scarcity, though it requires careful management of health risks. Similarly, the beneficial use of biosolids—stabilized wastewater sludge—in agriculture and land reclamation is governed by strict EPA regulations to ensure safety and efficacy. Finally, maintaining collection systems and mitigating Combined Sewer Overflows (CSOs), which discharge an estimated 850 billion gallons of untreated wastewater annually in the U.S., remain fundamental challenges addressed through runoff reduction, storage, and high-rate treatment.

1.0 Water Environment Assessment, Protection, and Restoration

A comprehensive framework for water environment management involves assessing entire watersheds, establishing rigorous standards, and implementing multi-faceted control strategies for all sources of pollution.

1.1 Watershed Management

Watershed management is the integrated study and management of a watershed's characteristics to ensure the sustainable distribution and use of its resources.

- **Definition:** The process involves creating and implementing plans and projects to sustain and enhance the functions of a watershed, which affect all plant, animal, and human communities within its boundaries.
- **Scope:** Key management features include water supply, water quality, drainage, stormwater runoff, and water rights.
- **Stakeholders:** Effective management requires the collaboration of landowners, land use agencies, stormwater management experts, environmental specialists, water purveyors, and local communities.
- **Management Process:** A cyclical, adaptive process is employed to guide management activities:
    1. **Identify Stakeholders:** Determine all parties involved.
    2. **Identify Interests & Objectives:** Define goals and desired outcomes.
    3. **Inventory & Assess Watershed:** Collect data on the watershed's characteristics.
    4. **Develop a Plan:** Create a strategy to achieve objectives.
    5. **Implement the Plan:** Put the strategy into action.
    6. **Reflect & Adjust:** Monitor results and modify the plan as needed.

1.2 Water Quality Standards and Wasteload Allocation

Establishing clear standards and allocating pollutant loads are foundational to protecting water bodies. New Jersey's system provides a detailed example of this approach.

New Jersey Water System Case Study

As the most densely populated state, located near major metropolitan areas and home to significant industry, New Jersey's waters face substantial pollution pressures.

- **Surface Water Classification:** NJ classifies its surface waters into three tiers to guide protection efforts.
    - **Outstanding National Resource Waters:** High-quality waters of exceptional national significance (e.g., in National/State Parks), protected from any degradation.
    - **Category One Waters:** Waters with exceptional ecological, recreational, water supply, or fisheries significance, protected from measurable changes in water quality.
    - **Category Two Waters:** All other waters not designated in the above two categories.
- **Phosphorus Criteria:** The state has established specific numeric criteria for total phosphorus (TP).
    - **Streams:** TP must be ≤ 0.1 mg/L, unless it is proven not to be a limiting nutrient.
    - **Lakes, Ponds, & Reservoirs:** TP must be ≤ 0.05 mg/L, unless site-specific criteria are developed.
- **Nutrient Policies:**
    1. Policies apply to all state waters.
    2. The Department can develop watershed-specific criteria through a Total Maximum Daily Load (TMDL).

3. Water quality-based effluent limits for nutrients, potentially stricter than the standard 1.0 mg/L for phosphorus, can be established to meet TMDL wasteload allocations.
4. Activities causing nonpoint nutrient discharge must implement Best Management Practices (BMPs).

Total Maximum Daily Load (TMDL)

A TMDL is a regulatory tool that calculates the maximum amount of a pollutant a water body can receive and still meet water quality standards.

- **Passaic River TMDL (New Jersey):**
  - **Goal:** To address phosphorus-impaired stream segments using chlorophyll-a (Chl-a) concentration as the target.
    - Wanaque Reservoir Target: 10 µg/L Chl-a (seasonal average).
    - Passaic River at Dundee Lake Reach Target: 20 µg/L Chl-a (seasonal average).
  - **Modeling:** An integrated watershed model was used, linking the DA-FLOW (Water Flow), WASP (Water Quality), and WAMIT (GIS Integration) models.
  - **Required Reductions:**
    - Phosphorus in wastewater treatment plant effluent to be reduced to **0.4 mg/L** (an average reduction of **38%**).
    - Phosphorus load from stormwater runoff to be reduced by **60%**.
  - **Outcome:** The TMDL process provides a quantitative method for environmental protection that allows for cost-effective, implementable control measures. Even if numeric phosphorus standards are not fully met, the model-driven targets are deemed sufficient to protect the water body's designated uses.
- **Chesapeake Bay TMDL:**
  - **Scope:** Considered the largest and most complex TMDL in the U.S., its watershed covers six states and Washington, D.C.
  - **Goal:** Uses chlorophyll-a as the target to determine necessary nutrient reductions.
  - **Required Reductions:**
    - Nitrogen load reduction of **25%**.
    - Phosphorus load reduction of **24%**.

1.3 Pollutant Source Control Strategies

Effective water quality management requires distinct strategies for point, nonpoint, and internal sources of pollution.

Point Source Control

This involves managing pollutants from discrete conveyances like pipes from wastewater treatment plants (WWTPs).

- **Innovative Treatment Technologies:**

    - Alternating aerobic and anaerobic microbiological processes for enhanced nitrogen and phosphorus removal.
    - Use of biological membranes, ultrasonic waves, and microwaves.
    - A recent (approx. 20 years ago) breakthrough was the identification of phosphorus-removing microbes via metagenomic analysis, providing a more reliable basis for controlling biological phosphorus removal.
- **Sludge Treatment and Energy Recovery:**
    - **Biodigesters:** Anaerobic microbiological processes that degrade organic matter in sludge and release energy.
    - **Example:** The DC Plant expansion is designed not only to meet nutrient discharge limits but also to harvest energy from its bottom sludge.
    - **Microbial Fuel Cells:** An emerging technology for generating electrical power directly from wastewater.

Nonpoint Source Control

This addresses diffuse pollution, primarily from stormwater runoff.

- **Management Practices:** Control relies on Best Management Practices (BMPs), Low Impact Development (LID), and Green Infrastructure (GI).
- **Barnegat Bay, NJ Case Study:** In 2011, New Jersey established a suite of rules to reduce nitrogen loads to the bay.
    1. **Fertilizer Regulations:** At least 20% of nitrogen in lawn fertilizers must be slow-release, and phosphorus application is prohibited unless a soil test shows a deficit. Fertilizers cannot be applied near river banks.
    2. **Stormwater Basin Modification:** Retrofitting existing detention basins into subsurface gravel wetlands, which use an anaerobic gravel layer to promote denitrification.
    3. **Soil Decompaction:** Loosening soil compacted during construction activities.
    4. **Land Preservation:** Acquiring open space to reduce the potential for new development.

Internal Source Control

This focuses on pollutants originating from within the water body itself.

- **Primary Source:** Bottom sediment is the primary internal pollutant source. In deep, anoxic (low-oxygen) conditions, phosphorus can be released from sediment, fueling algal blooms.
- **Management Techniques:**
    - **Dredging:** Hydraulic dredging is generally preferred over mechanical dredging due to lesser short-term impacts on water quality.
    - **Solidification:** For toxic sediment, solidification before dredging is advisable.
    - **Bioremediation:** In situ biological removal of bottom sediment is an option.

1.4 In Situ Water Body Treatment

These methods involve treating the water body directly to improve its quality.

- **"Alien" Methods (External Intervention):**
  - **Aeration:** A physical process to increase dissolved oxygen.
  - **Alum Addition:** A chemical process that precipitates inorganic phosphorus but increases the volume of bottom sludge.
  - **Bioaugmentation:** Introducing non-native species to remove pollutants. This carries significant risk, as the introduced species could grow out of control and alter the ecosystem.
- **Effective Ecological Methods (Case Study: Apopka Lake, Florida):**
  - **Marsh Flow-Way Restoration:** Converting muck farmland back into marshland to filter nutrient-rich water from the lake.
  - **Rough Fish Harvesting:** Removing certain fish species to extract nutrients from the ecosystem and manipulate the food web to improve water quality.
- **Self-Purification Enhancement:**
  - Considered the most ideal method, this approach focuses on utilizing and enhancing the natural self-purification capabilities of a water body.
  - This can be achieved through bio-stimulation, where indigenous microbes are selectively cultivated to remove specific pollutants like BOD, COD, nutrients, heavy metals, and harmful organics.

2.0 Water and Solids Reuse Strategies

Driven by water scarcity and sustainability goals, reusing treated wastewater and its solid byproducts is becoming standard practice.

2.1 Grey Water Reuse

The reuse of grey water (wastewater from non-toilet sources) for non-potable applications is a key water conservation strategy.

- **Applications:**
  - Landscape and agricultural irrigation
  - Flushing toilets
  - Cooler and boiler makeup water in industrial settings
  - Repelling saltwater intrusion into coastal aquifers
- **Historical Examples:**
  - **1977, St. Petersburg, FL:** Large-scale irrigation of parks, golf courses, and residential lawns.
  - **1984, Tokyo, Japan:** Water recycling project providing reclaimed water for toilet flushing in 19 high-rise buildings.
  - **2000-2010, The Solaire, NYC:** Reused water for toilet flushing, cooling tower makeup, and landscape/green roof irrigation.
- **Challenges and Disadvantages:**
  - Potential for surface and groundwater contamination.
  - High capital cost for installing separate plumbing systems.

    - Risk of cross-contamination with potable water lines.
    - Presence of unregulated emerging contaminants (e.g., Endocrine Disrupting Compounds) and pathogens that are not addressed by standard water quality tests.

Pathogen Survival Data

The persistence of pathogens on crops irrigated with reclaimed water is a significant health consideration.

Table 1: Pathogen Survival on Crops

Pathogen	Crop	Temperature	Survival (days)
Salmonella	radish, lettuce	sunny	10
		shady	31
E. coli	alfalfa	12 - 23 °C	1
		9 - 18 °C	4
	grass	12 - 23 °C	5
Taenia	grass/hay	30 °C	22 - 60
		10 - 16 °C	30 - 210
Poliovirus	grass	30 - 42 °C	0.33
		4 - 16 °C	2

Table 2: Poliovirus Survival on Vegetables In Situ

Vegetable	Month	Days Required for 90% Reduction	Days Required for 99% Reduction
Romaine lettuce	July	3.0	5.9
Butter lettuce	October	3.5	7.8
Artichokes	April	4.0	6.9
	May	3.0	5.7
	June	2.0	3.4

2.2 Solids and Biosolids Management

Wastewater sludge is processed into biosolids, a valuable resource for beneficial use.

- **Definition:** Wastewater sludge contains up to 12% solids by weight. After being stabilized, these solids are referred to as **biosolids**.
- **Process:**
    1. **Moisture Removal:** Thickening and concentration.
    2. **Stabilization:** Using methods like digestion or composting. Incineration also stabilizes solids but produces no useful biosolids.
- **Beneficial Use:**

- The nitrogen, phosphorus, and potassium content makes biosolids a useful fertilizer.
    - Use can be impaired by the presence of heavy metals, pathogens, or other contaminants.
    - There have been instances of contamination from biosolids application, highlighting the need for rigorous management.
- **Regulation (EPA 40 CFR Part 503):** The EPA regulates the use and disposal of sewage sludge based on three criteria:
    1. Presence of pollutants (e.g., heavy metals).
    2. Presence of pathogens.
    3. Attractiveness to vectors (e.g., rodents, flies).
- **Biosolids Classification:**
    - **Exceptional Quality (EQ):** Meets the most stringent limits for all three criteria and is considered equivalent to standard fertilizer with no restrictions.
    - **Non-EQ (Class A):** Pathogens are rendered non-detectable after treatment. No site restrictions apply.
    - **Non-EQ (Class B):** Pathogens are substantially reduced but not eliminated. Site access must be restricted for 30 days to 1 year, and waiting periods for harvesting and grazing are required.
- **New Uses in Land Restoration:** Biosolids are increasingly used to restore degraded lands, including:
    - Coal strip mines, gravel pits, and quarries
    - Construction sites and landfills
    - Enriching soils in forestland to sustain vegetation where topsoil has been lost.
    - **Example:** King County, Washington, has an extensive program using biosolids as a soil amendment in forested areas, with studies showing significantly improved tree growth.

3.0 Collection System Management and CSO Control

The infrastructure that collects and conveys wastewater is critical for protecting public health and the environment.

3.1 System Maintenance

Maintenance of collection systems aims to ensure their structural integrity and operational efficiency.

- **Objectives:** Reduce leaks, prevent sewage from seeping into groundwater, prevent groundwater from infiltrating pipes, and divert wastewater to appropriate treatment facilities.
- **Technology:** Sensor-based pipe leak detection is a key tool for identifying issues before they cause significant contamination or backups.

3.2 Combined Sewer Overflow (CSO) Control

In older cities, combined sewers carry both sewage and stormwater. During heavy rain, their capacity can be exceeded, resulting in a combined sewer overflow (CSO)—a discharge of untreated wastewater directly into water bodies.

- **Scale of the Problem:** An estimated **850 billion gallons** of CSO are discharged annually in the United States.
- **Three Primary Control Methods:**
    1. **Reduction of Runoff Volume:** Implementing green infrastructure and other measures to reduce the volume of stormwater entering the combined sewer system.
    2. **Storage and Treatment:** Constructing large basins or tunnels to hold the CSO during wet weather. The stored volume is then sent to the WWTP for full treatment after the storm passes. This approach is used in Greater Chicago.
    3. **High-Rate Treatment at Outfall:** Installing dedicated facilities at CSO outfalls to provide rapid treatment, typically including screening and disinfection, before discharge. An example is the Disinfection Demonstration Project in Bayonne, NJ.