Design of Nutrient Control Systems

An Online Continuing Education Course for Engineers

Course Number: EN-8003

Credit: 8 Hours / 8 PDH / 8 CPD

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1. Introduction

1.1 Purpose

This course provides a review of nitrogen and phosphorus control technologies and techniques currently applied and emerging at municipal wastewater treatment plants (WWTP). It includes a description of technologies and identifies key design and operational issues. Because the majority of WWTPs in the United States are equipped with secondary biological treatment, the focus of this course is on process and technology modifications/additions for nutrient removal at existing WWTPs, rather than on new treatment plant design. Emerging issues such as nutrient removal through decentralized treatment, sustainable technologies, and co-removal of emerging contaminants are also discussed.

1.2 Organization of the Course

This course is organized into 11 technical chapters as follows:

- **Chapter 2. Need for Nitrogen and Phosphorus Removal at Wastewater Treatment Plants** reviews the status of wastewater treatment in the U.S., the impairment of waterways by excessive nutrients, government and State initiatives to reduce nutrient pollution, and the barriers to implementation of such initiatives.

- **Chapter 3. Nutrient Constituents in Wastewater and Measurement Methods** describes the forms of nitrogen and phosphorus found in wastewater and the analytical techniques used to characterize and measure them.

- **Chapter 4. Phosphorus Removal by Chemical Addition** discusses the principles behind chemical precipitation, the types of chemicals used, where they are added in the process train, and traditional and advanced solids separation techniques. The chapter also reviews additional design and operational issues as well as how the choice of chemical impacts sludge handling.

- **Chapter 5. Biological Nitrogen Removal** examines the principles behind the process, current and emerging process configurations, key design and operational issues such as carbon sources and temperature effects, and potential impacts on sludge handling.

- **Chapter 6. Biological Phosphorus Removal and Combination Processes** discusses the principles behind biological treatment to remove phosphorus and treatment configurations that can remove both phosphorus and nitrogen from wastewater. The chapter provides descriptions of several processes, provides guidance on how to choose among them, and reviews operational and design considerations including the COD:P ratio, retention time, and temperature.

- **Chapter 7. Effluent Filtration** discusses types of filters that can be added as a tertiary treatment process to WWTPs and summarizes design and operating principles.

- **Chapter 8. Mathematical Modeling** explains the need for models in designing nutrient removal processes and examines available models including their input and calibration requirements.

- **Chapter 9. Nutrient Removal for Small Communities and Decentralized Wastewater Treatment Systems** discusses the latest treatment options for on-site wastewater treatment systems and clustered development systems.

- **Chapter 10. Sustainable Nutrient Recovery** highlights efforts to develop low-cost and low-energy technologies to make nutrient removal more efficient, including urine separation technology and resource recovery from sludge.

- **Chapter 11. Co-removal of Emerging Contaminants** discusses how some advanced technologies to remove nitrogen (N) and phosphorus (P) can achieve the additional benefits of removing some microcontaminants, including endocrine disrupting compounds (EDCs) and pharmaceuticals from wastewater.

The **References** section at the end of the course provides the full, alphabetized list of technical references reviewed in the development of this course.

2. Need for Nitrogen and Phosphorus Removal at Wastewater Treatment Plants

The purpose of this chapter is to provide an overview of the major factors driving decisions to enhance nutrient removal at WWTPs. Section 2.1 characterizes the industry based on U.S. Environmental Protection Agency (EPA) survey information. Section 2.2 describes the negative impacts of nutrient enrichment, highlighting the history of water quality changes in key regions of the country. EPA and State initiatives to reduce nutrient pollution from wastewater treatment discharges are summarized in Section 2.3, followed by a discussion of several barriers to enhancing nutrient removal at wastewater plants in Section 2.4.

2.1 Status of Wastewater Treatment in the U.S.

The 1972 Amendments to the Federal Water Pollution Control Act (FWPCA)(Public Law 92-500), also known as the Clean Water Act (CWA), established the foundation for wastewater discharge control in the U.S. The CWA's primary objective is to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." The CWA established a program to ensure clean water by requiring permits that limit the amount of pollutants discharged by all municipal and industrial dischargers into receiving waters. Discharges are regulated under the National Pollutant Discharge Elimination System (NPDES) permit program. As of 2004, there were 16,583 municipal wastewater utilities [also known as Publicly Owned Treatment Works (POTWs)] regulated under the CWA, serving approximately 75 percent of the Nation's population (U.S. Public Health Service and USEPA, 2008) with the remaining population served by septic or other onsite systems.

Wastewater treatment has generally been defined as containing one or more of the following four processes: (1) preliminary, (2) primary, (3) secondary, and (4) advanced - also known as tertiary treatment. Preliminary treatment consists of grit removal, which removes dense inert particles and screening to remove rags and other large debris. Primary treatment involves gravity settling tanks to remove settleable solids, including settleable organic solids. The performance of primary settling tanks can be enhanced by adding chemicals to capture and flocculate smaller solid particles for removal and to precipitate phosphorus. Secondary treatment follows primary treatment in most plants and employs biological processes to remove colloidal and soluble organic matter. Effluent disinfection is usually included in the definition of secondary treatment.

EPA classifies advanced treatment as "a level of treatment that is more stringent than secondary or produces a significant reduction in conventional, non-conventional, or toxic pollutants present in the wastewater" (U.S. Public Health Service and USEPA, 2008). Other technical references subdivide advanced treatment, using the terms "secondary with nutrient removal" when nitrogen, phosphorus, or both are removed and "tertiary removal" to refer to additional reduction in solids by filters or microfilters (Tchobanoglous et al, 2003). Effluent filtration and nutrient removal are the most common advanced treatment processes.

The CWA requires that all municipal wastewater treatment plant discharges meet a minimum of secondary treatment. Based on data from the *2004 Clean Watersheds Needs Survey*, 16,543 municipal WWTPs (99.8 percent of plants in the country) meet the minimum secondary wastewater treatment requirements. Of those that provide at least secondary treatment, approximately 44 percent provide some kind of advanced treatment (U.S. Public Health Service and USEPA, 2008). Figure 2-1 shows how secondary and advanced wastewater treatment have been implemented since 1940 and also provides projected treatment for 2024. Note that "No Discharge" refers to systems that do not discharge treated wastewater to the Nation's waterways and dispose of wastewater via methods such as industrial reuse, irrigation, or evaporation.

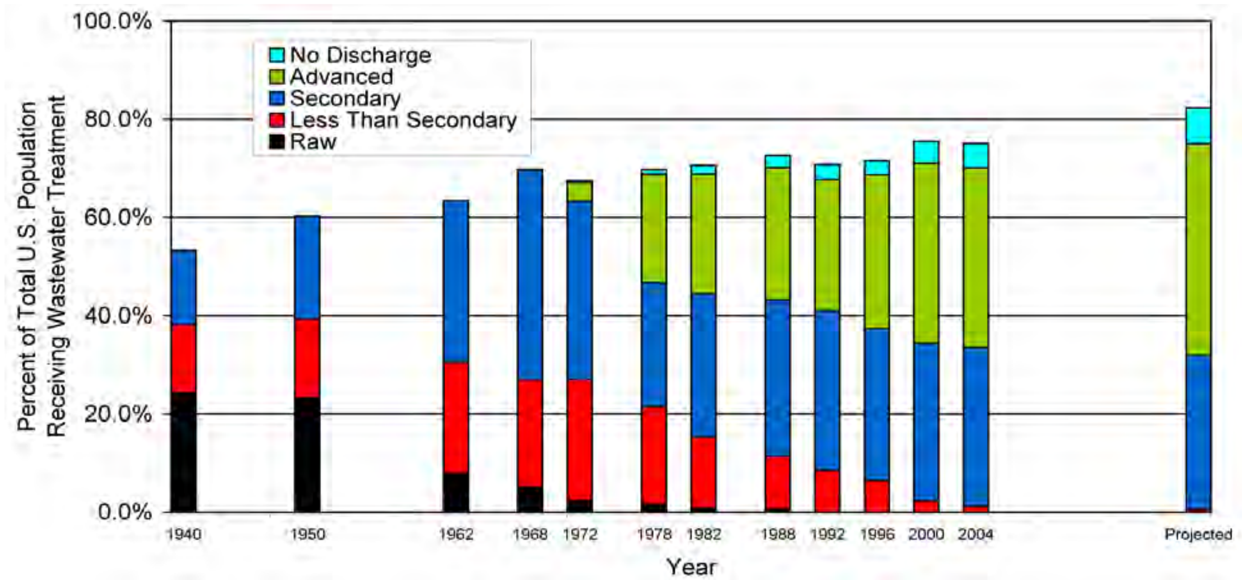

Figure 2-1. Population served by POTWs nationwide for select years between 1940 and 2004 and projected to 2024 (if all needs are met), organized by wastewater treatment type.
Source: U.S. Public Health Service and USEPA Clean Watersheds Surveys 2004 Report to Congress (U.S. Public Health Service and USEPA, 2008).

2.2 Nutrient Impairment of U.S. Waterways

The harmful effects of eutrophication due to excessive nitrogen and phosphorus concentrations in the aquatic environment have been well documented. Algae and phytoplankton growth can be accelerated by higher concentrations of nutrients as they can obtain sufficient carbon for growth from carbon dioxide. In addition to stimulating eutrophication, nitrogen in the form of ammonia can exert a direct demand on dissolved oxygen (DO) and can be toxic to aquatic life. Even if a treatment plant converts ammonia to nitrate by a biological nitrification process, the resultant nitrate can stimulate algae and phytoplankton growth. Phosphorus also contributes to the growth of algae. Either nitrogen or phosphorus can be the limiting nutrient depending on the characteristics of the receiving water. Nitrogen is typically limiting in estuarine and marine systems and phosphorus in fresh water systems.

According to the 2007 report *Effects of Nutrient Enrichment in the Nation's Estuaries: A Decade of Change*, increased nutrient loadings promote a progression of symptoms beginning with excessive growth of phytoplankton and macroalgae to the point where grazers cannot control growth (Bricker et al., 2007). These blooms may be problematic, potentially lasting for months at a time and blocking sunlight to light-dependent submerged aquatic vegetation (SAV). In addition to increased growth, changes in naturally occurring ratios of nutrients may also affect which species dominate, potentially leading to nuisance/toxic algal blooms. These blooms may also lead to other more serious symptoms that affect biota, such as low DO and loss of SAV. Once water column nutrients have been depleted by phytoplankton and macroalgae and these blooms die, the bacteria decomposing the algae then consume oxygen, making it less available to surrounding aerobic aquatic life. Consequently, fish and invertebrate kills may occur due to hypoxia and anoxia, conditions of low to no DO. Eutrophic conditions may also cause risks to human health, resulting from consumption of shellfish contaminated with algaltoxins or direct exposure to waterborne toxins. Eutrophication can also create problems if the water is used as a source of drinking water. Chemicals used to disinfect drinking water will react with organic compounds in source water to form disinfection byproducts, which are potential carcinogens and are regulated by EPA.

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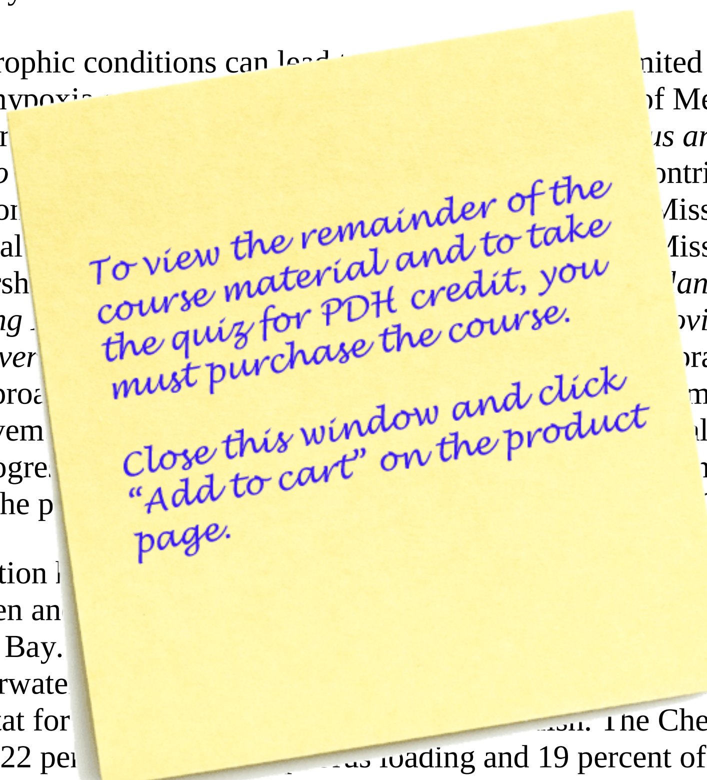

Nutrient pollution … ake Bay. Elevated levels of both nitrogen an … ity and loss of aquatic habitats in the Bay. … the sun's rays from reaching underwate … grow and provide critical food and habitat for … The Chesapeake Bay Program estimates that 22 pe … loading and 19 percent of the nitrogen loading in the Bay comes from municipal and industrial wastewater facilities (Chesapeake Bay Program, 2008).

The first national attention to nutrient contamination occurred in the Great Lakes. In the 1960s Lake Erie was declared "dead" when excessive nutrients in the Lake fostered excessive algae blooms that covered beaches and killed off native aquatic species due to oxygen depletion. At that time, phosphorus was the primary nutrient of concern due to the advent of phosphate detergents and inorganic fertilizers. With the enactment of the CWA and the Great Lakes Water Quality Agreement in 1972, a concerted effort was undertaken to reduce pollutant loadings, including phosphorus in the Lake. Although the health of the Lake improved dramatically, in recent years, there has been renewed attention to the re-emergence of a "dead" zone in Lake Erie, again due to nutrient loadings. Recent studies by scientists and the National Oceanic and Atmospheric Administration (NOAA) have also hypothesized a relationship between excessive