7. Strategies for Use in Nutrient Management

7.1 Introduction

Click here to view the Nutrient Reduction Tool.

Nutrients are important factors in the development of HCBs in aquatic ecosystems (Glibert and Burkholder 2006, Heisler et al. 2008, Smith, King, and Williams 2015). Nutrients can be carried to surface water bodies by several means, such as stormwater runoff (Section 7.5.2), wastewater discharges (including residential septic systems, Section 7.5.1 and 7.6.4), and agricultural practices.(Sections 7.5.3 and 7.6.1). The most prominent source of nutrients will vary by location, making it important for water managers to understand the land use in the surrounding area.

Phosphorus may be one of the most important nutrients contributing to HCBs in freshwater systems, while nitrogen has been a key element in marine systems. Hendriks and Langeveld (2017) note that inappropriate regulation, such as limiting nitrogen discharges without attention to phosphorus discharges, could result in more HCBs by favoring nitrogen-fixing cyanobacteria. However, as noted by USEPA (2015g), toxic cyanobacteria can out-compete other species under conditions of excess nitrogen and limited phosphorus. Recent research has suggested that nitrogen may be just as important as phosphorus in freshwater systems, with increases in both nutrients producing effects larger than the additive effect of each nutrient alone (Glibert and Burkholder 2006, Heisler et al. 2008, Paerl et al. 2019). Intracellular cyanotoxins, particularly nitrogen-rich cyanotoxins such as microcystin, tend to be lower when nitrogen is limited (Brandenburg et al. 2020). The forms and ratios of nutrients (for example, organic or inorganic) may determine which genera and even species of cyanobacteria dominate, so nutrient reduction practices should consider both nutrients (Paerl and Otten 2016).

Irrespective of the specific relationship between phosphorus and nitrogen with HCBs (and a similar phenomenon influencing primary production in aquatic ecosystems), excessive nutrients play a critical role in the formation of HCBs. Therefore, controlling nutrient entry into surface waters through Best Management Practices (BMPs) is important for HCB prevention and reduction. In fact, nutrient reductions have successfully reduced bloom density and produced shifts in algal communities in some lakes where BMPs have been implemented (Edmondson 1970, Paerl and Otten 2016, Lyon and Maxwell 1999, OECD 2003). Many nutrient reductions can be implemented through wastewater treatment upgrades, dredging, stormwater management, and changes in fertilizer use at large scales.

There are regulatory and non-regulatory options to consider when implementing nutrient management depending on the nutrient source (see Section 7.2). Further, public education and strategic communication may help garner support and cooperation in strategy implementation and success.

Overall, water managers are encouraged to prioritize nutrient reduction by following these steps. Some steps may require substantial resources; however, even limited amounts of data may be very useful in identifying priorities:

1. Check with regulatory agencies to determine whether key nutrient sources in a watershed have already been identified and whether watershed plans or nutrient concentration goals, such as TMDLs or site-specific criteria, have already been developed for the HCB-affected water body. USEPA's How's My Waterway? website was designed to provide information collected from states and federal, tribal, and local agencies related to the condition of water bodies throughout the United States.
2. Gather data to characterize relative nutrient loading using models and monitoring, as necessary. Identify predominant nutrient sources in the watershed and prioritize nutrient sources for reduction. Leverage local knowledge, GIS mapping, National Pollution Discharge Elimination System (NPDES) databases, etc. if no previous assessment exists.
3. Develop actions that secure community cooperation, such as outreach and education programs.
4. Prioritize efficient nutrient reduction strategies and the critical areas in the watershed where they should be installed.
5. Implement control strategies, emphasizing control of sources where the most effective reduction is achievable.
6. Monitor effectiveness of these actions and adapt your plan as needed.

While this Section touches on all six elements above, its primary focus is on assessing watershed nutrient reduction strategies. Here, we will explore these options and provide some recommendations about best practices.

7.2 Environmental Regulatory and Nonregulatory/Voluntary Programs for Nutrient

Control

In recent years, nonregulatory (voluntary) approaches to achieving environmental outcomes have been more favored than in the past (Lyon and Maxwell 1999, OECD 2003). The effectiveness of such programs is often not completely clear because of the numerous variables involved in an environmental outcome. Regulatory controls usually involve a system for tracking or reducing environmental discharges and reporting to an authority. Nonregulatory approaches often involve actions such as education, behavior change, best practices modification, and other practices that are not required by law. In general, a mixture of regulatory and nonregulatory approaches to mitigate environmental issues, including nutrient management and control, has been implemented in an attempt to reduce HCBs. A few of the measures pertaining to nutrient control to reduce HCBs are discussed below.

7.2.1 Regulatory Controls

Regulatory options involve permitting, monitoring, and reporting nutrient or pollutant discharges to help both the governing body and the water body manager better inventory and understand the amount of substance released and its potential impact on surface water.

7.2.1.1 Federal Controls: Clean Water Act

The 1972 Federal Clean Water Act (33 U.S.C § 1251) (CWA) provides multiple ways to regulate nutrient entry into water bodies. The CWA was designed to regulate discharges into surface waters from point sources, such as the end of pipes or constructed ditches (USEPA 2016). Water quality standards include criteria (narrative and numeric), water body uses (recreation, drinking water, aquatic life), and anti-degradation policies (reviews that ensure no backsliding of water quality). Water quality standards are used as the basis to establish water-body-specific water quality benchmarks, calculate permit effluent limits, and set goals for TMDL restoration efforts. There are no national numeric nutrient criteria because appropriate nitrogen and phosphorus levels are water body specific; however, USEPA has proposed nutrient criteria development recommendations for lakes and reservoirs that states and tribes can adopt (USEPA 2020b). In addition, some states have adopted statewide (Florida's Rule 62-302.531) or regional (Utah's Administrative Code UAC-R317-2-14) numeric nutrient criteria.

Point source pollution is controlled under NPDES. Under NPDES, government agencies may issue permits to industry, municipalities, or other organizations allowing the release of pollutants from a specific site. The permit imposes restrictions on the concentration of contaminants and volume of discharge from a regulated site and also contains monitoring and reporting requirements. USEPA delegates authority to conduct NPDES permitting to most states. More information about control of point source pollutants can be found in Section 7.5.

Nonpoint source pollution is generally managed through voluntary efforts, typically encouraged through incentive programs. For water bodies with excessive levels of nutrients due to nonpoint sources of pollution, Section 319 of the CWA provides a funding mechanism to incentivize addressing excess nutrient impacts from these unregulated sources. Typically, these funds are formally requested through a state or tribe that has developed nonpoint source watershed plans. More information about control of nonpoint pollutants can be found in Section 7.6.

In addition, water quality trading (WQT), a market-based approach to increasing water quality, can be applied within point sources of pollution, nonpoint sources of pollution, or across these pollutant sources. More information about WQT application can be found in Section 7.7.

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Stormwater, which includes rain and snowmelt runoff, can be classified as a point or nonpoint source. Stormwater NPDES permits can be issued for discharges related to municipal separate stormwater sewer systems (MS4s), construction activities, or industrial activities (USEPA 2019a). Most agricultural sources are excluded, though NPDES permits can include discharges from Concentrated Animal Feeding Operations (CAFOs) or "feedlots" (USEPA 2019c). Each of these activities could involve different types of pollutants. The purpose of the stormwater NPDES permits is to prevent surface water contamination by stormwater carrying pollutants from these sources.

There are multiple benefits to controlling stormwater, such as protection of wetland and aquatic ecosystems, improved water quality in surface waters, and protection of public health (USEPA 2019f). Another clear benefit is control of nutrients that could result in HCBs. More about stormwater management can be found in Section 7.5.2, as well as in the ITRC (2018a) *Stormwater Best Management Practices Performance Evaluation* report.

7.2.1.2 State and Local Controls

Regulatory controls can also be implemented by state or local municipalities to limit use of a nutrient. For example, the amount of phosphorus allowed in fertilizers has been imposed by some states to reduce implications of fertilizer runoff. Regulatory approaches must be designed and updated to achieve the intended goals.

7.2.2 Nonregulatory Controls

Nonregulatory options can be used alone or in combination with regulatory measures to reduce nutrient discharges into water bodies. Examples of nonregulatory controls can include education and outreach, voluntary compliance programs, bioremediation, and even watershed modeling or research. Several of these options will be described below.

7.2.3 Public Education

Community members who are educated about HCBs may be better equipped to help reduce excessive nutrients (eutrophication) and HCB events by nutrient control. Good risk communication or education can increase community members' understanding about HCB causes and consequences. Community members with more awareness about water quality issues and more longevity in an area might be more likely to join advocacy groups with goals of improving water quality (Pendall and Schmidt 2011, Persaud et al. 2016). Further, better informed residents may support policies that reduce algal and cyanobacterial blooms, such as better controlled agricultural runoff (Guo, Nisbet, and Martin 2019) or better lawn care stewardship.

Examples of community initiative, involvement, and commitment by residents are described in the literature (Foulon et al. 2019). For example, shoreline residents of Alberta receive a consultation from Shoreline Advisors to learn the natural history and ecology of their lake and discuss how they can manage their property to benefit the lake (Foulon et al. 2019). There is also some evidence that educating school-aged children on environmental issues can result in education of parents and others in the community as children impart their knowledge to others (Damerell, Howe, and Milner-Gulland 2013, Vaughan et al. 2003).

Often, education paired with laws or ordinances might be necessary for clear results. For example, fertilizer controls along with public education appear to have an effect on phosphorus entry into water bodies. In a study conducted in Ann Arbor, Michigan, a city ordinance on fertilizer reductions paired with public education and other factors resulted in a 28% reduction of total phosphorus entry into a river after one year (Lehman, Bell, and McDonald 2009).

Community access to information about HCBs from sources like time-critical social media posts, frequently updated online maps, and outreach for specific communities like dog owners, hunters, and others might also be useful in getting community support. See Section 5.2.6 for ideas on engaging the community.

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Public education and outreach were shown to be important factors in removing phosphorus from detergents in the late 1960s and early 1970s. During that time, the use of phosphorus in household detergents had increased from about 7% to 12% of detergents by dry weight in the 1950s to about 15% to 17% dry weight in the late 1960s (Knud-Hansen 1994). Eutrophication had begun on many lakes, including in the Great Lakes, resulting in low oxygen levels and declining fish populations. Information about the causes and consequences of the decline in lake water quality spurred many to advocate for action, including state-level legislation to limit phosphorus in detergents (Knud-Hansen 1994). While not all states passed laws related to phosphorus in detergents, the laws that were passed caused the industry to change its formulation more widely, resulting in a decline in phosphorus release and improvement of water quality. Therefore, public education and risk communication are tools that can be used in conjunction with regulatory and nonregulatory tools for point and nonpoint sources toward HCB prevention. As noted by Foulon et al. (2019), however, most educational programs and BMPs need in-depth evaluation for effectiveness in actual HCB control.

See Section 5 for more information on public outreach and education. You can find more information about outreach and education on USEPA's nutrient pollution policy and data web page.

7.3 Source Identification and Prioritization

Nutrients in aquatic environments can originate from both natural and anthropogenic sources. The latter include agriculture runoff, industrial and municipal wastewaters, and stormwater runoff (USEPA 2015b) and will be discussed in more detail below. The nutrients from these sources are also in different forms, such as dissolved and particulate materials, organic and inorganic compounds, and recalcitrant and labile substances. Atmospheric deposition due to fossil fuel use and agricultural activities can also be a significant source of nutrients (see http://nadp.slh.wisc.edu/committees/tdep/tdepmaps/ for deposition maps), accounting for up to 10–15% of total dissolved inorganic nitrogen input to the Chesapeake Bay watershed, for example (Da, Friedrichs, and St-Laurent 2018) and contributing to phosphorus loading (Brahney et al. 2015, Stoddard et al. 2016). The relative contribution of each source is specific for each water body. Developing a comprehensive understanding of the nutrient sources to a system is critical in understanding HCB–nutrient dynamics and developing nutrient control strategies.

Tools to support nutrient source identification, prioritization, and nutrient control planning include watershed modeling and nutrient source tracking, as described below.

7.3.1 Watershed Models

Watershed models are decision support tools that enable quantification of relative loading from different source categories and individual sources. Users can run predictive “what if” scenarios to compare outcomes from simulating the implementation of various interventions.

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Watershed planning models, such as BASINS, SWAT, SPARROW, and Model My Watershed, estimate how different conservation implementation scenarios across a watershed will affect downstream nutrient inputs. Implementation scenarios can include varying the BMP type, adoption rate, and whether the BMPs are targeted to high-risk areas or installed randomly. Watershed planning models can be coupled with process-based models that estimate the algal and HCB response within a water body, such as the Western Lake Erie Ecosystem Model (Verhamme et al. 2016) and NOAA HAB Forecasts, to estimate the potential HCB reduction under certain scenarios. At the field scale, determining the correct BMP to minimize sediment and nutrient loading can be difficult due to a multitude of factors that affect BMP efficiency (for example, soil type, slope, and crop rotation). Some models, such as the Nutrient Tracking Tool, STEPL, and Region 5 Model, can estimate the effectiveness of BMPs at the field scale, which can help local managers determine the best BMP. Another useful source for more information on evaluation of BMPs is the ITRC report *Stormwater Best Management Practices Performance Evaluation* (ITRC 2018a).

For more information on watershed models, *Nutrient and Sediment Estimation Tools for Watershed Protection* (USEPA 2018a) provides a detailed list of models and an explanation on the strengths of these various tools.

7.3.2 Nutrient Source Tracking

Nutrient source tracking (NST) uses state-of-the-art forensic tools to identify sources of nutrients. This method focuses on the most bioavailable forms of nutrients (for example, nitrate and dissolved phosphorus), which are primarily responsible for algal growth and formation of HCBs. Tools used in NST include DNA markers to identify human waste sources, stable isotopes of nitrate and water, and advanced chemical indicators of sewage such as pharmaceuticals and personal care products (PPCPs). These advanced tools are often combined with traditional tools to locate and abate specific sources. Thus, NST can result in effective nutrient source control, often at a lower cost, by directly targeting and abating the most bioavailable nutrient sources. Various approaches to NST can be used in combination to build multiple lines of evidence to support nutrient source identification. These include:

- Performing an isotopic analysis of nitrogen sources: Identifies a broad range of sources of nitrogen within a water body. This method is useful if sources are not known.
- Measuring chemical indicators of wastewater: Identifies nutrients that are specific to human or livestock waste. This method can be used to identify or confirm wastewater sources.
- Using source-specific DNA markers: Identifies sources of nutrients that can be linked to human or animal sources. In contrast to chemical indicators, this method can identify nutrient contributions from waste of specific groups or species of animal.
- Adding tracers to source water: Confirms sources of nutrients. This method is most specific, as tracers must be added to the source.

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In response to an algae biomass TMDL in the Ventura River Watershed in Ventura County, California, where a nitrogen load allocation for approximately 3,000 septic systems was assigned to a county environmental health department, NST was used as a strategy to refine this load allocation. Groundwater and surface water samples were collected downgradient of areas with varying septic densities and analyzed for nutrients, chemical sewage markers (PPCPs), and nitrate isotopes. Results showed that groundwater nitrate concentrations were higher downgradient of areas with higher septic densities, and chemical sewage markers and nitrate isotope results confirmed that septic effluent was a significant source. Surface waters were found to be affected where high-density septic systems were impacting groundwater discharging to the stream, resulting in a narrowing of contributing septic systems to approximately 30% of the total septic systems in the watershed.

These results are being used to help inform septic management actions, including sewering of septic areas in the watershed and potentially refining the septic load allocation in the TMDL. A summary of this project can be found in a report published by the California Stormwater Quality Association (Genkel, Ervin, and Steets 2019).

A similar NST study in the Atlanta region showed that septic system density was correlated with nitrate concentrations in streams during dry weather (Geosyntec 2019). These results are being used to inform septic management and policy in the region and show how NST can be used to identify nutrient sources and support management actions to reduce loading from identified sources to surface waters.

To identify sources of nutrients fueling HCBs in Lake Taihu, China, stable isotope analysis was used to trace and determine the main sources of nitrogen into two main bays within the lake (Zhen and Zhu 2016). Potential sources included industrial wastewater, domestic sewage, agricultural nonpoint sources, and aquaculture wastewater discharge. Stable isotope analysis was able to demonstrate that nitrogen input due to domestic sewage had decreased over the years to <20% of the total input, suggesting that management efforts should now be directed toward non-sewage sources of nutrients.

7.3.3 Recovery Potential Screening Tool

Historically, watershed restoration projects were typically selected from opportunities that were available at the same time as funding. That led to fragmented, often underexecuted projects. With this haphazard approach and the challenging dynamics of measuring aquatic restoration success, the performance measures and ecosystem functions expected often were not met. Ideally, a project selection method that is conceptual, quantitative, flexible, and transparent would be useful to decision-makers, stakeholders, and funders active in aquatic restoration.

For more than a decade, USEPA has been assisting states with creating their own customizable watershed prioritization platform. The Recovery Potential Screening (RPS) tool is an easy-to-use, Excel-based tool available for download by any state. It includes GIS-based ecological, social, and stressor indicators that rank restoration potential of waters depending on various scenarios. For the purposes of this Section, the user would target resource allocation for nutrient reduction strategies based on ecological and social conditions; however, the tool is much more dynamic and can serve as a collaborative mechanism to rank waters based upon the interests of users. For example, the tool is often used to inform TMDL prioritization in 303(d) Vision Plans.

The Utah Division of Water Quality crafted a Utah-specific RPS tool designed to rank water bodies that respond the best to nutrient reduction strategies—and thereby maximize restoration success. Currently, the Utah RPS tool has over 200 indicators across the three core areas for selection. In addition, these indicators are designed and developed to best reflect conditions to rank water bodies based on various spatial scales. Spatially, each indicator was constructed across all Hydrologic Unit Code (HUC)-8 and HUC-12 units statewide, and specific indicators can be selected for various scenarios. This flexibility allows scenarios to be generated across a diverse spatial range from overarching, statewide decisions to high-resolution, watershed-scale levels. Given the plethora of available GIS-based data, it is intended to be a living tool to incorporate new and current data.

The Connecticut Department of Energy and Environmental Protection took the RPS tool a step further and developed an Integrated Water Resource Management (IWRM) framework from the data and scenarios evaluated through its RPS tool. The IWRM framework includes five priority categories (including nutrient reduction) identified through known water quality issues, previous reports, and public engagement. In the IWRM approach, the RPS tool uses environmental data to prioritize which partnership plans should be developed and implemented. The Department is using the IWRM approach to identify restoration approaches for a popular recreational water body, Bantam Lake, that experiences cyanobacteria blooms.

7.4 Linking Nutrients to Land Use

Several strategies in nutrient management may be used to prevent blooms or reduce the magnitude, frequency, and extent of HCBs. These strategies can be divided into *structural* and *nonstructural* approaches. Although guidance materials reviewed in preparation of this document provided no standard definition of structural versus nonstructural strategies, the following working definitions (consistent with standard practice on how reduction measures are categorized) are applied here:

- *Structural strategies* in nutrient management typically incorporate unit treatment processes. They can be either passive and natural or active and mechanical, such as sedimentation, filtration, adsorption, ion exchange, or disinfection.
- *Nonstructural strategies* are generally programmatic in nature, such as education and outreach, regulation and enforcement, maintenance, or source control.

Which strategy you choose will depend on your water body's planned or designated use, characteristics, and nutrient source. The Interactive Nutrient Management Graphic and Table 7-1 will help you choose appropriate strategies to use in site-specific situations related to your water body, such as surrounding land uses and potential nutrient sources.

Categorizing nutrient sources as point sources and nonpoint sources refers to our ability to identify specific sources of nutrients and other pollutants to a body of water. These terms are defined more precisely in Sections 7.5 and 7.6 but are listed in Table 7-1 as related to specific land use types or features. Each of the point and nonpoint sources listed in the table is linked to a section of text that more fully describes the source, along with structural and nonstructural strategies to mitigate or prevent nutrients from entering the water from each source. Regulatory considerations and examples are also provided for several of these sources of nutrients. It should be noted that some sources of nutrients, such as stormwater runoff can be considered both point and nonpoint sources depending on whether the stormwater is released into the body of water at a specific site, like a drainage pipe, or enters the water through diffuse flow. Table 7-1 serves as a companion to the Nutrient Reduction Tool.

Table 7-1. Nutrient reduction strategy organization and selection based on source category and land use type or feature

Source Category	**Watershed Land Use Type**					**Description**
	Lake/Stream	**Agricultural**	**Forest**	**Urban**	**Suburban**	
Point Sources						
Municipal and Industrial Wastewater						Wastewater discharged directly into Waters of the United States
Stormwater						Rainwater or melted snow that is delivered to the water at a specific site
CAFOs						Agricultural facilities where many animals are raised, generating large amounts of manure and wastewater
Nonpoint sources						
Agricultural Runoff						Runoff from agricultural land
Forestry Management Activities						Includes removal of streamside vegetation, road construction and use, timber harvesting, and mechanical preparation for the planting of trees
Hydromodification /Habitat Alteration						Activities such as channelization and channel modification, dams, riparian buffers, and other activities resulting in streambank and shoreline erosion

Septic Systems						Underground wastewater treatment structures, commonly used in rural areas without centralized sewer systems
Municipal and Rural Roads						Stormwater flowing off paved and unpaved roads
Other Nonpoint Nutrient Sources						Other less prominent nonpoint nutrient sources may exist within a watershed.
Unlikely Source	Potential Source					Likely Source

7.5 Point Sources

The term *point source* is defined in Section 502(14) of the CWA as any discernable, confined, and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, CAFO, or vessel or other floating craft from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture. Any source that does not meet this legal definition is classified as a nonpoint source.

7.5.1 Municipal and Industrial Wastewater Management

Wastewater carries considerable nutrients from human waste and industrial processes that can contribute to HCBs. Wastewater treatment can play a role in reducing the nutrients released and decreasing the extent, magnitude, and duration of HCBs. Currently, many wastewater treatment facilities in the United States do not have nutrient permitting requirements. However, future regulatory requirements for nutrient reductions are likely for facilities upstream of water bodies with HCB problems, so it is worth considering proactive point source nutrient reduction strategies.

Wastewater treatment plants process water from homes and businesses. These waters may contain high levels of nitrogen and phosphorus from a variety of sources. Typically, wastewater treatment plants reduce nutrients to standards set and monitored by state and federal organizations before discharging to a water body. However, during times of high volume or heavy rainfall, wastewater treatment systems can operate less efficiently or overflow, releasing nutrients to the environment. Even when standards are met, wastewater can be a major source of nitrogen and phosphorus to a water body, contributing to HCBs.

Enhanced treatment systems enable wastewater plants to produce discharges that contain less nitrogen and phosphorus (USEPA 2019g). Sometimes appreciable nutrient reductions can be achieved with relatively inexpensive changes in plant operations (nonstructural changes). In other circumstances, particularly those where changes to achieve very low nitrogen or phosphorus levels are required, expensive structural changes to treatment plant operations may be needed.

7.5.1.1 Nonstructural Strategies

Industrial and municipal wastewater treatment plant operators can sometimes alter treatment processes to minimize the amount of nitrogen and phosphorus that is discharged to water bodies affected by HCBs. In other cases, operators can identify alternative discharge locations or modify the discharge schedule to reduce their load and minimize downstream HCB threats. Nonstructural strategies for wastewater nutrient reduction can also include policies, law, and public education. Some examples are:

- discharge management
- land application
- treatment process modifications
- technology-based performance requirements

Lagoon discharge management provides an effective and non-energy-intensive process for treating wastewater that uses ponds that operate largely through environmental and biological means. As such, treatment processes can depend on factors operators do not control, such as temperature, wind, and light. Treatment outcomes can cause excess nutrient discharge from lagoon ponds, which can contribute to HCBs downstream of lagoon releases.

To combat excess nutrient loads, nonstructural strategies to regulate lagoon release include coagulation, flotation, land applications, and plant systems. Newer, experimental strategies are being tested to remove nutrients from wastewater, such as absorption of nutrients with microalgae (Cai, Park, and Li 2013) or grasses on artificial floating islands in paper production wastewater (Ayres et al. 2019). These approaches can reduce nutrient loading by removing suspended solids and the associated particulate nutrient or by encouraging biological uptake of nutrients by plants and microbes.

Alternatively, the risk of pond effluent to HCBs can be minimized by altering the discharge timing. Most lagoons discharge episodically, so implementing controlled discharge to less sensitive periods for downstream waters affected by HCBs can be considered. Other modifications include separating ponds with plastic curtains held in place by floating and weighted anchors and more recent advancements that encourage growth and uptake of nutrients using floating mats of vegetation.

By their nature, mechanical plant processes can sometimes be more easily altered to optimize nutrient removal (see the Water Environment Federation's Nutrient Roadmap Primer). Treatment process modification can encourage microbially mediated removal by altering the amount of time that wastewater is exposed to aerobic and hypoxic environments. Chemicals can be introduced that change the alkalinity or amount of organic carbon in the wastewater to improve the efficiency of biological nutrient removal processes (USEPA 2015a). Another option is to add chemicals to induce precipitation of phosphorus (USEPA 2009).

Wastewater treatment plants differ extensively with respect to operational changes that could be manipulated to reduce discharged nutrients. Optimization studies, including experimental manipulations, need to be conducted on a facility-by-facility basis. Once changes are recommended, plant operators will require additional training to implement them effectively. Given the added expenses involved, it is important to note that optimization processes are unlikely to be implemented without encouragement, via regulatory requirements or incentives, from regulators. However, with proper incentives, considerable reductions are possible. For example, Montana recently hosted an on-site evaluation and operator training program for wastewater treatment facilities and lagoons. Treatment optimization successfully achieved an average reduction of 59% nitrogen and 33% phosphorus from facility effluent statewide. Optimization of existing infrastructure and processes cost $10,000–$100,000 per facility, primarily to purchase monitoring equipment. Replacing and upgrading that infrastructure could cost closer to millions of dollars. Regulators issued enforcement discretion letters for facilities while they experimented with implementing optimization techniques.

Both lagoon and mechanical point sources can minimize their nutrient load by moving all or part of their discharge to surrounding lands. According to USEPA (2015a), *land application* is a broad term used to describe systems that discharge effluent (which may be primary, secondary, or tertiary treated) into a natural soil system for additional treatment and dispersal into the receiving environment. Nutrient reduction from these processes can vary widely, sometimes becoming less effective over time if nutrient concentrations increase in the surrounding soils.

Pros. The advantages of these nonstructural strategies can include:

- reusable resource by-products
- reduced energy expenditures through optimized aeration processes
- low energy investment compared to other treatment alternatives
- reduced cost when compared to other treatment alternatives
- improved community relations

For more information about nonstructural wastewater treatment options that will reduce nutrient release, see the following sources:

- *Wastewater Technology Fact Sheet – Facultative Lagoons* (USEPA 2002)
- *Case Studies on Implementing Low-cost Modifications to Improve Nutrient Reduction at Wastewater Treatment Plants* (USEPA 2015a)

Cons. While each of the strategies listed can contribute to HCB prevention, there are some drawbacks to each as well.

Lagoon discharge management has the following disadvantages:

- Sufficient land is required.
- Nutrient removal efficiency may be lower when compared to other wastewater treatment approaches.
- Nutrient removal may be affected by environmental conditions, such as temperature.
- High ammonia loading under certain conditions may occur, although this can be remedied.
- For mechanical treatment, the chemicals needed for treatment add pollutants to receiving waters.

Regulatory or policy considerations. Regulatory and policy considerations should be reviewed when using these strategies.

Requirements for lagoon discharges, for example, fall under local and national regulations for environmental quality. In the United States, the most common issue related to effluent is exceedance of total suspended solids. These suspended solids are often associated with cyanobacteria or other biological growth, rather than from fecal or other waste from influent. Pond system upgrades can lower suspended solids and other nutrient loading to the discharge limits proscribed by law. More information can be found in *the User Guide – Optimization Methods and Best Management Practices for Facultative Lagoons* (MDEQ 2015).

Disinfection requirements can also change depending on the nature of land application being conducted. These requirements often depend on whether the public can access the land and the type of crop irrigation being conducted. In the United States, these requirements differ on a state-by-state basis, and the agency that oversees CWA implementation should be contacted to review potential land application options.

Application Examples. USEPA (2011) has thoroughly reviewed lagoon designs and developed principles for their design and operation. Because of the number of variables involved in designing lagoons, specific case studies are unlikely to be relevant for each case. However, with the global popularity of lagoons as a wastewater treatment approach, there is a large base of knowledge that can be accessed depending on the specific requirements of the lagoon requiring upgrades.

An example of treatment process modification can be found in a USEPA (2015a) report. Here, a wastewater treatment plant in Crewe, Virginia, used lime for alkalinity control and added molasses as an additional source of carbon. This process helped to enhance biological removal of phosphorus while also continuing nitrogen removal at a steady rate. The average total phosphorus effluent concentration was 0.06 mg/L. With aeration, the total nitrogen concentration dropped from 7.65 mg/l to 3.63 mg/l (USEPA 2015a, i).

Other considerations. Phosphorus is an important nutrient for plant growth, and experts have estimated that natural phosphorus deposits will have been depleted within the next century. Capturing phosphorus from wastewater for beneficial use is an important strategy for sustainability, as well as in HCB prevention.

7.5.1.2 Structural Strategies

Wastewater treatment plant upgrades can reduce the number of nutrients discharged to surface waters, which can reduce the number of HCBs. However, structural changes to wastewater treatment plants can be expensive. Changes to operational practices can also help to reduce nutrient discharge at a lower cost than some structural changes. There are currently no standards for the most effective types of upgrades.

Some examples of structural strategies within a wastewater treatment plant, as stated by USEPA (2015a), are:

- aeration modifications, which work to create an anaerobic environment that supports denitrification
- process modifications
- configuration modifications
- lagoon and other discharge modifications

Examples of structural strategies listed above are described in greater detail by USEPA (2015a) and illustrated with several case studies on low-cost modifications to reduce nutrients at wastewater treatment plants.

USEPA is continuing to work to better understand what types of wastewater treatment are most effective. The agency currently has a study underway to assess the most effective upgrades. See USEPA's National Study of Nutrient Removal and Secondary Technologies for more information.

In addition, new engineering designs continually seek to treat nutrients in innovative ways. One example is a system in Utah that inoculates glass tubing with green algae for tertiary wastewater treatment. The algae are then harvested for the renewable materials marketplace.

Pros. Federal grants and loans for may be available for wastewater treatment plant upgrades. Some of the benefits of structural improvements to reduce nutrient discharge are:

- reduced long-term costs of water treatment plant operation
- reduced greenhouse gas and other air emissions
- reduced nutrient loading, which enhances long-term water quality
- production of reusable resources from waste products
- improved community relations

Cons. A few of the drawbacks of wastewater treatment plant structural improvements are:

- complex implementation for certain treatments and reactor types

- expensive upfront costs
- incomplete removal of nitrogen and phosphorus
- unevaluated long-term durability of certain treatments or plants

Regulatory or policy considerations. Many legacy wastewater treatment plants release nutrients above the permissible limits of their host state. These permissible limits were designed in part to reduce eutrophication, and as HCBs and other water quality issues continue to receive further attention, these upgrades may become mandatory.

Application Examples. Wastewater plant upgrades can reduce the nutrient load in discharges. Successful process upgrades are tailored specifically to the situation, as in the following examples.

A water treatment plant in Olbergen, Netherlands, was discharging impermissible levels of nitrogen, phosphorus, and carbon/chemical oxygen demand (COD) because of waste from a potato processing plant (Abma et al. 2010). To address this issue, operators upgraded the plant's treatment system to biologically convert excess carbon/COD into biogas (methane) while removing excess hydrogen sulfide and phosphorus from the water and precipitating the waste phosphorus so it could be recycled as fertilizer. Operators also built a bioreactor to convert ammonia to nitrate. The generated biogas led to an extra annual 1.5 GWh of electric power, reduced total sludge production through the use of bioreactors, and saved €1.5 million (approximately $2.2 million) on discharge costs through decreased loading of nitrogen, phosphorus, and COD (Abma et al. 2010).

The Metropolitan Syracuse Wastewater Treatment Plant (Metro) in Syracuse, Onondaga County, New York, is another example of a treatment plant where upgrades successfully reduced nutrient levels in the wastewater effluent. In 1998, Onondaga County signed an Amended Consent Judgement with the State of New York to decrease the ammonia and phosphorus discharges into Onondaga Lake. The Metro plant, whose treated effluent discharged into Onondaga Lake, was upgraded with the largest biological aerated filter system in North America and the largest tertiary ballasted settling system in the country. The biological aerated filter resulted in year-round nitrification (conversion of ammonia to nitrate) and contributed to the reduction of Metro ammonia loads from 522 metric tons/year between 1998 and 2003 to 82 metric tons/year between 2004 and 2007. The tertiary ballasted settling system, which came online in 2005, contributed to the Metro phosphorus load decreasing from 34 metric tons/year (annual average between 1998 and 2004) to 13 metric tons/year (annual average between 2004 and 2007) and ensured that the Metro effluent total phosphorus concentrations met the 0.12 mg/L limit in 2007 (OCDWEP 2009) and the interim Stage II total phosphorous effluent limit of 0.10 mg/L starting in November 2009.

7.5.2 Stormwater Management

Stormwater is classified as a point source when it is discharged to a water body via piping or conveyances. Stormwater is regulated through the NPDES Stormwater Program. Controlling stormwater with MS4 permits and control of industrial activities, construction activities, and CAFOs are methods to prevent HCBs. More information about control of nonpoint sources is presented in Section 7.6.

Stormwater runoff can be a significant source of nutrients to urban watersheds. When stormwater flows over impermeable surfaces, it collects materials in its path, such as grass clippings, fertilizers, pesticides, animal waste, sewage, or other materials (Masoner et al. 2019, USEPA 2019f, MPCA 2019a). The nutrients that stormwater contains often depend on the surrounding land use.

Stormwater in municipal areas can contain a variety of substances that could contribute to HCBs, such as fertilizers, sewage, and other solid wastes (USEPA 2019c). In a recent study of urban stormwater at 21 sites across 17 states, stormwater samples were found to have a median number of 73 organic chemicals. Phosphorus detections ranged from 4 µg/L to 788 µg/L, with a median concentration of 92 µg/L (Masoner et al. 2019). Another study found that nutrient concentrations (especially phosphorus) in stormwater runoff were strongly related to road density and street canopy (Janke, Finlay, and Hobbie 2017).

Stormwater that flows from an industrial site could have a variety of substances, depending on the type of materials that are handled and produced at the site. Examples range from domestic sewage to deicing chemicals to food processing waste. Stormwater that flows over a construction site might have sediment or chemicals from the site that could contain nutrients, while stormwater running through CAFOs could collect nutrients from animal waste.

Specific strategies to manage stormwater from each of these sources are available from USEPA's NPDES Stormwater Program.

To help prevent HCBs, nutrients in stormwater need to be diverted from water bodies. This can be done using nonstructural and structural BMPs. A brief description of options is provided below, but more detailed information can be found in *Stormwater Best Management Practices Performance Evaluation* (ITRC 2018a).

7.5.2.1 Nonstructural Strategies

Nonstructural BMPs control nutrients in stormwater through policies and practices. Nonstructural BMPs can be used by businesses or residents and involve site design strategies, stormwater pollution prevention plans, governmental regulations, or programmatic implementation of daily practices that will prevent materials from contacting stormwater. Education and training programs to raise worker or community awareness about protecting water bodies from stormwater are also potential elements of nonstructural BMPs. Another type of nonstructural BMP is undisturbed natural forest and wetlands (Horner et al. 2002). Nonstructural BMPs could be implemented at a site level, but they could also be implemented at a community or regional level. More specific examples are described below.

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Restrictions on the application of lawn fertilizers containing phosphorus and nitrogen have been put into place in several states, such as Minnesota (Phosphorus Lawn Fertilizer Law), New Jersey (Healthy Lawns Healthy Water), and Vermont (*Soil Fertility and Fertilization Guidelines for Lawn Turf in Vermont*). Like the laws that reduced the use of phosphorus in laundry detergents, the lawn fertilizer restrictions reduced the amount of phosphorus in these fertilizers. For example, many lawn fertilizers in Minnesota have no or low concentrations of phosphorus, as indicated by a "0" in the label for nitrogen, phosphorus, and potassium, such as "22-0-15." In a 2007 survey, 97% of stores surveyed offered phosphorus-free blends (Barten and Johnson 2007). Slow-release fertilizers, now commonplace, also reduce nutrient inputs to local waters by delivering low pulses of nutrients into the soil over time. These fertilizers reduce the chance of "fertilizer burn" and can be applied less often, saving money in the long run. Tips for fertilizer application to reduce nutrient input in stormwater include:

- Apply minimal amounts.
- Use appropriate blends, such as low P.
- Apply once per year.

Housekeeping. Housekeeping involves keeping work areas and sites orderly to prevent the addition of nutrients or pollutants to stormwater that runs across the area. Housekeeping tips include:

- Pick up grass clippings.
- Use good spill prevention and response.

Storage practices. Maintaining good storage practices will also reduce the addition of nutrients to stormwater. Storage tips include:

- Store materials indoors.
- Store materials in places unlikely to come into contact with stormwater.
- Cover materials with tarps.

Soil erosion control on properties. Soil is an important source of nutrients, making erosion control important. Soil erosion control tips include:

- Leave vegetation in place when possible.
- Prevent stormwater from flowing over disturbed soil areas.
- Prevent soil compaction, which could reduce vegetation growth and result in erosion.

Outreach. Focused outreach or public education can be effective in controlling nutrients. Outreach tips include:

- Communicate with residents about good lawn maintenance.
- Train grounds workers on good practices.

At construction sites and industrial sites, nonstructural BMPs for stormwater can also include:

- controlling dust emissions
- training employees on good practices to reduce stormwater runoff
- installing water-protective landscaping
- aerating sites to avoid compaction from construction

Pros. Nonstructural BMPs can be low cost, easy to implement, and in some cases more effective than structural BMPs (Horner et al. 2002) in preventing nutrients from entering water bodies. Nonstructural BMPs that involve leaving natural areas in an undisturbed state have ecosystem benefits beyond HCB control (Horner et al. 2002). Employee training, another type of nonstructural BMP, is also part of good facility operations plan and may also meet other facility requirements, such as hazardous materials laws.

In the case of educational programs, Pecher et al. (2019) and Tonk et al. (2007) report that increasing awareness among citizens might not directly affect water quality. They found only modest success in reducing stormwater pollution in commercial areas after conducting educational campaigns initially. However, over the long term, greater awareness may lead to "major and influential developments," such as dedicated funding for stormwater management (Taylor and Wong 2003).

Cons. Nonstructural BMPs are often dependent on changing human attitudes and behavior, such as cleaning up grass clippings and limiting fertilizer use. In addition, while setting aside areas of forest or wetlands to protect them from development has many positive effects, large areas may be required to achieve the benefit, which is often not feasible in urban areas. There can be tremendous pressure to use the land for other purposes, such as residential or retail development.

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In locations where deicing of roadways occurs, deicing chemicals may run into stormwater structures. The type of chemicals used and the likelihood of them affecting water quality in a way that could lead to HCBs should be considered as well. For example, if chlorides reduce growth of vegetation around a stormwater structure, the effectiveness of the structure could decline. Further, deicers could raise the salinity of a water body. Some cyanobacteria can be more tolerant to salt than other freshwater species of algae, allowing more cyanobacteria to flourish (Pecher et al. 2019, Tonk et al. 2007).

New Hampshire has information on the environmental, health, and economic impacts of road salt, and Minnesota provides information on the environmental impacts of road salt and other deicing chemicals.

Regulatory or policy considerations. As mentioned above, several states and local governments have created policies on phosphorus in fertilizer. Effectiveness, however, often depends on how aware community members are about the policies and the importance with which they view the issue (Persaud et al. 2016).

Application Examples. Several states have implemented non-structural BMPs for stormwater management.

An example of implementation of nonstructural BMPs for nonpoint source is the Chesapeake Bay TMDL. After 25 years of little progress in improving the water quality of Chesapeake Bay, USEPA set a more aggressive plan to control nutrient entry into the water. The Chesapeake Bay TMDL combines over 270 TMDLs from surrounding areas to create one TMDL. The area is using point source strategies (like wastewater treatment plant upgrades), nonpoint source BMPs, policies on fertilizer use, and other practices to improve water quality. In 2018, USEPA reported a 60% decrease in the amount of phosphorus entering the bay (USEPA 2018b). USEPA also reports record acreage of underwater grasses after implementation of the strategies (USEPA 2018b). See the Chesapeake Bay TMDL for more information.

Another unique form of nutrient flow management is being implemented by the state of Vermont, where stormwater itself is being managed as a pollutant through a TMDL. Rapidly flowing stormwater can cause erosion and scour, contributing nutrients into a water body. Controlling the stormwater flow will help to increase infiltration. Read more about Vermont's TMDLs at the Vermont Department of Environmental Conservation's stormwater TMDLs web page.

7.5.2.2 Structural Strategies

Structural BMPs are constructed features that divert stormwater contaminants from surface water bodies. Structural BMPs are usually designed to slow stormwater rate of travel. They allow for cleaning through filtering or settling and can help prevent HCBs by preventing nutrients from entering water bodies. Most of the features described below can be used for point or nonpoint sources, depending on the design and purpose.

Some examples include:

- Algal flow ways: Algal flow ways are an engineered technology used to remove nutrients from a water body. The flow ways typically consist of screens with an attached algal community that are placed in a trough or raceway. Water flows over the screens, either by natural currents or through pumping, and the algal community takes up nitrogen and phosphorus to incorporate into biomass that can be harvested for high-value products such as biofuel. The University of Maryland provides more information on algal flow ways.
- Check dams: A check dam is a structure installed perpendicularly to the flow of a stream to slow the water flow. Check dams allow sediments and nutrients to settle out of the stormwater and reduce erosion. While this feature is often for nonpoint sources, it could also be used for point sources in some cases. See the *Minnesota Stormwater Manual* for more information on check dams for stormwater swales.
- Constructed embankments: Embankments are designed to capture and retain sediment in stormwater, reducing the nutrients that enter a body of water. See Sediment control practices – Sediment traps and basins in the *Minnesota Stormwater Manual*.
- Sedimentation systems: Like check dams and constructed embankments, sedimentation systems are designed

to reduce the speed of water flow to allow nutrients to settle out before entering a water body. Some examples are sediment traps and sediment basins. Many more examples are listed in the USEPA National Menu of BMPs for Stormwater.

- Infiltration ponds and permeable pavement: Unlike systems designed to clean water before it enters surface water bodies, infiltration ponds and permeable pavement allow stormwater to slowly infiltrate the soil, eventually returning the stormwater to groundwater. Nutrients and pollutants are removed from the water by the soil. See Infiltration basin in the *Minnesota Stormwater Manual* and *Soak Up the Rain: Permeable Pavement* from USEPA's website.
- Phosphorus or nitrate capture systems: Wood chip bioreactors have been developed for nitrogen removal; they work through the action of denitrifying bacteria. One recent study evaluated three designs for wood chip bioreactors for Mid-Atlantic ditch drainage systems and demonstrated a 25% to more than 90% reduction in nitrate (Christianson et al. 2017). Soluble phosphorus, on the other hand, can be precipitated into insoluble compounds in the soil by adding phosphorus-sorbent material such as gypsum, a coal combustion product (Bryant et al. 2011). Penn and Bowen (2018) describe the design of such systems for efficient removal of phosphorus.
- Riparian buffers: According to USEPA, riparian buffers are "vegetated zones adjacent to streams and wetlands that represent a BMP for controlling nitrogen entering water bodies." Riparian buffers serve as a buffer around streams and water bodies, slowing entry of nutrients and other pollutants into the water. Riparian buffers can be used for either point or nonpoint source control of nutrients, depending on design. See *Riparian Buffer Width, Vegetative Cover, and Nitrogen Removal Effectiveness: A Review of Current Science and Recommendations* (USEPA 2005b) for more information.
- Water harvesting for reuse: Collecting rooftop runoff into storage devices or implementing vegetated rooftops in a widespread adoption where water can be more slowly used for irrigation has been found to reduce peak stormwater loading, thereby reducing nutrient transport (Carter and Jackson 2007).

Please see ITRC *Stormwater Best Management Practices Performance Evaluation*, Section 3 – BMP Screening Tool and Considerations, for more information to consider on stormwater BMPs (ITRC 2018a).

Pros. If nonstructural BMPs fail to keep contaminants out of the stormwater, a structural BMP may help to prevent entry into a water body. Structural BMPs do not necessarily depend on human behavior and action (such as thoroughly cleaning up spills). They result in more immediate and measurable impact on water quality. In addition, structural BMPs can help lower flooding potential by slowing water down or detaining it outside of water bodies after a large rainfall.

Structural BMPs, like wetlands, rain gardens, or scenic ponds, might add aesthetic appeal or even recreational opportunities to an area.

Cons. Structural BMPs require maintenance to maintain their effectiveness. Dredging, reconstruction, or inlet or outlet clearance might be required on a regular schedule (MPCA 2015). BMPs with standing water, like stormwater ponds, may attract unwanted pests, such as mosquitoes (Metzger et al. 2008) or invasive weed species. They also can collect trash and debris and pose physical dangers, such as becoming a potential drowning hazard.

There may be high variability in the amount of nutrients both entering and exiting the system. The structural BMP installer should consider whether a BMP will be designed for typical runoff or to capture peak volumes. Extra steps, such as a way to establish and maintain a thermodynamic gradient, might be needed for dissolved phosphorus and adsorbed phosphorus (Rosenquist et al. 2010).

Small et al. (2019) found that even when the amount of a nutrient entering a water body is decreased, reduced eutrophication is not guaranteed. In a case study, preventing phosphorus from entering a lake by slowing the water prevented regular flushing of the lake. Warmer temperatures then induced release of phosphorus from the sediments, resulting in eutrophication (Small et al. 2019). Therefore, the selection of structural BMPs may need to be carefully evaluated for total impact on the lake systems.

Regulatory or Policy Considerations. It is important to recognize that there is a limit to what can be achieved if natural land uses have been considerably and permanently altered. Multiple water quality assessments have revealed that there are thresholds above which conversion of land to urban or agricultural uses is not practically countered by BMPs (Osgood 2017). These alterations and "tipping points" vary from region to region, so it is critical to discuss these practical limits with your state regulatory authorities to consider this factor in your decision making for local zoning and restoration prioritization.

Application Examples. The ITRC *Stormwater Best Management Practices Performance Evaluation (ITRC 2018b)* provides an overview of the various performance data inventories available, including state technology verification programs (which focus primarily on proprietary devices) and the International Stormwater BMP Database (BMPDB) (which includes data for all

BMP types).

The BMPDB is a publicly accessible repository for stormwater BMP performance, design, and cost information. The overall purpose of the project is to provide scientifically sound information to improve the design, selection, and performance of stormwater BMPs. The BMPDB is the largest known comprehensive database of stormwater BMP water quality performance study data that is regularly updated and maintained. Additionally, the BMPDB contains data from many parts of the United States, as well as several other countries. Continued population of the database and assessment of its data provides an improved understanding of the factors influencing BMP water quality performance and continue to promote improvements in BMP design, selection, and implementation.

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The Water Research Foundation, a water-quality-focused nonprofit research organization, is the current manager of the BMPDB project. As of November 2016, the BMPDB contains data sets from nearly 650 BMP studies, all accessible on the project website (www.bmpdatabase.org). The database contains searchable study data, a web-based map interface, and a statistical analysis tool. The database can be used online or downloaded as a Microsoft Access file. Periodic statistical summary reports are also available from the website.

ITRC has a guidance document specifically focused on stormwater BMPs (ITRC 2018a). With this guidance, users are encouraged to select BMP types for their site-specific conditions that are most effective for the bioavailable forms of nutrients controlling local HCB conditions. Other considerations should be weighed as well during BMP selection, including BMPs as *sources* of nutrients; for example, many vegetated BMPs include a vegetation support media that includes compost, which often exports nutrients into the BMP effluent. Be aware that for some BMP types, a statistically significant difference between influent and effluent concentrations may not be present. Effluent concentrations achieved by the BMP are relatively low and may be comparable to the performance of other BMPs that have statistically significant differences between inflow and outflow. For example, data sets that have low influent concentrations and similarly low effluent concentration (clean water in = clean water out) may not show statistically significant differences. However, this does not necessarily imply that the BMP would not have been effective at higher influent concentrations.

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This summary focuses solely on influent and effluent concentrations and does not characterize influent and effluent loads. For BMPs that provide significant volume reduction, load reductions may still occur in the absence of concentration reductions. Volume-related data can also be retrieved from the BMPDB and have been evaluated in detail for some BMP categories in reports posted at www.bmpdatabase.org.

7.5.3 Confined Animal Feeding Operations (CAFOs)

Agricultural facilities where many animals are raised generate large amounts of manure and wastewater. Animals may be in open feed lots or confined inside structures. Depending on the number of animals present, these facilities may be considered animal feeding operations (AFOs) or CAFOs. CAFOs are considered point sources by USEPA and may be regulated under NPDES if they discharge pollutants to waters. Management of nutrients produced by AFOs and CAFOs is a priority in many parts of the country—and an important component of nutrient reduction to reduce the incidence of cyanobacteria blooms.

Like other point sources, CAFO operations are regulated by NPDES regulations administered at the federal and state level. Facilities are defined by the number of animal units on site for farms raising cattle, dairy cows, sheep, pigs, horses, or poultry. Smaller farms may also be regulated as CAFOs if they have a point source discharge of waste and the regulating authorities identify them as a significant contributor of pollution to a receiving water body. The regulatory definitions of large, medium, and small CAFOs can be found in the Code of Federal Regulations.

7.5.3.1 CAFO Management Strategies

With a few exceptions, most states have been authorized by USEPA to identify and regulate CAFOs through a delegated state permitting program. Permit requirements may include a nutrient management plan and other documents that cover the:

- management of manure, litter, and wastewater
- proper management of mortalities
- proper disposal of chemicals used at the facility
- diversion of clean water away from the facility and strategies to keep animals out of surface waters
- implementation of conservation practices and BMPs to protect water quality
- protocols for testing of manures, wastewater, and soils

- protocols for the land application of manure and wastes
- documentation about how these elements were implemented

Permittees must provide annual reports describing their operations and renew their permit at regular intervals. Typically, inspections are required for permitted CAFOs; however, the frequency of these inspections may vary depending on the CAFO's size and any state-specific requirements.

Management and permitting of CAFOs incorporates many of the strategies discussed in Section 7.6.1. Large facilities in many parts of the country operate storage lagoons and other wastewater management approaches that may store large volumes of manure and wastewater for several months before being applied to the land.

Pros and cons. While large-scale animal operations may provide significant business efficiencies, the facilities, if not operated properly, can have a significant impact on local water quality. Operation of CAFOs have all the challenges of small-scale agriculture—field-based disposal of manure, soil erosion, and nonpoint source nutrient sources—as well as the challenges of managing significant amounts of manure and potential point source discharge from facility production areas, if not well managed. Oversight of these entities through a single NPDES permit allows development of a coordinated water quality management plan for the entire operation, which may consist of several individual facilities or farms and is potentially more efficient than having multiple, smaller permits for specific aspects of operation. The sheer size of some CAFOs will continue to require new and novel approaches for management and disposal of potentially large quantities of manure to ensure the protection of downstream water quality.

Regulatory or policy considerations. Oversight of AFO facilities requires regular inspection and interaction with facility operators. States with regulatory authority over AFOs and CAFOs may choose to require additional measures beyond those outlined in the CWA. The amount of regulatory oversight of AFOs varies widely across the country.

Application Examples. Many states manage large animal operations using different approaches. For example:

- Vermont requires implementation of Required Agricultural Practices for all farms, including CAFOs and AFOs.
- Iowa regulates AFOs—locations where animals are kept and fed for 45 days or more per year in a lot, yard, corral, building, or other area—as confinements or feedlots. Both types include manure storage structures but do not include livestock markets.
- Colorado defines three types of animal operations: AFOs, CAFOs, and housed commercial swine feeding operations.

7.6 Nonpoint Sources

As noted previously, any source that does not meet the legal definition of a point source is termed a nonpoint source. This includes any diffuse runoff that is not discharged through piping or conveyances (including stormwater) and any agricultural stormwater discharges and return flows from irrigated agriculture. This Section discusses the dominant nonpoint sources and strategies to mitigate nonpoint nutrient discharge.

7.6.1 Agriculture

Agricultural BMPs are intended to be practical, cost-effective actions that agricultural producers can take to conserve water and reduce the amount of pesticides, fertilizers, animal waste, and other pollutants entering our water resources. BMPs are designed to benefit water quality and water conservation while maintaining or even enhancing agricultural production. While BMPs do not always include a water quality monitoring component due to various exemptions or lack of regulatory requirements, it is understood that performance monitoring plays an important role in the verification and adaptive management of BMP efficacy.

7.6.1.1 Nonstructural Strategies

Nonstructural strategies support nutrient management in agriculture in many ways.

- Adopting nutrient management techniques: Agricultural producers can improve nutrient management practices by applying nutrients (fertilizer and manure) in the proper amount, at the proper time of year, with an appropriate method, and with the correct placement.
- Monitoring: A significant element of verifying the efficacy of nutrient management techniques is the implementation of monitoring programs that provide a frame of reference to performance metrics.
- Recordkeeping: Memorializing nutrient management techniques and associated monitoring fortifies the management process and provides for continuous improvement.
- Engaging in watershed efforts: The collaboration of a wide range of people, stakeholders, and organizations

across an entire watershed is vital to reducing nutrient pollution to our water and air. Agricultural producers can play an important leadership role in these efforts when they get involved and engage with their state governments, farm organizations, conservation groups, educational institutions, nonprofit organizations, and community groups.

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The USDA Natural Resources Conservation Council (NRCS) has recommended a 4R nutrient stewardship concept for nutrient management. The four Rs stand for *Right Source* (choose the right fertilizer product with the right nutrient ratio for the soil and crop needs), *Right Rate* (match fertilizer application rates with crop requirements), *Right Time* (synchronize nutrient availability with crop demand), and *Right Place* (place and keep nutrients where the crop can get to them and where nutrient use efficiency is maximized). Additional resources are also available from the North Central Region Water Network.

Pros. As both nonstructural and structural BMPs are used to control runoff from agriculture, the non-structural BMPs can offer a lower cost alternative to structural BMPs and often serve as a precursor to determine the appropriate practices to put into place.

Cons. Nonstructural BMP development often requires attitudes to change toward reliance on consulting with outside entities to develop beneficial strategies for implementation. Without realization of an economic benefit, changing these attitudes may be complicated.

Regulatory or policy considerations. In the absence of specific local, state, or federal permitting requirements, agricultural producers can often use local agricultural extension agencies to provide assistance and guidance in the preparation of nonstructural BMPs.

7.6.1.2 Structural Strategies

Structural strategies are continually improving as farmers adapt their land management activities to prevent the migration of nutrients and soils from agricultural lands. Examples include:

- Ensuring year-round ground cover: Agricultural producers can plant cover crops or perennial species to prevent periods of bare ground on farm fields when the soil (and the nutrients it contains) are most susceptible to erosion and loss into waterways.
- Planting riparian buffers: Agricultural producers can plant riparian buffers consisting of trees, shrubs, and grasses along the edges of fields; this is especially important for a field that borders water bodies. Planted buffers can help prevent nutrient loss from fields by absorbing or filtering out nutrients before they reach a water body. These buffers may serve as annual or perennial establishments to maximize their intended purpose and align with the agricultural producer’s goals in certain circumstances.
- Implementing conservation tillage: Agricultural producers can reduce how often and how intensely the fields are tilled. Doing so can help to reduce erosion, runoff, and soil compaction—and, therefore, the chance of nutrients reaching waterways.
- Managing livestock access to streams: Agricultural producers can install fencing along streams, rivers, and lakes, with an appropriate vegetated zone between the water body and the fence, to block access from animals, help restore stream banks, and prevent excess nutrients from entering the water.
- Fallow field water retention: During non-growing seasons and where applicable, fields can intentionally block water runoff, keeping runoff on the field over the winter. This technique allows suspended particles to settle, keeping sediments and associated nutrients out of adjacent water bodies. For an additional cost savings, no plowing and planting of a cover crop is required.
- Regenerative practices: Rotational grazing can maximize forage production by limiting livestock to defined portions of grazing areas, thereby reducing stress on other grazing areas and allowing for natural reseeding, improved soil fertility, and reduced compaction and runoff.
- Phosphorus or nitrate capture systems: Wood chip bioreactors have been developed for nitrogen removal; they work through the action of denitrifying bacteria. One recent study evaluated three designs for wood chip bioreactors for Mid-Atlantic ditch drainage systems, with the results demonstrating 25% to more than 90% reduction in nitrate (Christianson et al. 2017). Soluble phosphorus, on the other hand, can be precipitated into insoluble compounds in the soil by adding phosphorus-sorbent material such as gypsum, a coal combustion product (Bryant et al. 2011). Penn and Bowen (2018) describe the design of such systems for efficient removal of phosphorus.

Pros. BMPs, when used appropriately, can mitigate the nutrient enrichment of neighboring water bodies, which are the principal factors of eutrophication and HCBs. Importantly, BMPs can help reduce agricultural production costs through effective water and nutrient application rates and reduce erosion and soil loss—often more than offsetting implementation costs. Certain BMPs for agricultural producers can be funded through federal, state, or county cost-share programs.

Cons. BMP implementation costs are often an unanticipated capital expenditure for the agricultural producer. BMPs are often implemented on a field-by-field basis and change annually, making it difficult to track and measure success. Moreover, the implementation of BMPs may not reach the targeted loading reduction of nutrients for all cases, resulting in additional measures to meet watershed management goals.

Regulatory or policy considerations. Some states have developed policies that associate BMP implementation and maintenance with a presumption of compliance with water quality standards for the pollutants addressed by the BMPs to offset cost-prohibitive monitoring. Under certain circumstances, such as within watersheds that have developed basin management action plans for water quality improvements, the development and implementation of BMPs and performance monitoring, in some cases, have become mandatory.

Application Examples. Many states provide grants to farms that are using the newest structural strategies to protect water quality and manage nutrients while producing food. Your state's agriculture agency newsletter is a good way to learn about local examples. These two additional resources may also be helpful.

- USEPA Watershed Academy Web's Agricultural Management Practices for Water Quality Protection
- The Florida Department of Agriculture and Consumer Services' BMP Success Stories

Other considerations. Certain agricultural practices, such as CAFOs, are designated by law as point sources. Nutrient management strategies at these facilities use BMPs addressing both point sources and nonpoint sources.

7.6.2 Forestry Management

Forested watersheds in general do not release large amounts of nutrients to surface waters. They work to stabilize river flow and the timing and volume of water reaching lakes, ponds, and reservoirs. Trees, both young and old, store nutrients within their trunks and roots. Perennial shrubs and annual plants also capture and retain nutrients. Undisturbed forest duff layers formed from composting leaves and branches protect underlying soils from erosion and release nutrients slowly over time.

Nutrients within healthy and well-managed forested watersheds recycle within the forest itself and typically do not reach surface waters (Moore, Macrelis, and Bailey 2014). Water quality within healthy, large forests is typically good. Smaller tracts can also provide important downstream water quality protection. Natural events such as landslides, windstorms, fires, and heavy rain can create openings in forest cover that may release nutrients. Strategies outlined elsewhere may be of use to manage and reduce nutrients until these areas reestablish cover and natural recycling connections.

Activities in both managed woodlots and large tracts of forested lands typically disturb duff, expose soil, and otherwise facilitate the movement of sediment and nutrients to surface waters. Homes, businesses, and roads are found within large tracts of forested lands. BMPs specific to these land uses can be found elsewhere in this document. Strategies outlined below are designed to protect water quality in areas where forest harvesting and maintenance practices are underway.

7.6.2.1 Nonstructural Strategies

Nonstructural strategies for forestry management are broadly focused on working with landowners to understand forest ecosystems and raising awareness of the connection between forest activities and water quality impacts. Mechanisms to support and expand the use of BMPs through nonstructural strategies include:

- Conservation: Identify and preserve critical forested land and define healthy forest ecosystem services (clean water, climate control, recreational opportunities, etc.) in terms of their values to the community, particularly in areas experiencing rapid growth.
- Policy: Municipalities, states, and forestry organizations can articulate water quality goals and expectations for forest management through the creation of policy and forest management plans. State-level forest policy, such as the New Hampshire Forest Resource Strategies (NHDRED 2010), may establish consensus and strategies on how to conserve working forests, protect forests, and enhance forest resources for public benefit.
- Certification: Voluntary and mandatory certifications can be used to outline the goals of water-protective forestry approaches, review required practices and regulatory needs, and share BMPs that foresters can employ. Certification courses can share cutting-edge research and knowledge.
- Funding: Targeted funding programs, often through USDA's NRCS or state extension offices, can pay for forest management plans that encourage the use of new strategies and improved forestry practices. Loans from state or federal agencies may be available to purchase equipment that is then shared or leased by foresters.
- Technical assistance: State and federal forestry staff can help project managers select and implement BMPs.

- Forest management plans: Planning provides the mechanism to formulate short- and long-term goals to maintain forest biodiversity, balance forest uses, and identify appropriate forest management practices. Planning helps operators increase the efficiency of their management activities and build water-protective strategies into daily operations. Plans may also serve as communication tools among landowners, foresters, and local stakeholders.
- Public education and outreach: Targeted opportunities such as workshops and peer-to-peer training events can be highly effective in raising awareness about water and other forest resources, forest management plans, and preservation strategies. Federal, state, and local brochures and flyers can reinforce messaging.
- Partnerships: Priorities for preserving forest resources can be implemented through partnerships among forest, land conservation, and water resources organizations to leverage resources and results.

Pros. Nonstructural approaches can be very effective in delivering water quality goals in the forestry sector. Targeted policy and certifications set the standards for compliance. Funding and non-monetary assistance can encourage strategy adoption beyond basic compliance with regulations. Planning, education, and outreach reinforce policy goals and broaden public support for aspects of forestry management.

Cons. Policy and mandatory certifications may require a compliance, certification, and enforcement structure to be effective. Adequate funding requires a source of reliable revenue. Voluntary strategies may require significant outreach and education to gain acceptance. Stakeholder acceptance of some practices may take time to establish.

Regulatory or policy considerations. Forestry management impacts to water quality are considered nonpoint source and may have fewer state or federal regulatory oversight opportunities.

Application examples. Examples of nonstructural forestry management strategies supporting water quality nutrient management plans can be found in:

- Vermont's *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont*
- Forestry BMPs for Mississippi and Wisconsin
- USEPA Watershed Academy Web's *Forestry Best Management Practices in Watersheds*
- USDA's *A Citizens' Guide to National Forest Planning* for guidance on forest management planning (USDA 2016)
- The USDA Forest Service's ecosystem services information

Other considerations. Areas experiencing rapid forest conversion near critical water resources, particularly those that serve as source waters for valued recreational and potable water, should be prioritized for preservation and BMPs. A watershed that is converted to even 10% urbanized land use can impact the physical and biological integrity of the stream ecosystem (Wheeler, Angermeier, and Rosenberger 2005). In addition, it has been projected that from 2000 to 2030, 57 million acres of private, rural forests (15% of private forests nationally) will experience substantial increases in housing density (Stein et al. 2009).

7.6.2.2 Structural Strategies

Structural strategies are water-protective approaches to be used in the forest environment during the active logging phase. Strategies may be voluntary or required. They are designed to minimize water quality impacts (such as sediment releases during logging and transport activities), protect existing stream corridors, and facilitate recovery of the site after active logging has ended. Structural strategies can also be used to maintain and support stream habitat. Examples include:

- the use of skidder bridges to protect stream crossings
- roper construction of truck roads and skidder trails to prevent erosion
- water bars to manage the flow of water across logging roads
- construction of log landings to minimize erosion and soil compaction
- containment areas for fuel used by on-site equipment and control of hazardous materials

Pros. Forestry activities and logging may have significant impacts on water quality through erosion and sedimentation, release of fuels or hazardous substances, and increased water temperature. Properly designed structural BMPs control or eliminate those impacts while improving efficiencies and minimizing overall costs, when considering the full cost associated with forest resource impacts. Water quality benefits of these approaches can be easily measured.

Cons. Policy and mandatory structural requirements may require a compliance and enforcement structure to be effective. Structural strategies may require significant investment by foresters and may raise concerns about return on investment in poor market years (however, see Vermont's skidder bridge cost-share program).

Regulatory or policy considerations. State policy and mandatory participation may be necessary to achieve goals for structural strategies. Adoption of both mandatory and voluntary strategies might be facilitated with monetary support, which requires reliable revenues.

Application examples. Examples of forestry management strategies supporting water quality nutrient management plans can be found in:

- Vermont's *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont*
- The Mississippi Forestry Commission's Water Quality and Forestry Best Management Practices
- USEPA Watershed Academy Web's Forestry Best Management Practices in Watersheds

Other considerations. Funding to implement structural practices or equipment, such as funds allocated through USDA's Healthy Forest Reserve Program, state programs, or drinking water source protection programs, may be available to fund structural practices that protect water quality and availability for public water supplies.

7.6.3 Hydromodification, Habitat Alteration, Wetlands, and Riparian Areas

As defined on the USEPA website, hydromodification activities (USEPA 2016) include "channelization, channel modification, dams, and streambank and shoreline erosion." In the context of nutrient management for HCBs, these activities can alter water temperature and the rates and paths of sediment erosion, transport, and deposition. The channelization of streams and hardening of stream banks can increase the movement of nonpoint source pollutants within the watershed. Dams can negatively impact the temperature of the surface water they are influencing. Further, dams can also retain sediment that is high in nutrients from upstream locations. These nutrients can be released during dredging or other disturbance of the sediments. Streambank and shoreline erosion can also contribute increased levels of turbidity and nutrients to downstream waters (USEPA 2016, 2007).

As defined on the USEPA website, wetlands are areas where the water covers the soil or is present at or near the surface of the soil for varying periods of time during the year, including during the growing season. Wetlands also contain specially adapted plants (hydrophytes) and promote the development of wetland (hydric) soils. In addition, there is another similar regulatory definition of wetlands by the USACE and USEPA under Section 404 of the CWA.

Riparian areas as defined by USEPA are a natural buffer between upland areas and surface waters which may include wetlands, streams, and lakes. Both wetlands and riparian areas can act as natural filters of nonpoint source pollutants, including nutrients to downstream water bodies (Mitsch and Gosselink 2015).

7.6.3.1 Nonstructural Strategies

Nonstructural strategies for nutrient reduction related to hydromodification, habitat alteration, and wetland and riparian areas are focused on the protection of water resources and land downstream from increased pollution.

Pros. These nonstructural methods are currently being implemented by local, state, and federal governments.

Cons. It is more difficult to measure success with nonstructural strategies. This may make these strategies less appealing, as it is difficult to set concrete goals and benchmarks in terms of nutrient management.

Application Examples. Nonstructural approaches include both protection of existing functioning wetlands and habitats as well as restoration of those that are impacted by hydromodification and land use. Here are some examples of approaches states have taken:

- Maryland established the Shore Erosion Task Force, which published recommendations to be implemented under a comprehensive shore erosion control plan.
- Virginia's Chesapeake Bay Preservation Act was established to protect and improve the water quality of the Chesapeake Bay, its tributaries, and other state waters. This act protects and preserves buffers in certain counties in Virginia.
- The City of Atlanta, Georgia, has buffer ordinances on streams and wetlands within the city.
- The City of Seattle, Washington, designates riparian management areas (land within 100 feet of a riparian watercourse) as environmentally critical areas.
- The Vermont Agency of Natural Resources' River Corridor and Floodplain Protection section provides an opportunity for rivers to move with minimal damage to human infrastructure, the corridor, and floodplain protections. It also allows rivers to deposit phosphorus loads in their floodplains rather than in downstream lakes.

7.6.3.2 Structural Strategies

There are several structural strategies in terms of hydromodification, habitat alteration, wetlands, and riparian areas for nutrient reduction. The preservation, protection, and restoration of riparian areas and wetlands is a structural strategy

(USEPA 2007). Both preserved and restored wetlands can act as particulate filters, nutrient sinks, and transformers of nutrients (Jordan et al. 2003). Vegetated riparian buffers are considered a BMP for nutrient reduction to surface waters (Mayer et al. 2007). In addition, planting trees and shrubs in riparian areas can reduce erosion, decrease the amount of sunlight reaching the water, and reduce water temperatures, making the water body less optimal for algal growth (USEPA 2005b). The protection and restoration of streams and shorelines is another structural strategy (USEPA 2007). Stream restoration can include stabilizing stream banks, regrading stream banks to restore a floodplain, installing riffle-pool complexes, or increasing the sinuosity of a stream channel.

From Mitsch and Gosselink (2015):

"Wetlands created specifically to improve water quality are usually referred to as treatment wetlands. There are three types of wetlands used to treat wastewater or stormwater: natural wetlands, surface-flow constructed wetlands, and subsurface-flow constructed wetlands. […] Wetlands have been used to treat a variety of threats to nonpoint source pollution, stormwater runoff, landfill leachate, and confined livestock operations. The design of treatment wetlands requires particular attention to hydrology chemical loading, soil physics and chemistry, and wetland vegetation. Management issues include wildlife control and attraction, mosquito and pathogen control, greenhouse gas and water-level management. Treatment wetlands are not inexpensive to build and operate, but they usually cost much less than chemical and physical treatment systems."

Frequently, local public education and advocacy groups focus on the restoration and protection of surface waters. Many community groups aid in restoring riparian buffers by holding riparian buffer planting days.

Pros. Riparian buffer restoration can be an inexpensive way to reduce nutrients downstream and to protect surface waters from erosive stormwater. These areas can be replanted with trees, shrubs, or herbaceous vegetation that is generally locally available. If funds are not available, these areas can be preserved and allowed to revegetate on their own.

Created wetlands for treating municipal wastewater are most effective at lowering biological oxygen demand, sediment, and nutrient concentrations. See Case Study 1 (p. 651) in Mitsch and Gosselink (2015) for an example of nitrogen and phosphorus removal rates.

Cons. Wetland and stream restoration can be expensive in terms of materials and labor. Both of these restorative efforts generally require a team of experts to design and construct the restorations. In addition, these areas generally need to be monitored and often need to be maintained after construction. Also, metals and other toxic materials might become concentrated in substrates and wildlife tissues, so wetlands are not recommended for those types of application.

Regulatory or policy considerations. Activities in surface waters including stream and wetland restoration are regulated by USACE and often by states. USEPA may also have the opportunity to comment on such projects. In addition, there are state and federal agencies such as the U.S. Fish and Wildlife Service that protect threatened and endangered species and other species of concern. These agencies will likely have the opportunity to comment on activities in wetlands and streams.

Riparian buffers are often regulated by localities, particularly in certain watersheds such as the Chesapeake Bay watershed.

When used to meet water quality objectives, especially specific criteria, constructed wetland design must be rigorous in terms of hydrology, morphology, chemical loading, soils, and vegetation (see pages 668-682 in Mitsch and Gosselink 2015). Applying wastewater to a natural system can lead to unanticipated outcomes and may fail to meet water quality objectives.

Most literature involves deliberately engineered, constructed wetlands on areas that used to be uplands. It is not legal to discharge effluent that does not meet appropriate standards into Waters of the United States or individual state waters (and almost all states include wetlands in their definitions). Adding wastewater to natural systems is not likely to result in meeting required improvement criteria and can have unintended, negative consequences for the plant and wildlife communities of natural wetlands.

Application Examples. There is a great deal of research underway to evaluate the success of structural strategies to protect or restore wetlands. These examples will help you get started:

- Comín et al. (2001) studied the restoration of abandoned rice paddy wetlands and found that these wetlands were efficient in the removal of nitrogen and phosphorus.
- A study by Jordan et al. (2003) focused on the removal of nutrients by a restored wetland receiving variable amounts of water from agricultural runoff. They found that all the wetlands reduced nonpoint source pollution but that variability of inflow could decrease the capacity of the wetland to remove nutrients.
- Mayer et al. (2007) reviewed nitrogen removal by riparian buffers by assessing characteristics of riparian buffers and how these characteristics (buffer width, vegetation, etc.) influence the effectiveness of removing nitrogen.

Other considerations. Stream restorations can be constructed to generate nutrient credits for stormwater in states like Virginia and North Carolina. These areas can also be important assets in WQT programs.

7.6.4 Septic Systems

More than one in five households in the United States depend upon individual, on-site septic systems or small community cluster systems to treat their wastewater (USEPA 2005a). Septic systems treat wastewater in relatively small volumes (versus advanced centralized wastewater treatment plants) through both natural and technological processes, typically beginning with solids settling in a septic tank and ending with wastewater treatment in the soil via a drain field. Septic systems include a wide range of individual and cluster treatment system designs that process household and commercial sewage.

Septic systems that are properly planned, designed, sited, installed, operated, and maintained can provide excellent wastewater treatment at reduced infrastructure, energy, and operating cost. The proper use of septic systems reduces the risk of disease transmission and human exposure to pathogens and positively affects water resources by recharging and replenishing groundwater aquifers.

Although septic systems may contribute a relatively small portion of total nutrient loads within a catchment, they can still represent a significant source of in-stream nutrients fueling HCBs, especially during periods when flow is low. In addition, it is estimated that 10–20% of septic systems are not adequately treating waste (USEPA 2005a). State water quality agencies identify septic systems as the second-greatest threat to groundwater quality (USEPA 1998). Septic system failure results in contamination of surface and groundwater with excess nutrients.

▼Read more

Septic system failure can be attributed to three categories: design, operations, and maintenance.

- Design:
  - improper siting (shallow groundwater, trees and vegetation, impermeable soils, springs, proximity to surface water bodies or drinking water wells)
  - inadequate sizing
  - local septic system density
  - no absorption field in systems installed pre-1970s
  - inadequate construction (incorrect fittings, short-circuiting)
- Operations:
  - incorrect materials disposed in septic system
  - vehicles parked on absorption field or other activities that may damage the absorption field
- Maintenance:
  - periodic inspections not performed
  - pumping out of septic tank not conducted
  - loss of infiltration rate into absorption area and other age-related issues

7.6.4.1 Nonstructural Strategies

There are several options to address nutrient pollution prevention from septic systems to minimize risks of HCBs (NVPDC 1996). These fall into two categories: (1) nonstructural BMPs to prevent failure of septic systems and (2) nonstructural BMPs to minimize nutrient contamination from septic systems. State or municipal agencies provide guidance, policies, and regulations for the design, operation, and maintenance of septic systems (see USEPA's Septic Systems Guidance, Policy, and Regulations).

▼Read more

Some watershed groups provide assistance for pumpouts and repairs of septic systems. Bluegrass Greensource in Kentucky used funding assistance through an USEPA grant to provide cost-share grants for repairs or free pumpouts for those who attended a workshop on how to maintain their septic system to reduce harmful effects on water quality. This is just one example of how BMPs to prevent nutrient pollution can be achieved through homeowner outreach and education efforts.

Pros. Nonstructural strategies for septic system maintenance are relatively inexpensive and can be supported through homeowner outreach and education.

Cons. Reducing nutrient input to local water bodies through nonstructural strategies can be a slow process, taking 10–20 years to see a significant response. This is due to a number of factors, such as insufficient load reduction, low water exchange rate, and the release of "legacy" sources of phosphorus and other nutrients from sediments. In addition, septic systems are often grandfathered until they fail, and what constitutes a failure is often poorly defined.

Regulatory or policy considerations. In most states, septic tank maintenance is the responsibility of the building owner, and regulations often pertain instead to violations and necessary steps for remediation following septic system failure. Policy considerations can be specific to a region, and approaches to regulate septic system maintenance vary by municipality. Several case studies detailing steps taken by local governments are presented in Appendix E of USEPA's response to congress on decentralized wastewater systems.

Application Examples. Nonstructural approaches to septic system management vary greatly. Resources to help you learn about them include:

- Several case studies on increasing homeowner awareness are covered in USEPA (2012).
- Additional case studies highlighting successful outreach and education efforts can be found in USEPA's SepticSmart program.
- A study conducted by Silverman (2005) showed that a door-to-door campaign to educate homeowners in northwest Ohio on proper maintenance of septic systems did not change management practices and suggests that more intrusive measures may need to be implemented to control pollution.
- Four case studies are presented in Withers et al. (2012) that detail uncertainties in nutrient emissions from septic tanks in rural catchments of Europe and the UK.
- Investigation of temporal variability in septic system discharges revealed seasonal impacts on nutrient pollution in streams (Richards et al. 2016).

Other considerations. Even with outreach and education, many homeowners do not think about their septic system until it fails. In the meantime, septic systems that are not properly maintained will continue to release pollutants to groundwater and may represent a significant source of nutrients to fuel HCBs. Studies show that the most successful nonstructural strategies to reduce septic system failure include both education and support for the homeowner in conducting maintenance (USEPA 2012).

7.6.4.2 Structural Strategies

Structural BMPs for septic systems include considerations for siting, design, and installation of septic systems. Septic system technical fact sheets are available on the USEPA website and include several strategies to improve wastewater treatment and removal of pollutants.

Examples of common structural strategies to improve septic system operation include:

- Mound system: Enables the use of some sites that are unsuitable for in-ground systems. A more complete description is provided in Pipeline (National Small Flows Clearinghouse 1999).
- Effluent screen: Enhances the removal of solids to prevent blockages that can damage the drain field
- Leaching chamber: Alternative to gravel drain fields that can extend the life of the drain field
- Alternative filters: Increases loading rates with crushed glass, recycled textiles, synthetic foam, and peat instead of sand
- Recirculating sand filters: Eliminate odors and increase oxygen content of effluent

Pros. Structural strategies to improve nutrient removal using septic tank systems are often complementary to nonstructural strategies described above. They may be a more effective and proactive approach for reducing nutrients than maintenance alone. Many of the structural strategies listed above reduce the area needed compared to conventional septic systems or can be used in areas where conventional septic systems are not suitable.

Cons. Structural strategies for reducing nutrients in septic system effluent can be more costly to implement than nonstructural strategies. Technical advances to septic systems may be more costly to construct and require more frequent routine maintenance compared to traditional septic systems. Extreme temperatures may need to be taken into consideration during design.

Regulatory or policy considerations. In most states, local health departments issue construction and operating permits to install septic systems under state laws that govern public health protection and abatement of public nuisances. Under most regulatory programs, the local permitting agency conducts a site assessment to determine whether the soils can provide adequate treatment to ensure that groundwater and surface water resources will not be threatened. InspectAPedia provides a state-by-state list of septic system design and repair regulations in the United States.

▼Read more

Septic system inspections are also required by some states upon sale of property. Iowa state law, for example, requires that septic systems must be inspected prior to the sale of a home or building and that systems that are not adequate must be upgraded at the time of sale to meet minimum standards. Minnesota, on the other hand, requires that septic systems be inspected every 3 years and that owners must disclose septic condition and compliance when selling or transferring property. In Delaware, property owners must have their system pumped out and inspected prior to completion of a sale, with some exceptions.

Some states have incorporated water resource protection provisions to their septic system regulations because of the possible impacts from nitrogen and phosphorus. These provisions may include, but not be limited to, advanced treatment systems (aerobic systems or denitrifying drain field media amendments to promote nutrient removal), prohibition of septic systems exceeding certain development densities, and inspection requirements as a condition of permitting.

Application Examples. Research to improve septic system function is ongoing. Check with your regulatory authority to learn about systems approved for use in your area. These examples may be of interest:

- Mounded drain field design was investigated by De and Toor (2017), who showed that drip dispersal systems were most effective at reducing nitrogen and should be the preferred treatment approach in areas with shallow groundwater.
- Performance of recirculating sand filters was investigated in residential communities in California and Oregon (USEPA 1999).
- Crushed recycled glass was compared to sand by Gill et al. (2009). The glass performed similarly to sand in removal of nitrogen but was not effective at removing phosphorus. Addition of crushed glass to sand improved the rate and uniformity of percolation.

Other considerations. Structural strategies to enhance nutrient removal by septic systems should be carefully considered during new construction, when implementation of many of the technical advances discussed here would be most cost-effective.

7.6.5 Suburban and Rural Road Nutrient Management

In general, road management and maintenance practices facilitate the movement of water off the road surface as quickly as possible to maintain safe driving conditions. The management of stormwater flowing off paved and unpaved roads, as well as from roadsides, is important for the protection of downstream water quality. This Section discusses diffuse stormwater discharge from roads; stormwater discharge through pipes or conveyances is regulated as a point source and was discussed in earlier Sections. In the context of HCBs, stormwater from roads can be a significant contributor of nutrients and sediments to receiving waters. Surface materials from unpaved roads can wash off during storm events, and high flows from both paved and unpaved roads can cause erosion of adjacent roadsides. Stormwater management from roads that are hydrologically connected (cross or run adjacent to water bodies) is particularly important. Strategies discussed in this Section are focused on suburban and rural roads, where space is typically of less concern than in the urban environment, allowing for management options that may not be feasible in more developed areas. As noted previously, stormwater from urban roads is managed as point sources through MS4 permits, and corresponding nutrient control was discussed previously.

7.6.5.1 Structural and Nonstructural Strategies

Nonstructural approaches focus on raising awareness about the water quality impacts caused by stormwater flowing from roads, designing new roads to have the lowest feasible water quality impacts, and updating maintenance practices to reduce water quality impacts. Installation and repair activities can be planned in advance, allowing identification of the appropriate approach and efficient management of equipment and staff. Nonstructural approaches can also include the development of policy or legislation, permit requirements, and training opportunities.

Many structural road BMPs are designed to reduce erosion and minimize the movement of nutrients into adjacent waters. Generally, these BMPs promote getting water off the road quickly; stabilizing and vegetating roadsides, including adjacent ditches and stormwater structures (culverts, inlets, outlets, etc.); diverting runoff to vegetated areas where pollutants and nutrients can be captured in the soil; maintaining natural buffers and drainageways; minimizing the creation of steep slopes; and maintaining as much of the adjacent natural vegetation as possible.

Pros. Training and outreach around stormwater management from roads helps municipalities and road crews recognize locations and situations where surface waters may be impacted by nutrient-rich sediment and runoff. Planning for new roads and repairs of existing roads can then use the best available management strategies applicable to local conditions. Education and outreach opportunities can use experienced local road crew staff as mentors and trainers. Hearing about the successful use of new BMPs from peers increases acceptance and usage by other road managers.

State policy, regulations, and permitting may facilitate rapid adoption of stormwater rules across the entire state simultaneously. Funding opportunities can facilitate compliance and early adoption of the new requirements. With the large array of BMPs available for consideration, municipalities and responsible parties can develop road management plans to fit specific needs and budgets.

Cons. Not all states have mandatory stormwater management requirements for the construction of new roads or improvement of existing systems in the rural and suburban environment. Voluntary strategies may not gain widespread adoption due to cost and lack of available land to house BMPs. For existing roads, the cost of upgrades to meet water quality goals may be significant. Without dedicated funding to support implementation of strategies identified during training and prioritization exercises, road improvements may be delayed or never take place. BMPs must be adequately sized to accommodate increasing stormwater volumes expected with climate change, thus increasing cost.

Regulatory or policy considerations. Policies and regulations may be required to support widespread adoption of road management BMPs. Funding and other support structures (for example, training and certifications) typically are necessary to support adoption.

Application Example. Examples of nonstructural strategies for road design and maintenance include:

- Connecticut's highway stormwater products
- Vermont's Municipal Roads General Permit, which requires communities to complete a road stormwater management plan by the end of 2020 and provides a suite of technical assistance and funding to facilitate compliance, including the Road Erosion Inventory and the Better Roads Programs
- Washington Department of Transportation's Municipal Stormwater Permit

Examples of structural approaches can be found in:

- Maryland's structural stormwater controls
- Nebraska's *Drainage Design and Erosion Control Manual* (NDOT 2020)
- Vermont's *Vermont Better Roads Manual* (Gould 2019)
- Washington's *Highway Runoff Manual*

7.6.6 Other Management Strategies for Nonpoint Source Nutrient Management

Other, less prominent nonpoint nutrient sources may exist within your watershed. Any location that has been developed or otherwise altered from its natural state could contribute or convey nutrients to surface waters. Roadside and agricultural ditches, resource extraction, marinas and boating facilities, developed lots in otherwise forested watersheds, and lakeshore development are all examples of areas that may be locally important sources of nutrients.

7.6.6.1 Nonstructural Strategies

Since these sources are frequently localized and small scale, education and outreach campaigns are often the primary nonstructural strategies. Policy and regulations may be appropriate where a single type of nonpoint source nutrient loading is abundant (for example, low-density development around lakeshores) or may be a concentrated disturbance (for example, gold dredging in streams).

Pros. Small or scattered nutrient sources can be important drivers of HCBs, particularly for smaller water bodies. On larger water bodies, the cumulative effects of these small sources may be significant. To successfully reduce the occurrence of HCBs in low-nutrient lakes, managing these smaller sources is often as important as managing larger ones.

Cons. Management of these smaller sources is often voluntary or difficult to enforce. Homeowners are typically most directly affected and may not recognize the importance of managing their small nutrient contributions. It can be difficult to implement a permitting or regulatory program for smaller and less abundant nutrient sources.

Regulatory or policy considerations. Often policy, statutes, and regulations are necessary to address these smaller sources. Without strategic and frequent reinforcement of messaging around the importance of these small nutrient sources, it can be difficult to get the stakeholder support necessary to create policy and regulations.

Application examples. Many states have addressed smaller nutrient sources through voluntary and required approaches, including:

- lakeshore regulations for new development in Maine, Minnesota, and Vermont
- voluntary lakeshore guidance, such as Maine's LakeSmart program, Minnesota's Restore Your Shore tool, and Vermont's Lake Wise program
- boating pumpout requirements, such as New York's regulations
- resource extraction
- green infrastructure, such as Illinois' Green Infrastructure Plan

7.6.6.2 Structural Strategies

Structural BMPs for smaller or localized sources often focus on reducing the amount of impervious surface and directing stormwater away from surface waters. These approaches decrease the overall volume of water and the cumulative nutrient load it delivers. Reducing flow also controls the physical erosion of ditches and streambeds receiving stormwater. Redirecting nutrient-laden stormwater onto vegetated areas allows water to infiltrate the soil, removing contaminants and supporting groundwater recharge.

Pros. Many of these small structural approaches are inexpensive to include when planning new development or can be retroactively applied on the landscape. They can be combined to create an overall stormwater management approach over a larger area.

Cons. The smaller scale of these BMPs can make them seem less important when compared to larger sources within the watershed. Application of these smaller scale projects is often voluntary. Maintenance of these smaller structural BMPs, critical for continued effectiveness, is often neglected.

Regulatory or policy considerations. Design and construction requirements for small-scale structural BMPs may vary by state. Check with your state agencies regarding permits. In some arid areas of the United States, stormwater management intersects with water rights management, and BMPs used elsewhere may not be allowed.

Application examples. Check your state's stormwater management entities for more information on managing small nutrient sources:

- "*Slow it. Spread it. Sink it!*" green stormwater infrastructure guidance from Santa Cruz, California (RCDSCC 2009)
- Vermont's *Vermont Guide to Stormwater Management for Homeowners and Small Businesses* (VTANR 2018)
- Connecticut's *Guidebook for Marina Owners and Operators for the Installation and Operation of Sewage Pumpout and Dumping Stations*
- Alaska's Alaska Clean Harbors certification program
- USEPA's green infrastructure website

7.7 Water Quality Trading

WQT is a market-based approach to efficiently distribute and incentivize treatment upgrades or other approaches for reducing nutrient loads within the same watershed HUC. WQT is based on the premise that nutrient control from some sources may require costly measures, while measures to reduce the same nutrient at other sources are less expensive. Trading allows greater, less costly nutrient reductions from one source to be transferred to another source where reductions may be more expensive. This flexibility allows for better outcomes at lower costs, capitalizing on cost differentials and economies of scale. In the United States, WQT objectives include increasing the speed at which reduction measures are implemented, as well as increasing the use of technological advancements to meet TMDLs established under the CWA. WQT promotes nutrient reduction at lower cost while advancing improved environmental conditions.

WQT also balances less nutrient reduction at one source with more nutrient reduction at another source that was not meeting required reductions. This system increases the efficiency of nutrient reductions overall and incentivizes polluters with resources to make larger strides in pollutant reduction. For more information on the advantages and disadvantages of WQT, see "*Three Strengths and Weaknesses of Water Quality Trading Policies*" (Fialko 2018).

More information about WQT options is available at USEPA's FAQs about Water Quality Trading.

Pros. WQT enables significant cost savings in achieving nutrient reduction goals while also potentially addressing multiple pollutants.

Cons. WQT also has some disadvantages. Its trading potential may depend on market conditions and available trading partners. Also, trading must be restricted to avoid "hot spots," or areas where discharges are high (MPCA 2019b, Fialko 2018).

Regulatory or policy considerations. WQT has other regulatory and policy considerations as well. In the United States, for example, WQT must be consistent with the CWA. Generally, USEPA supports reductions in nutrients and sediments but will consider other pollutants on a case-by-case basis. Load allocations for each point source should be established based on TMDLs. Where a TMDL has yet to be established, a baseline for the specific pollutant should be established based on performance requirements or other management practices developed from the necessary water quality standards.

Application examples. A Morgan and Wolverton (2005) review of WQT in the United States identified 19 ongoing pollutant trading programs. Most of these systems had already established TMDLs for the pollutant(s) being regulated, which included one or more of water flow, heavy metals, phosphorus, and nitrogen. The prices of implementing and operating the trading programs varied between the projects. However, for the highest cost programs, high implementation costs were found to be due to the level of detail required for an application, length of time for approval, and complications during negotiation. Operation costs were high due to monitoring costs, extensive application reviews, oversight, and inspection. In cases where trades did not occur, some of the many reasons were not finding reasonable trading prices, not tracking water quality changes, lack of stakeholder or polluter participation, and compliance issues. WQT reviews by Greenhalgh and Selman (2012) and Shortle (2013) provide comparisons across point–nonpoint, point–point, and nonpoint–nonpoint trading programs within the United States and across the world.