Petroleum Refining Industry Contribution to Nationwide Surface Water Nutrient Loadings

API PUBLICATION 4782
AUGUST 2016

AMERICAN PETROLEUM INSTITUTE

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Executive Summary

This analysis was commissioned by API to provide member companies and the public with a better understanding of the water quality problems associated with nutrient discharges to the nation's surface waters, the current federal and state regulatory responses to nutrient-related water quality problems, the scientific and implementation challenges of nutrient controls, and the petroleum refining industry's relative contribution to nationwide nutrient discharges to surface waters.

The overwhelming majority of total nitrogen (TN) and total phosphorus (TP) nutrient loadings to surface waters is from nonpoint sources. A significant contribution also comes from municipal wastewater effluents. Petroleum refineries contribute only 0.1 % of the nationwide TN loading and only 0.08 % of the nationwide TP loading to surface waters. Clearly, nutrient control efforts targeting the petroleum industry, though perhaps important in specific circumstances, will not resolve the majority of nutrient impairments of our nation's waters; control efforts must focus on reductions in nonpoint source and municipal nutrient loadings if meaningful gains in water quality are to be achieved.

The key findings of this study are as follows:

- The two so-called macronutrients, TN and TP, are almost always the growth-limiting nutrients for aquatic plant growth and are the focus of regulatory agency efforts to control such growth to protect water quality.
- The quantities of TN and TP that cause aquatic plant growth sufficient to impair water quality and designated uses are inherently water body specific. The physical and chemical characteristics of each water body are important determinants of the type of aquatic plants, their growth rates, and the total density of such growth, which in turn determine impairment of water quality and/or designated uses of the water body.
- The enrichment of surface waters with the plant nutrients TN and TP causes impairments of water quality and failure to attain designated water uses in a large number of surface water bodies in the United States, including rivers and streams, lakes and reservoirs, estuaries, and coastal waters.
- The inherent water body–specific characteristics of nutrient enrichment have made it difficult for states to establish scientifically sound water quality standards for nutrients. Because of this difficulty, many states rely on narrative water quality standards to address nutrient enrichment.
- The U.S. Environmental Protection Agency (EPA) has been encouraging states to adopt numeric standards for TN and TP for the past 20 years. The water body–specific characteristics of nutrient enrichment have made a "one-size-fits-all" approach to numeric nutrient standards impossible, so most states have been slow to adopt numeric nutrient standards.
- EPA's most recent initiative is for states to adopt "independently applicable" numeric standards for both TN and TP, regardless of which one is the limiting nutrient in a specific surface water body. Many states have rejected this approach as not scientifically justified.
- There are many sources of TN and TP that discharge to surface waters. These can be both natural and anthropogenic. However, the research shows that anthropogenic sources are the principal cause of excessive nutrient concentrations in surface waters. Nonpoint sources such as agriculture, fertilizer application in urban and suburban areas, urban runoff, and atmospheric deposition are typically cited as the source of 90 % or more of the excess nutrients discharged to surface waters of the United States.
- This study of nutrient loading sources using data compiled from EPA databases, the scientific literature, technical textbooks, and several states has shown that on a nationwide basis (Figure ES-1):

- 84.6 % of the TP loading and 84.1 % of the TN loading on surface waters are due to nonpoint sources.
- Municipal wastewater effluents (publicly owned treatment works [POTWs]) account for 14.1 % of the TP loading and 14.6 % of the TN loading.
- The total industrial point source loadings of TP and TN are estimated at 1.3 % of the national totals.
- Petroleum refineries contribute 0.08 % and 0.1 % of the nationwide TP and TN loadings on surface waters, respectively.

- These relative loadings demonstrate that nutrient control efforts must focus on reductions in nonpoint source nutrient loadings if there are to be any meaningful results in reducing nutrient enrichment of the nation's surface waters.
- This analysis does not conclude that point source nutrient contributions are insignificant in all water bodies, and it is not intended to justify inaction in such instances. Rather, each water body must be evaluated by considering its physical, chemical, and biological characteristics; the point and nonpoint sources that contribute nutrients; and the effects of such nutrients on aquatic plant growth before establishing limitations on TN and TP for point source discharges.

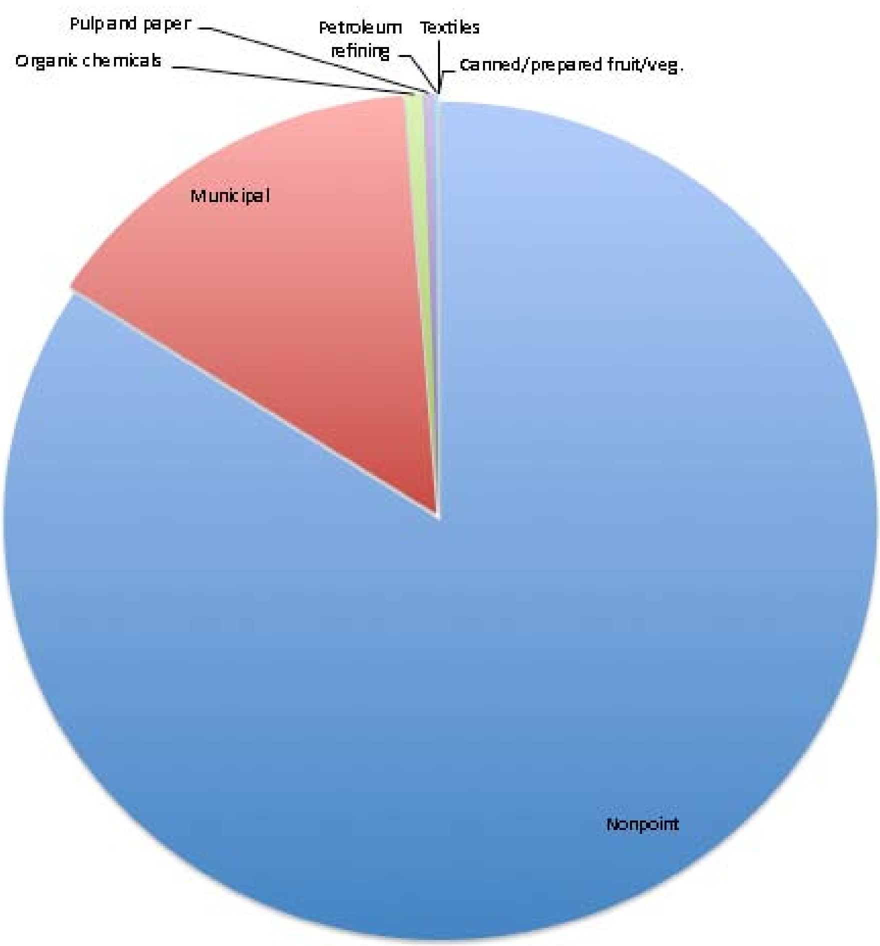

Figure ES-1—Percent Contributions to Total National Nutrient Loadings

Abbreviations

BMP	Best Management Practice
CWA	Clean Water Act
DMR	Discharge Monitoring Report
ELG	Effluent Limitation Guideline
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right-to-Know Act
NEIWPCC	New England Interstate Water Pollution Control Commission
NPDES	National Pollutant Discharge Elimination System
PCS	Permit Compliance System
POTW	Publicly Owned Treatment Works
SAB	Science Advisory Board
TBEL	Technology-based Effluent Limit
TCEQ	Texas Commission on Environmental Quality
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TPDES	Texas Pollutant Discharge Elimination System
TRI	Toxics Release Inventory
WQBEL	Water Quality–based Effluent Limit

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Petroleum Refining Industry Contribution to Nationwide Surface Water Nutrient Loadings

Chapter 1—Introduction

The U.S. Environmental Protection Agency (EPA) and many states have agreed that loadings of nutrients to surface waters are generally increasing and excess nitrogen and phosphorus levels are contributing to degradation of surface water quality in certain water bodies (EPA, 2009a). EPA and the states have been working for decades on approaches to controlling nutrients, and it is probable that more stringent water quality–based effluent limits (WQBELs) for nitrogen and phosphorus could be imposed on point source dischargers in future years. This report provides an overview of the national issue of nutrient enrichment of surface waters, the sources of such nutrients, and the significance of petroleum refining industry discharge contributions to nationwide nutrient loadings.

Scope

This study is based on using available published data on nutrient enrichment of U.S. surface waters; EPA and state nutrient control guidance, policy, and water quality standards; prior analysis performed for API by a third-party consultant; petroleum refinery effluent quality data from the EPA Integrated Compliance Information System/National Pollutant Discharge Elimination System (ICIS-NPDES); and permit data collected from the files of the Texas Commission on Environmental Quality (TCEQ).

Organization

Chapter 2 presents a description of nutrients and their effects on water quality and receiving water uses. The terminology describing nutrient enrichment in surface waters is presented, and the fundamental interactions among nutrients, aquatic biology, and other water quality constituents are summarized to provide a basic understanding of the issues and complexities involved in evaluating the effects of nutrients on water quality.

Chapter 3 presents the evaluation of the petroleum refining industry's contribution of nitrogen and phosphorus, the primary nutrients of concern, to surface waters of the United States. The petroleum refinery contributions are compared with the contributions from other point and nonpoint sources of these constituents, including discharges from publicly owned treatment works (POTWs), agricultural sources, and urban runoff. A ranking of nutrient contributions from the petroleum refining industry relative to the other point and nonpoint source categories is based on the combined data available for nitrogen and phosphorus.

Chapter 4 provides an overview of the history of and recent developments in nutrient control policy and regulation. A summary of nutrient enrichment impacts of major point source categories and nonpoint sources on both national and regional scales is presented. The chapter also summarizes surface water body impairments and major nutrient total maximum daily load (TMDL) studies at the national level.

Chapter 5 presents a summary of the principal findings in the report and the conclusions of this evaluation.

Principal Finding

The overwhelming majority of total nitrogen (TN) and total phosphorus (TP) nutrient loadings to surface waters is from nonpoint sources. A significant contribution also comes from municipal wastewater effluents. Petroleum refineries contribute only 0.1 % of the nationwide TN loading and only 0.08 % of the nationwide TP loading to surface waters. Clearly, nutrient control efforts targeting the petroleum industry, though perhaps important in specific circumstances, will not resolve the majority of nutrient impairments of our nation's waters; control efforts must focus on reductions in nonpoint source and municipal nutrient loadings if meaningful gains in water quality are to be achieved.

Chapter 2—Nutrients and Their Water Quality Impacts

When the term “nutrient” is used in a water quality context, it is typically referring to substances used for growth by rooted and floating aquatic plants. Nutrients are also required by the biological treatment systems used to treat wastewaters containing biodegradable organics. In this report, the term “nutrient” is used to describe substances that promote aquatic plant growth in surface waters.

This chapter provides background information on the nutrients in surface waters and how these influence aquatic plant growth, which in turn may impact surface water quality. Such impacts can be beneficial as well as detrimental, which is often misunderstood.

Nutrients in Surface Waters

In June 1998 the EPA published its *National Strategy for the Development of Regional Nutrient Criteria* (EPA 822-R-98-002) (EPA, 1998). In this document, EPA identified nutrients as substances necessary for metabolism by living organisms (i.e., growth, reproduction). In the context of water quality criteria, nutrients are substances that are necessary for the metabolism of aquatic plants[1] (e.g., algae, submerged aquatic vegetation). Nitrogen and phosphorus (in various compounds) are required in relatively large amounts by plants and are termed “macronutrients.” Micronutrients are substances needed in much smaller amounts and include iron and molybdenum. The micronutrients rarely control the growth rates and total biomass of aquatic plant life in a water body because they are typically present in quantities vastly in excess of the plants’ needs. The major elements nitrogen and phosphorus, individually or collectively, usually limit aquatic plant growth rates and total plant biomass in surface waters and as such are the nutrients that are the subject of this study as well as EPA’s water quality standards policies and guidance.

Physical, chemical, and biological processes alter the speciation of nutrients and transfer nutrients among media: air, soil, water, and biological organisms. Nutrient species that are biologically available for plant growth include the dissolved inorganic ions ammonium (NH_4^+), nitrate (NO_3^-), and orthophosphate (PO_4^{-3}). Organic forms of nitrogen and phosphorus become available for plant growth through chemical and biological processes that transform them to biologically available inorganic species.

Nutrients, which promote and accelerate algae and macrophyte growth, undergo continuous cycling and are converted to various chemical forms through different physical, chemical, and biological processes. Photosynthesis, sedimentation, ingestion and metabolism of plants by zooplankton and fish, excretion of wastes, chemical desorption from sediments, microbial decomposition of particulate and dissolved organic nitrogen and phosphorus are examples of the physical, chemical, and biological processes that affect the availability of nutrients for aquatic plant growth. Nutrients that are present in particulate form or organic matter are generally not directly available to plants and thus reduce the pool of nutrients that are available for uptake by rooted plants and algae. These biologically unavailable forms of nutrients may be slowly released due to biological processes in the sediment or water column; however, some fraction of these bound nutrients are refractory and are essentially permanently removed from the pool of available nutrients.

A simplified explanation of the interaction between plants (i.e., algae or phytoplankton, periphyton, aquatic macrophytes) and nutrient nitrogen in an aquatic ecosystem is presented in Figure 1. As shown in Figure 1, nitrogen in aquatic systems occurs as organic nitrogen and inorganic nitrogen. Organic nitrogen is nitrogen within a carbon-based molecule, such as in plant or animal tissue. Nitrogen that is not chemically bound in organic material is inorganic. Through degradation, organic nitrogen is converted to inorganic nitrogen (predominantly ammonium and nitrate ions) and becomes readily available for uptake by algae and plants for growth.

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[1] The terms “phytoplankton,” “periphyton,” and “macrophytes” are terms used to describe categories of aquatic plants. Phytoplankton are free-floating algae, periphyton are algae that attach to rocks or rooted vegetation, and macrophytes are rooted (submerged) and floating vascular aquatic plants. Aquatic plant growth is referred to as primary production because it represents the base of the aquatic food chain.

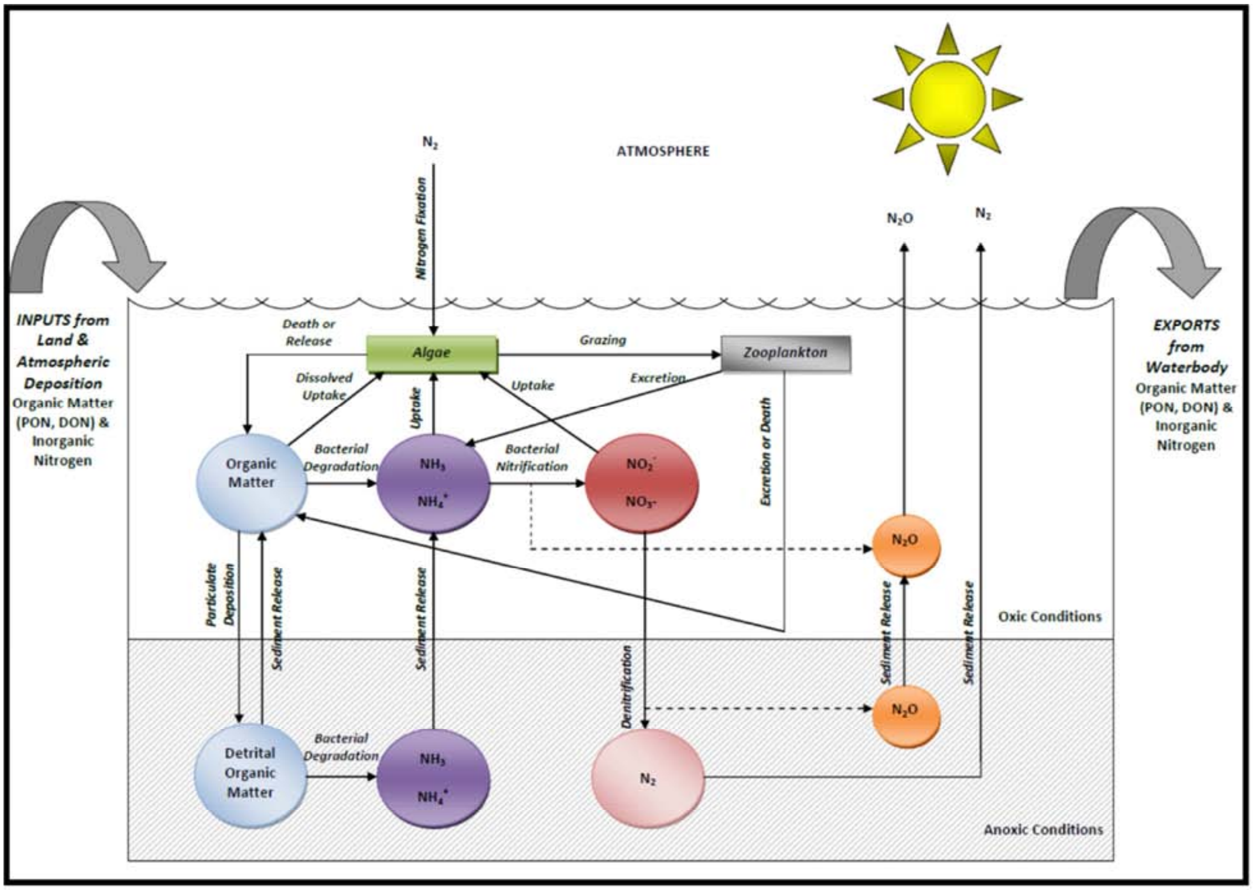

Figure 1—The Aquatic Nitrogen Cycle

As shown in Figure 2, phosphorus in aquatic systems occurs in organic and inorganic forms. Organic and inorganic phosphorus can either be dissolved in the water or attached to particles in the water column or in the sediment. Organic phosphorus is chemically bound to a carbon-based molecule, as in plant or animal tissue. Phosphate that is not chemically bound to organic material is inorganic. Inorganic phosphate is the readily available form of phosphorus required by algae and other aquatic plants for growth. Organic phosphorus only becomes available for aquatic plant growth through the action of biological and chemical processes that degrade it to inorganic phosphorus.

Watershed inflows and atmospheric deposition are the external loadings of nutrients to a surface water body. The phosphorus cycle differs from the other major biogeochemical cycles in that it does not include a gas phase; although a small amount of phosphoric acid (H_3PO_4) may make its way into the atmosphere, potentially contributing to atmospheric deposition as a source, the quantity is generally insignificant in terms of the nutrient balance on a surface water body.

Similar to nitrogen, biological, physical, and chemical processes affect the amount of bioavailable phosphorus that is present in any given surface water body. Figure 2 illustrates the major pathways for phosphorus in a surface water body. A substantial fraction of the organic phosphorus that is bound to particulate matter, including dead aquatic plants, can be stored in the sediment of a water body and may become more or less permanently removed from the nutrient pool.

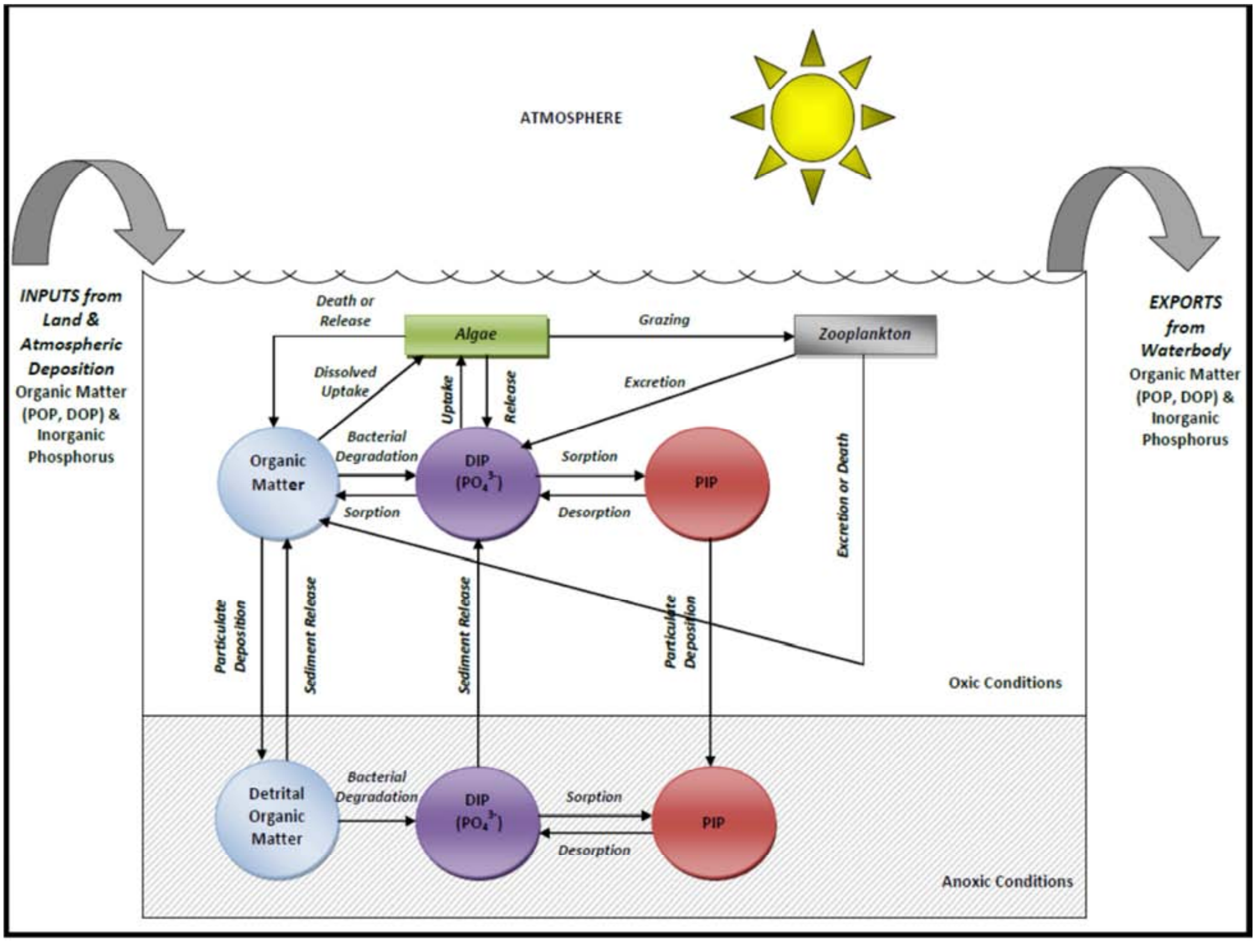

Figure 2—The Aquatic Phosphorus Cycle

Water Quality Effects of Nutrients

Aquatic plants are an essential component of healthy aquatic ecosystems, and nutrients are necessary to sustain their growth.[2] Algae (or phytoplankton) use nutrients to grow and are important food for zooplankton, invertebrates, and some filter feeders (e.g., oysters, clams, and menhaden). These species are prey for other forms of life and represent the base of the aquatic food web. Rooted aquatic plants (macrophytes) provide cover and food for aquatic animals (e.g., fish, insects). An excess or absence of nutrients, however, can cause the aquatic system to be imbalanced. The term “nutrient enrichment” is used to describe an excessive amount of nutrients in surface water that may result in water quality impacts that may have adverse effects on the uses of the water body. Because aquatic plants support aquatic life at higher trophic levels, very low nutrients can result in a water body with low populations at these higher trophic levels including a depauperate fishery.

The impetus for the development of water quality criteria for nutrients is that when nutrients are abundant in a surface water body, aquatic plants can grow to such an extent that they interfere with the uses of the water body. Excessive aquatic plant growth can adversely affect fish populations, can increase the costs of treating the surface water for use as a public water supply, and can interfere with recreational uses.

2 The terms “phytoplankton,” “periphyton,” and “macrophytes” are terms used to describe categories of aquatic plants. Phytoplankton are free-floating algae, periphyton are algae that attach to rocks or rooted vegetation, and macrophytes are rooted (submerged) and floating vascular aquatic plants. Aquatic plant growth is referred to as primary production because it represents the base of the aquatic food chain.

Surface waters can be grouped into three categories, based on their aquatic plant life growth characteristics:

- Oligotrophic—surface water bodies that are nutrient limited such that primary productivity is very low. In most oligotrophic waters, primary productivity is limited to the extent that higher trophic level production (i.e., the fishery) is also limited.

- Mesotrophic—surface waters with nutrient concentrations that are in between oligotrophic and eutrophic levels.

- Eutrophic—surface waters that have abundant concentrations of nutrients, resulting in dense aquatic plant populations that can adversely affect the uses of the surface water (e.g., the fishery, recreation, public water supply).

- Hypereutrophic—surface waters that are severely impacted by aquatic plant growth, adversely affecting water uses and possibly exhibiting a "pea soup" appearance due to high algae populations.

It is important to acknowledge that slightly to moderately eutrophic surface waters often support highly productive and valuable fisheries and that in such cases the eutrophic condition does not adversely affect either recreation or public water supply uses. Eutrophication is a natural process and, in and of itself, is not necessarily an undesirable condition in terms of the designated uses of a surface water body. These facts are often overlooked or glossed over in the discussion of nutrient enrichment of the nation's surface waters.

Nutrients enter surface waters from nonpoint sources (e.g., agriculture, urban, undeveloped open land and/or forest) in runoff from precipitation, irrigation, or through drainage ditches and tile drains and from direct point sources [e.g., POTWs and/or industry]. Nutrients may enter groundwater by rainfall infiltration, septic tank drainfields, or from irrigation of crops (Figure 3). Nutrient concentrations in nonpoint source flows are affected by physical and biological features of the land, including soil types and slope or topography and vegetative cover, as well as by biological and geochemical processes that can change the chemical form of the nutrient and/or transfer it from the dissolved aqueous phase to the solid phase to possibly the atmospheric gas phase.

As shown in Figure 3, the occurrence and transport of nutrients in streams, lakes, estuaries, and groundwater involves complicated interconnections among surface water and groundwater systems, atmospheric contributions, and natural and human activities. The principal natural factors of climate, vegetative cover, soil type, geology, and slope of the land, govern the amount and timing of transport of nutrients to surface water and groundwater. Human activities that can affect nutrient transport include irrigation, groundwater pumping, the construction of impervious surfaces (e.g., roads and/or parking lots), artificial subsurface drainage (e.g., tile drains), and best management practices (BMPs) (e.g., riparian buffer strips, detention pond, etc.). Thus, nutrient concentrations in surface and groundwater are inherently site specific. Nutrient transport in water depends on the chemical properties of the nutrients, affecting mobility and persistence. Some compounds, such as nitrate, are soluble and are transported in the dissolved form in both surface water and groundwater. Most forms of phosphorus attach to soil particles rather than dissolve. Phosphorus is predominantly transported to streams with eroded soil, particularly during times of high runoff from precipitation or in irrigation return flows.

Every surface water body responds to nutrient loads differently. Rivers and streams, lakes, bays and estuaries, and the open near-shore ocean waters are very different in terms of the sensitivity and response of their aquatic plant populations to the primary nutrients. The physical properties and hydrodynamics of surface water bodies are major influences on their responses to influxes of plant nutrients. The term "assimilative capacity" refers to the ability of an aquatic system to accommodate additional loadings of nutrients or oxygen-demanding substances with no adverse effect on water quality and uses. The assimilative capacity of a water body can vary widely and is dependent on the prevailing physical, chemical, and biological conditions.

Because of the site-specific characteristics of aquatic plant growth, the consequences of nutrient enrichment are highly site specific and time specific and are not uniform. For example, a river with elevated nutrient concentrations and high turbidity (low light penetration) will have lower aquatic plant biomass levels than a river with similar physical characteristics but with low turbidity (high light penetration). There are many factors that influence the relationship between the nutrient loading and assimilative capacity of a water body. The relative types and location of sources, canopy, self-shading, wetlands, seasonality (including the delivery and timing of nutrient loads), flushing rates/residence times, water depth, water column stratification, turbidity, population of filter-feeding animals, and temperature and ice cover all influence the growth rate and total biomass of aquatic plants. Because of these factors, a "one-size-fits-all" solution does not work for solving nutrient-related problems.

In summary, nutrients are a natural and necessary component of surface water and only become a water quality problem when they are present in amounts that cause excessive aquatic plant growth that in turn interferes with designated uses including aquatic life protection and propagation, recreation, and public water supply. Because water chemistry, local climate, and other site-specific factors influence and may limit aquatic plant growth rates and total biomass, a simple relationship between these factors and the primary nutrients nitrogen and phosphorus is rarely scientifically justified except on a data-driven, water body–by–water body approach, which explains why states have been slow to adopt numeric standards in spite of EPA's insistence on such actions.

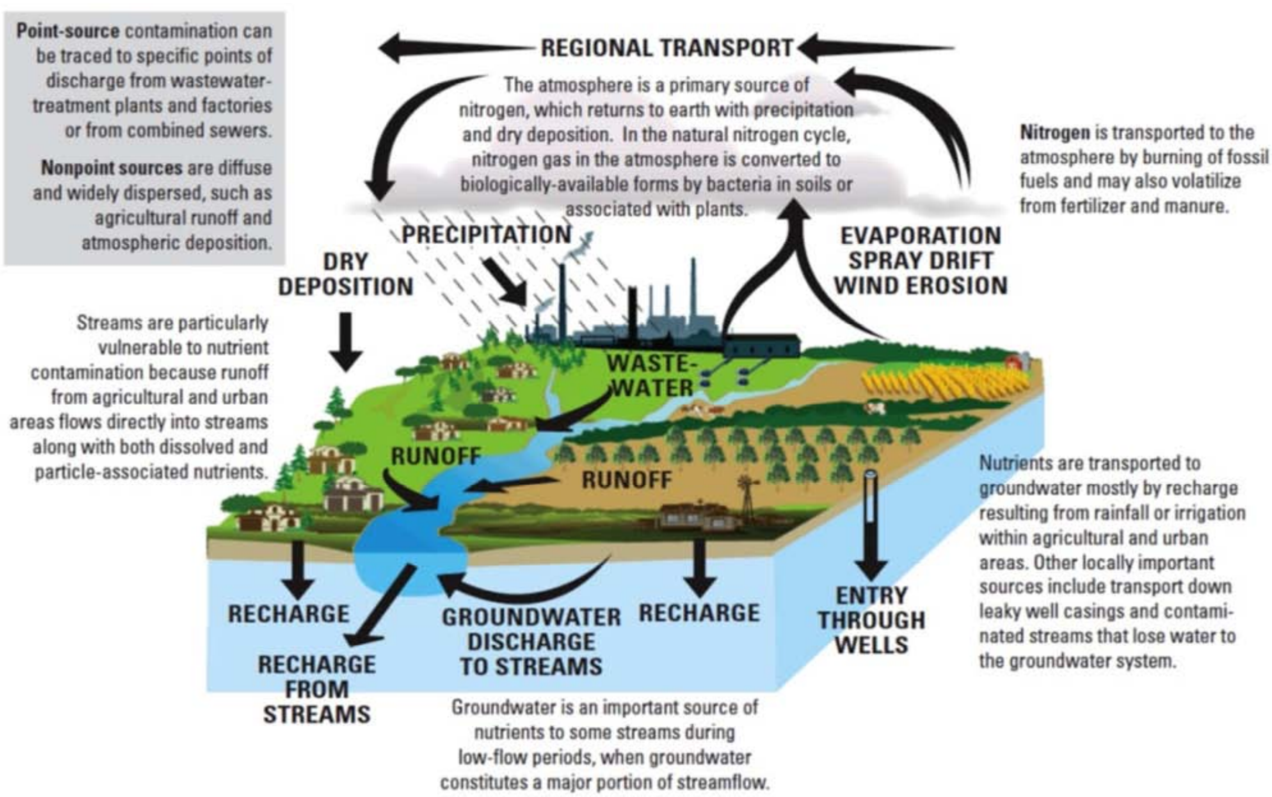

Figure 3—Nutrients from Nonpoint and Point Sources Are Cycled Throughout the Hydrologic System, but May Be Affected by Different Chemical, Physical, and Biological Processes in Different Parts of the System (USGS, 2010a)

Chapter 3—Nutrient Sources

The principal aquatic plant nutrients, nitrogen and phosphorus, are discharged to surface waters from a wide variety of sources, both point and nonpoint. This chapter characterizes and quantifies the nitrogen and phosphorus in petroleum refinery discharges, selected other industrial point source discharges, municipal (domestic) wastewater treatment plants, and nonpoint sources including dry weather and wet weather discharges from agriculture, silviculture, urban and suburban areas, and natural areas that are relatively unaffected by anthropogenic activity. The chapter concludes with a comparison of the relative contribution of each source category to the overall national nutrient discharge loadings to waters of the United States.

It is recognized in this evaluation that the relative contributions of different sources of nutrient loadings are variable; in some urbanized locations nutrient loadings may be dominated by point sources and nonpoint sources such as urban runoff. In other locations, agricultural-related nutrient loadings are the most important sources of nitrogen and phosphorus loadings to surface waters. Therefore, although broad characterizations of the sources of nitrogen and phosphorus are recognized in this report, it is acknowledged that the different categories of point and nonpoint sources may have different degrees of importance to the overall nutrient balance of a particular surface water system.

Nutrient Data Sources

Under the CWA's National Pollutant Discharge Elimination System (NPDES) permit program, water quality is protected by regulating point sources that discharge pollutants into waters of the United States. Point sources are discrete and direct conveyances of water such as pipes or man-made ditches. Industrial and municipal point sources must obtain permits that authorize the discharge of pollutants in limited quantities. The NPDES permit program is administered by authorized states (three states and several territories are not authorized, and EPA issues NPDES permits in these states/territories).

NPDES permits are required to include self-monitoring provisions for the pollutant discharges limited by the permit. The self-monitoring results required by an individual NPDES permit (EPA- or state-issued) must be reported to the enforcement authority (EPA or state) through the submission of a discharge monitoring report (DMR). Data are entered into a national database available to the public. The reported data are compared with the limits specified by the permit to determine facility compliance using the actual pollutant concentrations and/or loads discharged by the facility compared to the permit limits.

The principal limitation of DMRs in providing nutrient data is that the refinery effluent limitation guidelines (ELGs) limit only one nitrogen species, ammonia, and have no limits on any form of phosphorus. This is also true of most industrial point source categories and many POTWs that discharge these nutrients. Only if a permitting authority has included limits on constituents such as nitrates and total phosphorus, which is done only on a case-by-case basis, will self-monitoring data provide these nutrient data in DMRs.

NPDES permit applications include data on the most important nutrients in refinery wastewater, including ammonia, nitrates, and total phosphorus. Unfortunately, permit applications are generally not available online and can usually only be accessed by reviewing NPDES permit files of the individual states under freedom of information statutes.

The Toxics Release Inventory (TRI) was established under Section 313 of the Emergency Planning and Community Right-to-Know Act (EPCRA) to assess industrial nutrient loadings to surface waters. The TRI requires certain facilities within specified industry sectors to file reports of their disposal, waste management, or environmental release of toxic chemicals listed on the EPCRA Section 313 list, if they manufacture, process, or otherwise use more than established threshold quantities of these chemicals (EPA, 2015b). Facilities reporting to TRI are typically larger facilities involved in manufacturing, metal mining, electric power generation, and commercial hazardous waste treatment.

Unfortunately, the utility of TRI data for evaluating nutrient loadings from petroleum refining and other industries is limited by the following characteristics of the inventory:

- The nitrogen data in the inventory is for unionized ammonia-nitrogen and nitrates only.

- There are no usable data on phosphorus.

- Not all manufacturing facilities are required to report to the annual TRI. A threshold of the total amount of the listed constituents is used to determine if a report is needed.

At the typical pH range [7–8 standard units (SU)] of treated refinery effluents, unionized ammonia constitutes 0.8 % to 44 % of total ammonia in the wastewater, and it is impractical to estimate from the TRI database a typical or average total ammonia concentration representative of all refinery discharges. Thus, it is impossible with any accuracy to use the TRI to estimate industrial category TN or TP loadings. Because of these limitations of the TRI database, no TRI data were used in this study to develop nutrient loadings for industrial point sources or to compare industrial categories.

Other sources of nutrient data in wastewater and nonpoint source discharges are found in the technical/scientific literature. For example, nutrients in treated municipal wastewater are well characterized in a number of texts and published papers.

The above data sources (except NPDES permit applications) were used to evaluate refinery, other industry, municipal, and nonpoint source nutrient discharges. Those sources were supplemented by collecting data from refinery Texas Pollutant Discharge Elimination System (TPDES) permit applications on file at the TCEQ and conducting additional reviews of the technical literature to obtain flows and effluent nutrient composition data for municipal and industrial wastewaters.

Petroleum Refining Industry Nutrient Loadings

Petroleum refineries process crude petroleum and natural gas liquids into a wide range of hydrocarbon products including gasoline, kerosene (jet fuels), distillate fuel oils, residual fuel oils, lubricants, petroleum coke, and hydrocarbon gases used as chemical feedstocks (e.g., methane, ethane, propane, and butane) or fuels. Integrated petroleum refineries also manufacture first- and second-generation petrochemicals that are used to manufacture other petroleum-based chemicals and polymers.

Refining processes that are significant wastewater sources include:

- desalting that removes salt and suspended solids from the crude petroleum before further processing;

- atmospheric and vacuum distillation that separate the crude petroleum into fractions consisting of liquids and gases with similar hydrocarbon chain lengths;

- cracking and hydrocracking processes that break (“crack”) long-chain hydrocarbons into molecules with shorter carbon chain lengths;

- coking of residual hydrocarbons to produce petroleum coke;

- processes (e.g., alkylation, isomerization, reforming) that add to or rearrange the hydrocarbon molecules to produce desired product characteristics;

- purification processes that remove impurities (sulfur, ammonia) from hydrocarbon intermediates and products (e.g., hydrotreating, solvent extraction, caustic washing).

Each step in the refining process generates wastes, including air emissions, process wastewater, and solid wastes (e.g., sludge, spent catalysts) (EPA, 1995). Wastewaters generated from refineries can be classified in four categories: process wastewater, utility wastewater (e.g., cooling water, treatment of water for process and cooling use, boiler blowdown), sanitary waste, and storm water (surface water runoff from process and crude and product storage areas).

Nutrient Sources in Refineries

Nitrogen and phosphorus are found in all refinery wastewater categories. Process wastewater is the principal source of nitrogen in untreated refinery wastewater, where it is primarily present in the form of ammonia (NH_3) (EPA, 1995; IFC, 2007; IPIECA, 2010). Cooling water typically does not come into direct contact with process hydrocarbon streams and contains fewer contaminants than process wastewater; however, the water used in recycle cooling systems contains chemical additives including phosphates (EPA, 1995). Cooling tower blowdown is typically the principal source of phosphorus in refinery wastewater. Sanitary wastewater contains nitrogen and phosphorus, but in refineries is a minor source in terms of both volume and loading. Storm water runoff from process and storage areas may contain nitrogen and phosphorus, but these flows will typically represent low contributions to the total refinery nitrogen and phosphorus loadings in the combined refinery wastewater.

Process wastewaters contain ammonia, reduced sulfur compounds, and metals, all derived from naturally occurring impurities in the crude oil feedstock. The nitrogen content of crude petroleum varies widely depending on the source. The largest volumes of wastewater generated by petroleum refining processes consists of “sour” process wastewater and nonoily/nonsour, highly alkaline process wastewater (IFC, 2007). Sour water—water containing reduced sulfur compounds and ammonia—is generated from desalting, topping, vacuum distillation, pretreating, light and middle distillate hydrodesulphurization, hydrocracking, catalytic cracking, coking, and visbreaking/thermal cracking. Sour water may also be contaminated with hydrocarbons, organic sulfur compounds, organic acids, and phenol (IFC, 2007). Sour process wastewater is treated in a steam stripping unit process (sour water stripper) to remove hydrocarbons, hydrogen sulfide, ammonia, and other compounds, before recycling for internal process uses, or final treatment and disposal through an on-site wastewater treatment unit. Liquid effluent may also result from accidental releases or leaks of small quantities of products from process equipment, machinery, and storage areas/tanks (IFC, 2007).

Refinery wastewaters are typically treated in on-site wastewater treatment facilities and then are discharged to surface waters as authorized by NPDES permits (EPA, 1995). Refinery wastewaters are highly treated prior to direct discharge in order to comply with the petroleum refining ELGs that specify best practicable treatment currently available (BPT) and best available technology economically achievable (BAT) as promulgated at 40 *CFR* Part 419. A small number of refineries perform on-site pretreatment to comply with the EPA pretreatment standards (40 *CFR* Part 419) and transfer the wastewaters to POTWs for final treatment and discharge.

Refinery wastewaters are treated using both in-plant treatment methods and end-of-pipe systems. Because of the ubiquity of ammonia and sulfur in crude petroleum all refineries use sour water strippers to remove ammonia and hydrogen sulfide from the water. The recovered ammonia and hydrogen sulfide are managed in a sulfur treatment system. The sour water stripper(s), which are considered an in-plant treatment process, significantly reduces the nitrogen loading in the refinery wastewater.

The end-of-pipe treatment system for a direct discharging refinery typically consists of gravity oil/water separation, secondary oil/water separation, equalization, and biological treatment. Additional effluent polishing using final effluent filtration and/or settling in polishing ponds is common. Tertiary treatment for additional removal of nutrients is uncommon but is practiced where dictated by regulation (IFC, 2007; IPIECA, 2010). Some refineries also use underground injection of some wastewater streams (EPA, 1995).

Pretreatment at indirect discharging refineries (to POTWs) typically consists of sour water stripping and gravity oil/solids separation. Secondary oil/solids separation is also common.

The petroleum refining ELGs (40 *CFR* Part 419) require that NPDES permits for refineries limit the following constituents, as a minimum: 5-day biochemical oxygen demand, chemical oxygen demand, total suspended solids, oil and grease, ammonia-nitrogen, total sulfides, total phenols, hexavalent chromium, total chromium, and pH. NPDES permitting authorities may add additional constituent limits, typically WQBELs, to the required list.

Some direct discharge refineries use biological nitrification to minimize ammonia discharges to surface waters. The nitrification of ammonia when employed is required to achieve site-specific WQBELs. Because ammonia is a major oxygen-demanding substance in surface water (1 mg/L of NH_3-N exerts roughly 4 mg/L biochemical oxygen demand) and is also toxic to aquatic life at low concentrations, refineries (and other point sources) that discharge to surface waters with limited assimilative capacity are required to reduce ammonia to concentrations well below that allowed by the ELGs. This fact is important when evaluating the DMR data for refineries because the location of the refinery will typically determine the quantity of ammonia it can discharge. When nitrification is required for a point source, the TN in the treated effluent is primarily in the form of nitrate.

Refinery DMR Data Analysis

Sources of data used to assess the petroleum refining industry nutrient loadings are DMR data for 23 refineries and TPDES permit application data for 5 Texas refineries, obtained from the TCEQ Central Records public files. Information regarding the 23 refineries was compiled from the EPA Permit Compliance System (PCS) database and from the EPA ICIS-NPDES database. The ICIS-NPDES database is replacing but has not fully replaced the PCS database; therefore, both databases were used to obtain the most recent datasets for direct-discharging petroleum refineries. The following is a summary of the criteria considered for selection of refineries to be included for further evaluation of "typical" nutrient concentrations and loadings discharged in refinery wastewater:

- No more than 25 facilities due to allotted resources and project scope for the study.
- Representative geographic spread across the United States.
- Facilities that will represent the range in operable capacity across the petroleum refining industry.
- Facilities in locations of nutrient "hot spots" where water bodies are large and/or significant with recognized eutrophication/nutrient impacts.
- Facilities with nutrient data available for analysis.

The DMR dataset consisted of 59 refineries that satisfied most of the above criteria and was further reduced to 25 refineries by random selection. The final list of 23 refineries was developed with feedback from API members (Table 1).

DMR data on the 23 refineries was compiled for the 1998 to 2010 time period. The DMR data in this assessment represent end-of-pipe effluent measurements and include effluent flow data and nutrient data. The primary nutrient forms measured in refinery wastewater were total ammonia as nitrogen (hereafter total ammonia) and TP as phosphorus (hereafter total phosphorus). Additional nutrient forms measured included total Kjeldahl nitrogen (TKN) (which is equal to the sum of total organic nitrogen and ammonia nitrogen), nitrate nitrogen, organic nitrogen, and TN; however, these forms are not typically measured across all refineries and available data are limited. Consequently, the analysis focused on data summaries and analyses on total ammonia and TP data. Because of the limited data on nitrate nitrogen, which is the predominant form of nitrogen discharged by refineries that practice biological nitrification, the DMR data were supplemented with NPDES permit application data, as described in the following section.

Table 1—Refineries in DMR Database

Corporation	State	Site	Barrels per Calendar Day	NPDES	Receiving Waters
Tesoro Corporation	AK	Kenai	72,000	AK0000841	Cook Inlet
Royal Dutch/Shell Group	AL	Saraland	80,000	AL0055859	Chickasaw Creek
Martin Resource Management Group	AR	Smackover	7,500	AR0000591	Smackover Creek (1–3) & Holmes Creek (4)
ConocoPhillips	CA	Rodeo	120,200	CA0005053	San Pablo Bay
Suncor Energy Inc	CO	Commerce City West	67,000	CO0001147	All but 010 before entering Sand Creek
Marathon Oil Company	IL	Robinson	206,000	IL0004073	Sugar Creek
WRB Refining LLC	IL	Wood River	362,000	IL0000205	Mississippi River
CVR Energy Inc	KS	Coffeyville	115,700	KS0000248	Verdigris River
Midsouth Energy LLC	KY	Somerset	5,500	KY0003476	Sinking Creek
Motiva Enterprises LLC	LA	Convent	235,000	LA0006041	Mississippi River/St. James Canal
Chevron Corporation	MS	Pascagoula	330,000	MS0001481	Mississippi Sound of Bayou Casotte
Ergon Inc	MS	Vicksburg	23,000	MS0034711	Yazoo River Diversion Canal
CHS Inc	MT	Laurel	59,600	MT0000264	Yellowstone River
Tesoro Corporation	ND	Mandan	58,000	ND0000248	Missouri River and/or Heart River
Husky Energy Inc	OH	Lima	150,000	OH0002623	Ottawa River
ConocoPhillips	OK	Ponca City	198,400	OK0000256	621200 Arkansas-001/Omaha Creek-002
Sunoco Inc	PA	Philadelphia	335,000	PA0011533	Schuylkill River In Watershed 3-F
Valero Energy Corporation	TX	Texas City	214,000	TX0006009	Texas City Ship Canal
Chevron Corporation	UT	Salt Lake City	45,000	UT0000175	Oil Drain Canal
Western Refining Inc	VA	Yorktown	66,300	VA0003018	York River
Murphy Oil Corporation	WI	Superior	34,300	WI0003085	Allouez Bay
Ergon Inc	WV	Newell	20,000	WV0004626	Ohio River
Frontier Oil Refining & Marketing	WY	Cheyenne	47,000	WY0000442	Crow Creek and Porter Draw

A review of available NPDES permits for a subset of the 23 refineries reveals that most effluent limits for ammonia-nitrogen are based on mass loadings as required by the refinery ELGs; however, some facilities also have concentration limits as well. Effluent limits for TP were generally listed as a concentration limit, or a limit was not specified but the permit required that the parameter be monitored and reported. The effluent concentration limits for ammonia-nitrogen ranged from 2.18 mg/L to 20 mg/L, and the effluent concentration limits for TP as phosphorus ranged from 1.0 mg/L to 2.0 mg/L. Table 2 summarizes the DMR data for total ammonia and total phosphorus. Table 3 presents the DMR data for the other nitrogen species.

The public record files of the TCEQ were examined to obtain TP and TN from representative petroleum refinery TPDES applications. Applications for TPDES permits require dischargers to collect and analyze four effluent samples, with each sample at least one week apart, for total phosphorus, ammonia-nitrogen, organic nitrogen, and nitrate nitrogen. The sum of the ammonia-nitrogen, organic nitrogen, and nitrate nitrogen concentrations represents the TN concentrations in each refinery's effluent. Table 4 presents the TCEQ data that are used to supplement the Table 2 and Table 3 data.

The TPDES data demonstrate that the Texas refineries achieve essentially complete nitrification of ammonia, whereas Table 2 and Table 3 data show substantially greater effluent ammonia concentrations. However, the TN data from the refineries in Tables 3 and 4 are consistent (8.4 mg/L for Table 3 refineries and 9.32 mg/L for Table 4 refineries). Because typically nitrification of ammonia does not result in removal of TN from the wastewater, this close agreement from the two sets of data supports use of the median TN concentration to estimate refinery nitrogen loadings.

The medians of the nutrient data compiled in Tables 2, 3, and 4 were calculated to determine the following estimates used in this study to represent typical petroleum refinery effluent (combined process wastewater, cooling water, utility water, and storm water) nutrient concentrations for projection of total annual loads discharged by refineries to surface waters:

- total phosphorus (TP) as P = 1.01 mg/L;
- total nitrogen (TN) as N = 8.35 mg/L.

The median is used rather than the arithmetic mean as a measure of central tendency of the combined refinery effluent data because the median is not biased by individual high and low values in the dataset.

EPA's *Technical Support Document for the 2004 Effluent Guidelines Program Plan* (EPA, 2004) provides an estimated median petroleum refinery wastewater flow rate of 4.26 million gallons/day (MGD) (1,360 million gallons/year) based on the year 2000 PCS database. EPA determined that in the 2000 PCS database there were 103 refineries that it classified as major dischargers and 32 that it classified as minor dischargers. The median flow rate of 4.26 MGD was calculated using the data from the refineries that EPA classified as major dischargers.

The median flow rate consists of treated process wastewater, cooling and utility wastewater, and treated storm water (it excludes storm water discharged separately from treated refinery effluent). The median refinery flow, combined with the median TP and TN effluent concentrations estimated for this study, can be used to calculate approximate annual discharges of TP and TN to U.S. surface waters by direct-discharging U.S. petroleum refineries.[3]

3 The nutrient loadings from indirect-discharging refineries, i.e., those that discharge to POTWs, are included in the POTW nutrient load estimates.

Table 2—Effluent Flow, Ammonia Nitrogen, and Total Phosphorus Concentration and Load for the 23 Refineries in the DMR Data Analysis for the 1998 to 2010 Time Period

YEAR	FLOW, IN CONDUIT OR THROUGH TREATMENT PLANT	NITROGEN, AMMONIA, TOTAL (AS N)		PHOSPHORUS, TOTAL (AS P)	
	AVERAGE EFFLUENT FLOW (MGD)	AVERAGE CONCENTRATION (MG/L)	AVERAGE LOAD (LB/DAY)	AVERAGE CONCENTRATION (MG/L)	AVERAGE LOAD (LB/DAY)
1998	24.0	4.4	48.0	0.5	47.9
1999	33.1	3.8	38.9	1.1	57.0
2000	10.0	6.4	27.2	1.2	52.0
2001	10.2	6.8	29.9	1.0	46.6
2002	7.6	4.2	24.5	1.4	15.6
2003	5.2	4.1	26.3	0.9	31.2*
2004	5.7	5.7	30.3	2.0	9.1
2005	5.1	4.5	25.8	1.0	21.2
2006	5.3	6.2	29.9	1.8	23.1
2007	32.7	4.2	25.0	2.0	5.9
2008	6.2	4.7	21.0	0.4	10.6
2009	4.2	6.0	20.1	0.9	8.7
2010	13.3	3.0	11.1	0.3	18.9
Average	***12.5***	***4.9***	***27.5***	***1.1***	***26.8***

*Phosphorus loads were not reported in the DMRs in 2003. This number represents a calculation of total flow and average phosphorus concentrations.

**DMR data for the Chevron Texaco Products Facility (NPDES Permit MS0001481) contained outliers and were excluded from the ammonia load calculations.

The annual total loadings of TN and TP to U.S. surface waters were estimated by multiplying the refinery median flow of 4.26 MGD by the total number of direct discharging refineries (135) in the year 2000 and by the median TP and TN concentrations and a conversion factor of 8.34 (to convert mg/L to lb/MGD). The resulting estimated annual nutrient loadings discharged to surface waters of the United States by the petroleum refining industry are as follows:

- TP = 1,768,000 lb/year;
- TN = 14,618,000 lb/year.

This estimate does not include discharges of nutrients by refineries discharging to POTWs. EPA identified 21 refineries as indirect dischargers (EPA, 2004). These indirect discharger loadings are captured in the estimates of the POTW contributions of nutrients to surface waters described in the next section of this report.

Table 3—DMR Effluent Concentrations (in mg/L) for Various Forms of Nitrogen*

Year	Nitrogen, Kjeldahl Total (as N)	Nitrogen, Nitrate Total (as N)	Nitrogen, Organic Total (as N)	Nitrogen, Total (as N)
1998	NA	63.3	NA	0.9
1999	NA	3.6	NA	0.5
2000	0.5	10.9	NA	0.8
2001	1.3	9.0	NA	0.7
2002	0.7	21.7	2.0	1.7
2003	1.7	6.7	2.6	NA
2004	0.5	11.9	2.7	NA
2005	0.8	7.5	2.5	NA
2006	5.9	7.4	3.0	NA
2007	3.0	7.0	3.4	19.3
2008	5.0	7.6	3.2	20.6
2009	3.6	6.8	2.8	9.7
2010	2.2	10.2	3.0	21.3
Average	***2.3***	***13.4***	***2.8***	***8.4***

*Nitrate-N data from three refineries; TKN and TN data from two refineries; Organic Nitrogen from one refinery.

Table 4—TPDES Permit Application Data for Nutrients (mg/L)

TPDES Permit No.	Average Flow (MGD)	Total Phosphorus (as P)	Ammonia Nitrogen (as N)	Organic Nitrogen (as N)	Nitrate Nitrogen (as N)
TX0005835	13.8	0.83	<0.2	1.41	4.76
TX0088331	1.5	1.03	0.23	1.84	14.1
TX0009148	7.1	2.72	NA	2.47	7.48
TX0002976	1.4	1.72	1.9	1.13	22.5
TX0005991	15.8	0.96	0.1	4.1	0.05
Median	***7.1***	***1.03***	***<0.21***	***1.84***	***7.48***

Other Point Source Nutrient Loadings

All point sources, both industrial and municipal (POTW), discharge some quantity of the nutrients TP and TN. The TN and TP characteristics of treated wastewaters discharged by POTWs and several of the most important industrial categories were estimated from literature sources to calculate nationwide nutrient loadings from these sources.

Municipal Treatment Plants (POTWs)

The TN and TP concentration data for municipal wastewater were compiled from literature sources. Table 5 presents a summary of the compiled data for POTWs at three increasingly stringent levels of treatment.

Table 5—Municipal Point Source Nutrient Concentrations (mg/L)

CATEGORY	TOTAL NITROGEN	TOTAL PHOSPHORUS
Municipal Secondary Treated Domestic Wastewater[a]	15.3*	3.4
Municipal Tertiary Treated Domestic Wastewater[a]	15.9*	0.1
Municipal BNR Domestic Wastewater[b]	2–12	0.1–0.5

*Value is approximate and was estimated based on nitrogen forms reported (i.e., TN = TKN + NO_3).

**BNR denotes Biological Nutrient Removal.

[a] Metcalf & Eddy (2003), p. 1384, Table 13-16.

[b] Metcalf & Eddy (2003), p. 1386, Table 13-17.

All of the POTWs in the United States treat to secondary treatment or higher levels.

The total volume of treated municipal wastewater discharged in the United States in 1995 has been estimated as 1.5×10^7 million gallons (FAO, 2013). Based on census records, the U.S. population increased by 5 % between 1995 and 2000, the year of the PCS database used to estimate the refinery nutrient loadings. The total volume of treated municipal wastewater used in this projection of nutrient loads was adjusted to 1.5×10^7 million gallons/year to represent the year 2000 loadings.

Review of EPA and other literature references provided an estimate of the fractions of POTWs applying secondary treatment, advanced treatment for total phosphorus, and advanced treatment for TN. Based on EPA's compilation of POTW data, these fractions are estimated as 0.72, 0.19, and 0.09, respectively (EPA, 2013).

Table 6 presents the estimated POTW loadings of TP and TN discharged to waters of the United States in the year 2000 in million pounds/year (Mlb/year).

Table 6—Municipal Point Source Nutrient Loads (Mlb/year)

CATEGORY	TOTAL NITROGEN	TOTAL PHOSPHORUS
Municipal Secondary Treatment	1440	321
Municipal Phosphorus Removal	381	2.49
Municipal Nitrogen + Phosphorus Removal	5.9	1.18
Total Municipal	1880	325

Other Industrial Point Source Categories

Most industries also discharge TN and TP to surface waters as a result of their manufacturing operations. The two largest industrial categories, in terms of total volumes of treated effluent discharged and their corresponding nutrient mass loadings, are the organic chemicals industry and the pulp and paper industry. Both of these industries generate wastewaters requiring biological treatment, but their untreated wastewaters are typically nutrient deficient for successful biological treatment to remove oxygen-demanding substances. Thus, plants in these industries add chemicals to the raw wastewater ahead of treatment to supply nitrogen (usually as a form of ammonia-nitrogen) and phosphorus to ensure that their biological treatment systems operate properly. The amounts of nutrients added to ensure adequate treatment are typically based on maintaining effluent concentrations of TN and TP of 3–5 mg/L and 1 mg/L, respectively. Therefore, for the purposes of this comparison, it is assumed that treated wastewaters from the organic chemicals industry and pulp and paper industry will contain TN and TP concentrations of 5 mg/L and 1 mg/L, respectively.

Two other industrial categories, textiles and canned and preserved fruits and vegetables, are included in the industrial nutrient discharge estimates in this study because both categories have relatively elevated effluent TP and TN concentrations. Their total nutrient loadings on a nationwide basis are low, however, because their total wastewater flows are low.

There are other industrial categories that discharge nutrients, but, in general, their contribution to the total nutrient loadings to U.S. surface waters is lower than organic chemicals, pulp and paper, and petroleum refineries. For example, the steam electric power industry is the largest industrial user and discharger of surface water; however, the vast majority (greater than 90 %) of this industry's wastewater flow is once through cooling water that does not contribute nutrients to surface waters (although it may transfer nutrients from one location to another in a water body or between water bodies).[4] Industries such as inorganic chemical manufacturing and iron and steel manufacturing typically do not have significant amounts of nutrients in their wastewater discharges (although certain subcategories in these industries may contain significant TN or TP in their discharges). For this comparison of national nutrient loadings, these other industries are grouped because sufficient reliable information to estimate their nutrient contributions is difficult to find, and they are not expected to increase total national point source loadings estimates substantially in comparison with the organic chemicals and pulp and paper industry contributions.

Table 7 presents the estimated contributions of TN and TP from the organic chemicals and pulp and paper manufacturing industries along with two other industries, textiles and canning, relative to nationwide loading contributions from petroleum refining.

[4] Power plants that use recirculating cooling systems may discharge phosphate-containing chemicals that are added for water treatment.

Table 7—Industrial Point Source Nutrient Loads (Mlb/year)

CATEGORY	TOTAL NITROGEN	TOTAL PHOSPHORUS
Organic Chemicals	88.8	16.8
Pulp and Paper Manufacturing	57.4	11.5
Textile Manufacturing	1.34	0.27
Canned and Preserved Fruits and Vegetables	0.57	0.28
Petroleum Refining	14.6	1.77

Nonpoint Source Nutrient Loadings

Nonpoint sources are the dominant sources of nutrient releases to U.S. surface waters. The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) studies estimate that more than 90 % of nitrogen and phosphorus released to the environment originates from nonpoint sources (Puckett, 1994; Carpenter et al., 1998; USGS, 2010a). A USGS report notes that the contribution of nonpoint sources to the TN added to major watersheds of the United States varies nationally from nearly zero in some predominantly urban watersheds to as much as 100 % in agricultural and other rural watersheds (Puckett, 1994).

Variations in the occurrence and distribution of nutrients in streams reflect, in part, differences in land use and associated nutrient sources. Nonpoint inputs, such as those from fertilizers and manure from livestock, are the major sources of nutrients in agricultural areas, whereas both point and nonpoint sources—including wastewater effluent from municipal or industrial facilities; fertilizers applied to lawns, golf courses, and parks; septic systems; and atmospheric deposition—are the major sources in urban areas (USGS, 2010a). In undeveloped areas, nonpoint inputs, such as atmospheric deposition and natural sources released by weathering of rocks and soil, typically are the largest sources (USGS, 2010a).

The Nationwide Urban Runoff Program (NURP) studied runoff between 1978 and 1983 from commercial and residential land uses in 28 urban areas and provides reliable estimates of the quality of storm water runoff from urbanized watersheds. The average TN and TP runoff concentrations estimated from this national database are 3.7 mg/L and 0.5 mg/L, respectively (51 Federal Register 41237).

In 2006, USGS issued a report that estimated the TN and TP inputs to the land surface from atmospheric deposition, agricultural and urban application of fertilizer, and land application of manure (USGS, 2006). The USGS estimates are for application rates to the land; quantities released to surface waters in nonpoint source runoff will be lower than these loadings. The fraction of the TN and TP land input that is released to surface waters has also been estimated by the USGS (USGS, 2010a). There is considerable variation based on soil properties, vegetative cover (including crops), and local hydrology, but on a nationwide basis, the assumption that an average of 25 % of the TN and TP input to the land surface is released to surface waters is consistent with the USGS study.

Based on the USGS studies, the estimates of the nonpoint TN and TP loadings to surface waters due to atmospheric deposition, fertilizer application, and manure application are shown in Table 8.

Table 8—Nonpoint Source Nutrient Loadings (Mlb/year)

CATEGORY	TOTAL NITROGEN	TOTAL PHOSPHORUS
Loadings to Land	43,294	7,786
Releases to Surface Water (25 %)	10,823	1,946

The loadings shown in Table 8 include urban runoff that is regulated by NPDES permits for Municipal Separate Storm Sewer Systems (MS4 permits).

Comparison of Nutrient Sources

The estimates of the nationwide loadings of TN and TP to surface waters for major point source categories and for nonpoint sources developed in this study are compared in Table 9 to illustrate the relative importance of each category of sources.

Table 9—Comparison of Nutrient Sources to U.S. Surface Waters

SOURCE	TOTAL N LOAD (MLB/YEAR)	TOTAL P LOAD (MLB/YEAR)	PERCENT OF TOTAL N LOAD	PERCENT OF TOTAL P LOAD
Nonpoint Sources	10,823	1,946	84.6	84.1
Municipal Wastewater	1,883	325	14.6	14.1
Organic Chemicals	83.8	16.8	0.65	0.73
Pulp and Paper	57.4	11.5	0.45	0.50
Petroleum Refining	14.6	1.8	0.11	0.08
Textiles	1.3	0.3	0.01	0.01
Canned/Preserved Fruits/Veg.	0.6	0.3	<0.01	0.01
TOTALS	***12,864***	***2,302***	***100***	***100***

As shown in Table 9 and described in the scientific literature, nonpoint sources contribute the vast majority of TN and TP discharged to U.S. surface waters. The only point source category that contributes more than 1 % of TN and TP to surface water releases is treated municipal wastewaters, which is also supported by the research on nutrient loadings.

Petroleum refinery discharges of TN and TP are estimated to constitute 0.11 % and 0.06 % of the national surface water loadings of these two nutrients.

Limitations of the Nationwide Comparison

The estimates of nationwide nutrient loading contributions by source categories are useful in determining how to allocate research, technical resources, and regulatory action to address impairments of surface water uses by nutrients. The nationwide source contributions presented in this report, however, cannot be used to assess the relative importance of nonpoint and point sources to local, watershed-specific nutrient loadings and resulting water quality conditions.

On a national basis, and indeed in the majority of surface water bodies, nonpoint sources are the predominant contributors to TN and TP loadings. There are surface waters where point source nutrient loadings are significant, however, and in some cases may be the dominant loading source. This is why water quality standards for nutrients, and their implementation, must be inherently watershed specific and even segment specific in order to ensure scientifically justified, equitable, and cost-effective control of anthropogenic nutrient enrichment.

Chapter 4—Regulation of Nutrient Discharges

EPA is requiring states to develop water quality criteria for nutrients and related measures of eutrophication to prevent designated uses of surface waters from being impaired due to excessive growth of aquatic vegetation. EPA has consistently told states that they must develop and implement nutrient criteria, either as numeric standards or as narrative criteria with a numerical translator method. EPA has required that all states adopt nutrient criteria plans and follow these plans to develop their standards. EPA's current policy is that if states have adopted a nutrient criteria plan and are on the schedule established in their plan, EPA will consider that they are making acceptable progress toward nutrient standards. If a state is not making acceptable progress, then EPA has stated that it will adopt nutrient standards for that state under the authority of the Clean Water Act (CWA).

Water Quality Criteria and Standards

Water quality criteria are required by the CWA to protect the designated uses of a surface water body [see 33 U.S.C. §1313(c)(2)(A)] and are not intended to achieve some arbitrary reference standard or goal that is not directly linked to a beneficial use. Water quality standards are not intended to return a surface water body to a "natural" condition that is perceived to have occurred before anthropogenic influences were present; they are adopted to protect the applicable beneficial uses. EPA's ecoregion nutrient criteria guidance does not attempt to correlate nutrient concentrations in surface water with effects on designated uses, and because of this, many states are reluctant to adopt these criteria as standards.

State-adopted water quality standards are required by Section 303 of the CWA. States must establish numeric or narrative water quality criteria and designated beneficial uses (a designated use and associated criteria are two parts of a standard) for all surface waters in the state. The EPA is required by Section 304(a) of the CWA to publish national water quality criteria for various pollutants, and these criteria are to be used as guidance by the states when they develop and adopt state-specific enforceable water quality standards. EPA can disapprove state water quality standards if they are judged to insufficiently protect beneficial uses and can promulgate federal standards for the state. In these cases, the EPA national criteria are typically promulgated as the applicable state standards.

Section 304(a) of the CWA gives EPA the authority and responsibility for the development of water quality criteria. Section 304(a)(2) directs EPA to develop information to be used in establishing the parameters needed to address the goals under Section 101(a) of the CWA (restore the biological, physical, and chemical integrity, as well as providing for aquatic life protection and recreation, for all surface waters of the United States). Section 304(a)(1) requires EPA to develop and publish water quality criteria guidelines. These criteria guidelines are to be based on the latest science and do not include consideration of economic impacts or technological feasibility. EPA criteria are not the standards that the CWA requires to be adopted by the states, although it is typically EPA's desire that states adopt criteria at least as stringent as the federal criteria.

Water quality standards (the designated use and the numeric or narrative criteria for specific pollutants) are important because all NPDES permits issued to point source dischargers must contain pollutant limits that are based on the state standards and ensure that the discharge will not cause or contribute to the failure of a water body to achieve its designated uses. When a permit-issuing authority determines that a discharge has a reasonable potential to cause or contribute to the exceedance of any water quality standard, the permitting authority must include WQBELs in the NPDES permit for that discharge. These WQBELs are calculated from the applicable water quality standard and will be lower than technology-based effluent limits (TBELs), if the permitted discharge already is subject to TBELs for the pollutant.

EPA Nutrient Policy and Guidance

EPA's national nutrient strategy included as a first step the development of Section 304(b) national nutrient criteria for streams and rivers, lakes and reservoirs, estuaries and coastal marine waters, and wetlands. National criteria were to be developed on an ecoregion[5] basis, in order to represent acknowledged regional differences in the potential for nutrient enrichment of surface waters. In its national nutrient strategy, and in its CWA Action Plan (March 24, 1998), EPA established a goal of having nutrient water quality standards adopted in all states by the end of calendar year 2003. This policy stated that if a state did not adopt water quality standards for nutrients by the end of 2003, EPA would promulgate its national ecoregion nutrient criteria as the state nutrient standards.

EPA Ecoregion Criteria

EPA has published the following national nutrient criteria technical guidance manuals:

- Lakes and Reservoirs, EPA-822-B00-001, April 2000.
- Rivers and Streams, EPA-822-B-00-002, July 2000.
- Estuarine and Coastal Marine Waters, EPA-822-B-01-003, October 2001.

These guidance manuals describe the methodology that EPA used to develop its ecoregion criteria and are intended to guide states in developing their water quality criteria for nutrients.

The EPA ecoregion criteria are referred to as a reference condition. The reference condition is calculated as the lowest 25th percentile of the causal variables TP and TN, and two response variables, chlorophyll-*a* and light penetration, in the surface water quality database for each ecoregion. The 25th percentile of these four variables is used to characterize a "minimally impacted" surface water condition within the ecoregion for a particular class of surface water.[6] Such calculations, using only an internal reference condition, would effectively assign an impaired designation to up to 75 % of the waters in each class of water body in an ecoregion. There is, obviously, no scientific basis for this policy assumption as no effort was made by EPA to correlate either the causal variables or the response variables to the attainment of designated uses in the water bodies used to develop the criteria.

EPA described the concept behind its ecoregion nutrient criteria in its 2001 notice of data availability (66 Fed. Reg. 1671):

> Because EPA's nutrient water quality criteria are intended to represent water quality conditions that are reflective of those **minimally impacted by human activities**, they are presumed to protect any threatened or endangered species that reside in or make use of those waters. However, there remains a small possibility that the nutrient criteria will not protect all listed endangered or threatened species. Consequently, EPA recommends that States and authorized Tribes develop more protective, site specific modifications of the criteria as necessary to protect threatened and endangered species, where sufficient data exist indicating that endangered or threatened species are more sensitive to a particular level of a nutrient parameter or over-enrichment condition than that reflected by EPA's nutrient water quality criteria. (Emphasis Added)

[5] EPA divides the nation into 14 ecoregions based on landscape-level geographic features including climate, topography, regional geology and soils, biological geography, and broad land use characterizations. EPA assumes that within an ecoregion, data from all water bodies of a similar classification (e.g., lakes) can be aggregated for nutrient enrichment evaluations.

[6] This frequency distribution criterion is applicable to freshwater lakes, reservoirs, streams, and rivers; frequency distribution is one of several reference approaches EPA allows for establishing nutrient criteria in estuaries and coastal waters.

The EPA's ecoregion water quality criteria documents are intended by EPA to serve as a starting point for states to develop more refined nutrient criteria, as appropriate, using the EPA technical guidance manuals identified above and other scientifically defensible approaches.

EPA's ecoregion nutrient criteria have a fundamental flaw, in that no attempt was made to correlate either the causal or response variables to adverse impacts on designated uses. Given that standards are to consist of designated beneficial uses of surface waters and numeric standards designed to protect such uses, the ecoregion criteria are *a priori* incomplete and cannot be used by states to establish the standards required by CWA Section 303(a). Thus, states have not adopted the ecoregion criteria published by EPA.

In 2008, EPA published a report that compiled data related to state implementation of its nutrient criteria (EPA, 2008). The report reviews actions taken by states since EPA's release of nutrient criteria guidance in 1998. The report represents EPA's 2007 commitment to periodically review state nutrient criteria development actions and report on the progress being made by states.

EPA "Urgent Call to Action"

In response to the challenges posed with adopting such stringent and overly protective criteria, an EPA and State Task Group met in 2008 to 2009 to produce the document entitled *An Urgent Call to Action: Report of the State-EPA Nutrient Innovations Task Group* (EPA, 2009b). The document discusses the scope and impact of nutrient pollution, the primary sources of nutrients, and tools and authorities and provides the Task Group's findings and recommendations. It also contains an updated description of different actions States were taking to make progress in reducing nutrient loads.

A major statutory impediment to nutrient control is that EPA and the states generally lack authority to control nonpoint sources, consisting principally of agricultural and silvicultural runoff. Thus, EPA often expects states to continue to use the NPDES permitting program as a tool to reduce nutrient loadings. The "Call to Action" report states (EPA, 2009b):

> The valid and growing perception that nutrient reduction burdens are not equitably shared or cost-effectively managed across all sources or between upstream and downstream contributors is a major barrier to accelerating progress. There is growing reluctance and resistance on the part of highly regulated entities and downstream users to pay for increasingly expensive loading reductions, even where necessary and possible, when upstream sources are not held responsible for their own nutrient contributions to the same watershed. Combating the challenge of widespread nutrient pollution will require a renewed emphasis on prevention and a profound change in how we share accountability and responsibility between sources, within watersheds, and across state lines.

Despite this accurate assessment of the limitations of its nutrient criteria approach, EPA continues to take specific actions to encourage states to use the NPDES program as the principal tool to make progress in reducing nutrient loads without quantifying the associated benefits with those actions. These efforts include the Chesapeake Bay "federal consequences letter" (described below), a letter to the Illinois Environmental Protection Agency (Illinois EPA) regarding renewal of NPDES permits, a letter to the New England Interstate Water Pollution Control Commission (NEIWPCC) regarding independent applicability of TN and TP criteria, and a recent framework memorandum to Regional Administrators about working with states to reduce nutrients.

EPA Region 5 Position Letter

In a January 21, 2011, letter to Illinois EPA, EPA Region 5 stated that the agency has "become increasingly concerned about the impact of nutrients on water quality, including impacts downstream from outfall locations" (EPA, 2011a). The letter was prompted by Region 5's review of permit applications, fact sheets, and NPDES permits for 20 Illinois point sources. EPA indicates that 40 *CFR* §122.44(d) and 40 *CFR* §123.25(a) apply whether criteria are expressed in a numeric or narrative form in state water quality standards. EPA indicated that they expect Illinois EPA to follow these regulations when developing permits for nutrient discharges. EPA requested that Illinois EPA establish by April 15, 2011, draft procedures for making permitting determinations. It is notable that EPA's letter, consistent with Agency practice, does not describe how Illinois should relate NPDES permit limits for nutrients with nutrient enrichment in downstream waters and effects of elevated nutrients on designated uses.

EPA Letter on Nutrient Criteria and Independent Applicability

The independent applicability policy for water quality standards was adopted by EPA in the early 1990s to regulate the discharge of toxic pollutants. It is included in the Federal rules at 40 *CFR* 122.44. The *Technical Support Document for Water Quality-Based Toxic Controls* (EPA, 1991) states that:

> This policy establishes that a demonstration of water quality standards nonattainment using one assessment method does not require confirmation with a second method and that the failure of a second method to confirm impact does not negate the results of the initial assessment.

NEIWPCC sent a letter to EPA (January 3, 2011) that questioned the scientific justification of the application of the Agency's independent applicability policy to nutrients, which EPA has asserted requires states to adopt numeric criteria for both nitrogen and phosphorus and that data for response variables (transparency, chlorophyll-*a*) should be disregarded when making NPDES permitting decisions regarding nutrient enrichment of a receiving water body. In other words, EPA's policy states that conflicting evidence of equal or better quality (e.g., data indicating no designated uses of a water body are adversely affected when the applicable nitrogen and phosphorus criteria are exceeded) are not to be used in the determination of a whether or not the water body is achieving its designated uses. The NEIWPCC succinctly expressed its concern regarding EPA's position on proposed Florida nutrient regulations that divorced receiving water responses to nutrient (i.e., response variables) from a requirement for concentration standards on TN and TP:

> In summary, the Northeast states believe that EPA has failed to produce sufficient scientific evidence or a viable legal or policy basis for the imposition of independent applicability of numeric nutrient criteria. In addition, the Northeast states do not agree that numeric criteria for both nitrogen and phosphorus are necessary for all water bodies. Numeric criteria should only be required for the limiting nutrient in a system unless dual limitation is demonstrated.

Because phosphorus (not nitrogen) tends to be the nutrient that limits aquatic plant growth and total biomass in freshwaters, NEIWPCC asserted that states should not have to target both nitrogen and phosphorus unless it was clear that both nutrients were causing nonattainment of beneficial uses.

In a March 1, 2011, letter, EPA responded to the letter from the NEIWPCC expressing concern about EPA's position on "independent applicability when assessing for use attainment and listing waters for nutrient impairment" (EPA, 2011b). EPA responded that because both nitrogen and phosphorus *could* be limiting for downstream waters, that states should be required to target both. EPA's reasoning was stated as follows:

> States may assess waters for nutrient response parameters (e.g., chlorophyll-*a*, Secchi depth, dissolved oxygen) in conjunction with nitrogen and phosphorus; however, relying solely on a response parameter and/or biological assessment to determine impairment may not sufficiently protect all waters. Assessing waters by evaluating the pollutants directly causing impairment (nitrogen and phosphorus) helps ensure protection of both near-field and downstream waters, and also helps prevent degradation of water quality. Some water bodies may not exhibit a local response to nitrogen and phosphorus loading due to site-specific characteristics (e.g., turbidity limits light availability and therefore primary production), the season (e.g., lower winter temperatures limit productivity), or the natural lag-time between nitrogen and phosphorus loading and a biological response. Even when a local response has not been clearly demonstrated, these waters may be discharging nitrogen and phosphorus loads to downstream waters that may exhibit a response to nitrogen and phosphorus. EPA recognizes that there is analytical, spatial, and temporal variability associated with

> environmental data, that should be considered in deriving numeric criteria for nitrogen and phosphorus. EPA can work with states to adjust the state-adopted causal parameter criteria to account for site-specific conditions that continue to ensure attainment of applicable water quality goals.

This approach means that even if states have developed biological criteria to assess whether macroinvertebrate and fish populations are healthy, or have developed numeric standards for chlorophyll-*a* and/or turbidity, EPA still expects the state to develop numeric TN and TP criteria, and assess whether ambient TN or TP levels are exceeding that criteria. This interpretation has little scientific justification and is equivalent to stating that states should adopt water quality standards for biochemical oxygen demand (BOD) in addition to their standards for dissolved oxygen, the response variable that actually affects aquatic life.

Framework Memorandum to Regional Administrators

In 2011, the EPA Office of Water sent a memorandum to its Regions (EPA, 2011c), in which the Acting Assistant Administrator for Water "urges the Regions to place new emphasis on working with states to achieve near-term reductions in nutrient loadings." The memorandum goes on to cite five reasons (e.g., medium to high levels of nitrogen and phosphorus in 50 % of the nation's streams, a rising number of reported algal blooms, assessments that suggest that 78 % of coastal waters are experiencing eutrophication, etc.) why states should move more expeditiously to adopt numeric criteria for TN and TP.

The memo reaffirms the Agency's position that:

> … numeric nutrient criteria targeted at different categories of water bodies and informed by scientific understanding of the relationship between nutrient loadings and water quality impairment are ultimately necessary for effective state programs…. numeric standards will facilitate more effective program implementation and are more efficient than site-specific application of narrative water quality standards.

The memo concludes with additional steps that states should incorporate into their framework for managing nitrogen and phosphorus pollution, including prioritization of watersheds, setting watershed load reduction goals, etc. These steps include ensuring the effectiveness of NPDES permits for point sources in priority sub-watersheds "that contribute to significant measurable [nitrogen and phosphorus] loadings." EPA expects that states will establish a work plan and phased schedule for development of "…numeric N and P criteria for at least one class of waters within the state (e.g., lakes and reservoirs, or rivers and streams) within 3–5 years (reflecting water quality and permit review cycles), and completion of criteria development in accordance with a robust, state-specific workplan and phased schedule."

EPA's Science Advisory Board Review of EPA's Methodology for Establishing Nutrient Criteria

In 2010, EPA's Office of Water requested that the Agency's Science Advisory Board (SAB) review the Agency's draft guidance document titled *Empirical Approaches for Nutrient Criteria Derivation* ("Guidance," EPA 2009a). This draft guidance was intended as an alternative to the ecoregion criteria method for developing numeric nutrient water quality standards, which focuses on the use of reference conditions for "unimpacted surface waters" for deriving nutrient criteria. The draft empirical methods guidance responded to the interest of many states in using empirically derived (based on data) stressor-response relationships as the basis for developing numeric nutrient endpoints for water quality standards.

The SAB's review (EPA, 2010c) described both positive and negative aspects of the proposed empirical methods. The SAB's review included the following conclusions:

> The Committee recognizes the importance of U.S. EPA's efforts to support numeric nutrient criteria development and encourages the Agency to continue this important work. In addition, we recognize the stressor-response approach as a legitimate, scientifically based method for

> developing numeric nutrient criteria if it is appropriately applied (i.e., not used in isolation but as part of a tiered weight-of-evidence approach using individual lines of evidence as discussed here).
>
> In general, we find that improvements in the Guidance are needed prior to its release to make the document more useful to state and tribal water quality scientists and resource managers.
>
> In general, we find that the scope, limitations, and intended use of the Guidance should be more clearly described. The Guidance addresses only one type of "empirical" approach for derivation of numeric nutrient criteria (i.e., the stressor-response framework). As illustrated in many of the examples in the Guidance, considerable unexplained variation can be encountered when attempting to use the empirical stressor-response approach to develop nutrient criteria. The final Guidance should clearly indicate that such unexplained variation presents significant problems in the use of this approach. Further, the final document should clearly state that statistical associations may not be biologically relevant and do not prove cause and effect. However, when properly developed, biologically relevant statistical associations can be useful arguments as part of a weight-of-evidence approach (further discussed in Section 3.3, recommendation #7 of this advisory report) to criteria derivation. Therefore, the final Guidance should provide more information on the supporting analyses needed to improve the basis for conclusions that specific stressor-response associations can predict nutrient responses with an acceptable degree of uncertainty. Such predictive relationships can then be used with mechanistic or other approaches in a tiered weight-of-evidence assessment including cause and effect relationships to develop nutrient criteria.

The SAB report provided numerous recommendations for improvement. The SAB report was released on April 27, 2010; EPA issued a formal response from the Administrator on May 28, 2010. The Administrator's response focused on the fact the SAB identified the approach in the guidance as "a legitimate, scientifically based method for developing numeric nutrient criteria." The Administrator's response also notes that the Agency is currently revising the guidance to address many of the comments provided by the SAB.

It is important to note the guidance reviewed by the SAB is focused on a stressor-response approach for developing nutrient criteria. This approach is one of only three approaches that states can use for development of numeric nutrient criteria; the other two approaches are the reference condition approach and the mechanistic modeling approach. However, given the emphasis on the stressor-response approach, this may be the one currently preferred by EPA.

In November 2010, EPA published the final guidance titled, *Using Stressor-Response Relationships to Derive Numeric Nutrient Criteria* (EPA, 2010a). One of the key points made by the SAB was that development of load-response models to determine load reductions (not numeric nutrient criteria), as is being done for the Chesapeake Bay, is a valid approach to addressing impairments. EPA, however, continues to insist that development of independently applicable numeric nutrient criteria is needed. EPA did not address this issue explicitly in the final guidance, presumably because it conflicts with its long-stated policies on nutrients.

Nutrient Status and Trends in the United States

The CWA gives states the primary responsibility for protecting and restoring surface water quality. CWA Section 305(b) requires each state to report biennially on the water quality and use attainment for all of its surface waters. The state must also identify specific surface water bodies that are not achieving their designated uses on the state's CWA Section 303(d) list of impaired waters. EPA has issued guidance to states recommending they combine these two responsibilities into a single integrated report because findings were not always consistent (EPA, 2015a). Most states are moving toward the integration of their 305(b) and 303(d) reports. However, EPA guidance on integration is relatively new, and states are not required to integrate their reports. Because 303(d) lists require public comment and EPA approval, this process may delay the development of the 305(b) report, so states sometimes prepare separate 303(d) and 305(b) reports (EPA, 2015a).

Nutrient-impaired Surface Waters

EPA has a website titled "National Summary of Impaired Waters and TMDL Information" to summarize impaired waters, causes of impairments, and approved TMDLs reported by states in the 305(b) and 303(d) reports (EPA, 2010d; EPA, 2011d). The website includes tabulations of the rivers, lakes, reservoirs, and estuaries that have been identified by the states as being impaired due to nutrients. Tables 10, 11, and 12 are summary tabulations EPA has prepared for rivers, lakes/reservoirs, and bays/estuaries, respectively. One important caution to observe when reviewing these data is that states have their own, independent assessment methods for determining if a surface water body is impaired due to nutrient-related causes. Though impairments related to low dissolved oxygen concentrations, elevated pH values, and diurnal swings in these response variables may be consistent among states, consistency among state impairments based on visual observation, chlorophyll-*a* concentrations, or TN and TP concentrations is much less likely.

In the case of rivers (Table 10), many states have only assessed a fraction of their total river miles for attainment of designated uses. The percentage of assessed river miles in a state that are identified as impaired due to nutrients may be misleading if states are targeting for assessment those rivers that are likely to be impaired because of known pollutant loadings and/or their proximity to population centers. Hawaii is a good example—the state identifies 59 % of assessed rivers as being impaired by nutrient-related causes but has assessed only 5 miles of river as impaired (0 % of stream miles in the state).

As shown in Table 11, states typically have assessed a much greater fraction of their lake/reservoir areas and some have identified significant portions of lake surface area as impaired by nutrient-related causes. This is understandable, because as described in Chapter 2, lakes and reservoirs effectively capture and accumulate the majority of TN and TP that enter them.

Bays and estuaries that are shown as impaired by nutrients are strongly weighted by Long Island Sound and Chesapeake Bay (Table 12). States such as Virginia, Delaware, and Connecticut show high percentages of nutrient-impaired estuarine and bay waters, while other states with substantial surface areas of bays and estuaries (e.g., Texas, Louisiana, Alabama) have relatively low fractions of bay/estuarine waters that are assessed as impaired by nutrients. Table 12 also shows the importance of each state's methods for assessing nutrient impairment. Maryland, which borders substantial portions of Chesapeake Bay, reports zero (0) percent of bay/estuarine waters as impaired by nutrients, while Delaware and Virginia, both of which also include Chesapeake Bay as surface waters within their jurisdiction, report 98 % and 91 % of their estuarine/bay waters as impaired by nutrient-related impacts.

United States Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Report on Nutrients in the Nation's Streams and Groundwater, 1992–2004

In 2010, the USGS produced a report on nutrients in the streams and groundwater of the United States based on data collected from 1994 to 2004 (USGS, 2010a). The overall finding from the USGS report, related to surface waters, was that nutrient concentrations in streams and groundwater in basins with significant agricultural or urban development are substantially greater than naturally occurring background levels. For example, median concentrations of TN and TP in agriculturally impacted streams are about six times greater than background levels. Findings also indicate concentrations in streams typically were two to 10 times greater than EPA's ecoregion nutrient criteria. This latter finding is consistent with the expectation that EPA's methodology for its ecoregion criteria assumes by design that 75 % of surface waters will not meet the criteria. USGS did not attempt to determine if the surface waters surveyed achieved their designated uses.

Table 10—Rivers Assessed as Impaired by Nutrient-related Causes

State	Rivers assessed (miles)	% of river miles assessed	Rivers with a nutrient-related impairment (miles)	% of assessed rivers that have a nutrient-related impairment	% of nutrient-impaired rivers that have all impairments addressed by a TMDL or alternative restoration plan	Reporting Cycle (year)
Alabama	10,538	14%	1,146	11%	53%	2010
Alaska	602	0%	15	2%	100%	2010
Arizona	2,764	3%	144	5%	6%	2008
Arkansas	9,979	11%	1,440	14%	2%	2008
California	32,803	16%	13,350	41%	±	2004
Colorado	59,639	56%	281	0%	14%	2010
Connecticut	2,367	41%	2	0%	73%	2010
Delaware	2,506	100%	2,208	88%	37%	2006
Florida	10,476	20%	5,587	53%	0%	2010
Georgia	13,393	19%	1,272	9%	78%	2010
Hawaii	9	0%	5	59%	±	2006
Idaho	60,291	52%	7,160	12%	61%	2008
Illinois	15,424	18%	4,430	29%	1%	2006
Indiana	24,070	67%	2,188	9%	0%	2010
Iowa	20,075	28%	304	2%	27%	2010
Kansas	27,408	20%	15,095	55%	±	2008
Kentucky	10,774	22%	1,878	17%	0%	2010
Louisiana	9,484	14%	4,469	47%	27%	2010
Maine	61,795	100%*	486	1%	9%	2010
Maryland	6,331	72%	0	0%	±	2002
Massachusetts	2,745	28%	749	27%	2%	2010
Michigan	76,439	100%*	2,003	3%	26%	2010
Minnesota	14,558	16%	1,978	14%	2%	2010
Mississippi	3,853	5%	200	5%	80%	2010
Missouri	16,516	32%	1,446	9%	±	2010
Montana	20,242	11%	7,692	38%	3%	2010
Nebraska	8,672	11%	34	0%	±	2010
Nevada	4,490	29%	1,007	22%	2%	2006
New Hampshire	16,896	100%	789	5%	7%	2010
New Jersey	18,974	96%	7,864	41%	9%	2010
New Mexico	6,262	6%	1,125	18%	15%	2010
New York	27,280	52%	1,857	7%	±	2010
North Carolina	12,080	32%	242	2%	±	2010
North Dakota	54,606	100%	518	1%	6%	2010
Ohio	52,483	90%	30,427	58%	±	2010
Oklahoma	12,473	16%	2,366	19%	0%	2010
Oregon	46,038	40%	18,959	41%	±	2006
Pennsylvania	86,034	100%*	3,722	4%	0%	2006
Rhode Island	917	65%	53	6%	0%	2010
South Carolina	5,378	18%	559	10%	8%	2010
South Dakota	6,207	7%	408	7%	0%	2010
Tennessee	30,629	50%	3,631	12%	4%	2010
Texas	23,546	12%	2,048	9%	0%	2010
Utah	10,569	12%	968	9%	58%	2010
Vermont	5,555	78%	19	0%	32%	2008
Virginia	17,728	35%	1,941	11%	2%	2010
Washington	1,997	3%	396	20%	0%	2008
West Virginia	18,818	58%	163	1%	3%	2010
Wisconsin	15,132	18%	2,593	17%	45%	2006
Wyoming	7,504	7%	57	1%	0%	2010

Note - "Nutrient-related" impairment includes waters impaired for nutrients, algal growth, ammonia, noxious aquatic plants, and organic enrichment/oxygen depletion. Impaired waters include those from Integrated Reporting Categories 4 (mostly with a TMDL) and 5 (need a TMDL). Values are rounded to the nearest whole number. Therefore, values < 0.5% = 0% and values > 99.5% = 100%. Data pertaining to % of assessed waters that have a nutrient-related impairment are likely an underestimate given that states may not necessarily assess each water for nutrients, specifically.

± These states have not provided the necessary information in their data submission to distinguish between Category 4 and Category 5 impaired waters, therefore these data were not reported.

* In some cases the state erroneously reported a greater # of waters assessed than the total # of waters in the state, resulting in > 100% assessed, as indicated by the 100%*.

Source: State's most recent electronic Integrated Report or 305(b) Report data submitted to the EPA's Assessment, TMDL Tracking And ImplementatioN System (ATTAINS) website. Date of data pull: 11/4/11

Table 11—Lakes/Reservoirs Assessed as Impaired by Nutrient-related Causes

State	Lakes/reservoirs assessed (acres)	% of lakes/ reservoirs assessed in the state	Lakes/reservoirs with a nutrient-related impairment (acres)	% of assessed lakes/reservoirs that have a nutrient-related impairment	% of nutrient-impaired lakes/reservoirs that have all impairments addressed by a TMDL or alternative restoration plan	Reporting Cycle (year)
Alabama	430,976	88%	81,740	19%	53%	2010
Alaska	5,981	0%	1,137	19%	73%	2010
Arizona	114,976	34%	4,895	4%	9%	2008
Arkansas	64,778	13%	6,513	10%	71%	2008
California	1,051,246	50%	473,954	45%	±	2004
Colorado	155,399	95%	10,211	7%	0%	2010
Connecticut	30,438	47%	3,719	12%	7%	2010
Delaware	2,954	100%	2,594	88%	69%	2006
Florida	1,124,399	54%	919,000	82%	0%	2010
Georgia	349,375	82%	6,932	2%	20%	2010
Hawaii	No data	No data	No data	No data	No data	2006
Idaho	223,244	48%	150,119	67%	9%	2008
Illinois	146,732	47%	131,114	89%	3%	2006
Indiana	231,083	100%*	23,408	10%	±	2010
Iowa	178,265	88%	28,736	16%	34%	2010
Kansas	255,902	100%*	207,460	81%	±	2008
Kentucky	219,418	96%	9,485	4%	0%	2010
Louisiana	668,847	62%	89,605	13%	22%	2010
Maine	1,984,170	100%*	36,533	2%	76%	2010
Maryland	18,676	24%	0	0%	±	2002
Massachusetts	85,056	56%	19,826	23%	22%	2010
Michigan	872,179	98%	6,048	1%	3%	2010
Minnesota	3,758,412	84%	480,679	14%	1%	2010
Mississippi	36,807	7%	0	0%	0%	2010
Missouri	290,442	99%	167,979	58%	±	2010
Montana	533,651	63%	180,267	34%	2%	2010
Nebraska	138,672	50%	105,220	76%	±	2010
Nevada	299,148	54%	54,765	18%	±	2006
New Hampshire	185,273	100%	47,215	25%	0%	2010
New Jersey	47,846	66%	16,640	35%	17%	2010
New Mexico	62,978	6%	10,007	16%	0%	2010
New York	535,659	68%	151,206	28%	±	2010
North Carolina	176,466	57%	71,951	41%	±	2010
North Dakota	700,259	98%	140,550	20%	3%	2010
Ohio	21,134	100%*	0	0%	±	2010
Oklahoma	604,594	58%	424,172	70%	±	2010
Oregon	138,358	22%	126,335	91%	±	2006
Pennsylvania	No data	No data	No data	No data	No data	2006
Rhode Island	15,582	75%	2,385	15%	54%	2010
South Carolina	127,397	31%	23,638	19%	0%	2010
South Dakota	135,577	18%	11,322	8%	0%	2010
Tennessee	565,543	99%	38,066	7%	±	2010
Texas	1,461,997	73%	25,998	2%	0%	2010
Utah	468,877	97%	150,431	32%	18%	2010
Vermont	229,722	100%	139,927	61%	8%	2008
Virginia	112,677	75%	47,165	42%	0%	2010
Washington	464,530	100%*	37,031	8%	0%	2008
West Virginia	13,199	59%	96	1%	100%	2010
Wisconsin	678,111	36%	260,011	38%	90%	2006
Wyoming	18,924	6%	15	0%	0%	2010

Note - "Nutrient-related" impairment includes waters impaired for nutrients, algal growth, ammonia, noxious aquatic plants, and organic enrichment/oxygen depletion. Impaired waters include those from Integrated Reporting Categories 4 (mostly with a TMDL) and 5 (need a TMDL). Values are rounded to the nearest whole number. Therefore, values < 0.5% = 0% and values > 99.5% = 100%. Data pertaining to % of assessed waters with a nutrient-related impairment are likely an underestimate given that states may not necessarily assess each water for nutrients, specifically.

± These states have not provided the necessary information in their data submission to distinguish between Category 4 and Category 5 impaired waters, therefore these data were not reported.

* In some cases the state erroneously reported a greater # of waters assessed than the total # of waters in the state, resulting in > 100% assessed, as indicated by the 100%*.

Source: State's most recent electronic Integrated Report or 305(b) Report data submitted to the EPA's Assessment, TMDL Tracking And ImplementationN System (ATTAINS) website. Date of data pull: 11/4/11

Table 12—Bays/Estuaries Assessed as Impaired by Nutrient-related Causes

State	Bays/estuaries assessed (mi^2)	% of bays/estuaries assessed in the state	Bays/estuaries with a nutrient-related impairment (mi^2)	% of assessed bays/estuaries that have a nutrient-related impairment	% of nutrient-impaired bays/estuaries with a TMDL or alternative restoration plan	Reporting Cycle (year)
Alabama	734	100%*	0	0%	0%	2010
Alaska	31	0%	1	2%	100%	2010
California	904	42%	30	3%	±	2004
Connecticut	612	100%	305	50%	59%	2010
Delaware	30	7%	29	98%	10%	2006
Florida	5,317	100%*	1795	32%	0%	2010
Georgia	63	7%	14	22%	100%	2010
Hawaii	36	65%	30	83%	±	2006
Louisiana	4,954	65%	858	17%	22%	2010
Maine	156	5%	1	0%	0%	2010
Maryland	2,499	99%	0	0%	±	2002
Massachusetts	247	99%	53	21%	21%	2010
Mississippi	No data	No data	No data	No data	No data	2010
New Hampshire	99	100%	14	14%	0%	2010
New Jersey	740	97%	158	21%	9%	2010
New York	1,222	80%	152	12%	±	2010
North Carolina	2,932	94%	133	5%	±	2010
Oregon	No data	No data	No data	No data	No data	2006
Rhode Island	159	100%	49	31%	0%	2010
South Carolina	588	100%*	14	2%	23%	2010
Texas	6,011	100%*	614	10%	0%	2010
Virginia	2,301	92%	2096	91%	0%	2010
Washington	No data	No data	No data	No data	No data	2008

Note - "Nutrient-related" impairment includes waters impaired for nutrients, algal growth, ammonia, noxious aquatic plants, and organic enrichment/oxygen depletion. Impaired waters include those from Integrated Reporting Categories 4 (mostly with a TMDL) and 5 (need a TMDL). Values are rounded to the nearest whole number. Therefore, values < 0.5% = 0% and values > 99.5% = 100%. Data pertaining to % of assessed waters with a nutrient-related impairment are likely an underestimate given that states may not necessarily assess each water for nutrients, specifically.
± These states have not provided the necessary information in their data submission to distinguish between Category 4 and Category 5 impaired waters, therefore these data were not reported.
* In some cases the state erroneously reported a greater # of waters assessed than the total # of waters in the state, resulting in > 100% assessed, as indicated by the 100%*.
Source: State's most recent electronic Integrated Report or 305(b) Report data submitted to the EPA's Assessment, TMDL Tracking And ImplementatioN System (ATTAINS) website. Date of data pull: 11/4/11

The report also provides information on nutrient sources. The principal finding was that nutrient concentrations in streams are directly related to land use, associated fertilizer applications, and human and animal wastes in upstream watersheds. TN concentrations are higher in agricultural streams than in streams draining urban, mixed land use, or undeveloped areas, with a median concentration of about 4 mg/L—about six times greater than report background concentrations[7]. TN concentrations in agricultural streams generally were highest in the Northeast, Midwest, and the Northwest, which have some of the most intense applications of fertilizer and manure in the nation. Surface water TN concentrations in parts of the Midwest are exacerbated by subsurface tile drains, installed to improve dewatering of poorly drained soils. Atmospheric deposition, such as occurs in the Northeast, accounts for a significant portion of the TN in streams in some relatively undeveloped watersheds.

TN concentrations are lower in urban streams than in agricultural streams, with a median concentration of less than 2 mg/L, but are still about three times greater than background concentrations. Some of the highest concentrations of TN in urban streams were measured downstream of municipal wastewater treatment facilities.

TP concentrations were greatest in streams in agricultural and urban areas, with a median concentration of about 0.25 mg/L—about six times greater than background concentrations. Like nitrogen, high

7 The report determined background concentrations for streams to be 0.034 mg/L TP and 0.058 mg/L TN (USGS, 2010a). By comparison, EPA's ecoregion stream criteria range from 0.01 to 0.076 mg/L for TP and 0.12 to 2.18 mg/L for TN (EPA, 2007).

concentrations of phosphorus in agricultural settings are associated with high applications of fertilizers and manure. Urban sources may include treated wastewater effluent, sanitary and combined sewer overflows, and septic system drainage (in less urbanized settings), as well as runoff from residential lawns, golf courses, and construction sites.

The report concludes that nutrients are an issue and the level of nutrients entering receiving waters is not decreasing. The report indicates the largest contributors are nonpoint sources, and one major source is agriculture, especially in areas that rely heavily on tile drains.

The TMDL Process for Impaired Waters

Water quality monitoring programs provide the data and information needed to assess the condition of a surface water body and to identify changes or trends in water quality that indicate either an existing problem or a potential water quality problem. If monitoring data show that a water quality standard is exceeded, the water body is placed on the CWA 303(d) list—a database of impaired water bodies. Section 303(d) requires that states develop a list of impaired surface waters that will require evaluation and implementation of a TMDL for causative pollutant(s) or condition(s) to remove the impairments. When a TMDL is required, it often means that point sources of the causative pollutant will have to reduce their current loadings even if they already have TBELs or WQBELs for the subject pollutant in their current permit.

TMDLs establish the allowable pollutant load that can enter a water body based on the relationship between in-stream conditions and pollutant loading from point sources (i.e., confined sources such as outfalls, pipes, ditches) and nonpoint sources (i.e., diffuse sources such as residential lawns, roads, agricultural fields). This allowable loading represents the maximum quantity of the pollutant that the water body can receive without exceeding water quality standards. The TMDL consists of wasteload allocations for point sources and load allocations for natural background conditions and nonpoint sources. The TMDL also takes into account a margin of safety, which reflects the uncertainty in predicting how well pollutant reduction will result in meeting water quality standards.

Once a TMDL has been adopted, the TMDL is implemented through point source controls and nonpoint source controls. Point source controls typically consist of more stringent permit limits on effluent discharges that are established and enforced through the NPDES permit program under Section 402 of the CWA. NPDES permit limits and water quality goals in the case of impaired waters are linked by the Section 303(d) program; therefore, revisions in NPDES permits for discharges to impaired waters must be consistent with TMDL allocations. Nonpoint source controls typically consist of BMP installations (e.g., buffer strips in watershed) or restorations (e.g., stream bank restoration) that are implemented through voluntary programs, partnerships, and grants under Section 319 of the CWA. The regulatory authority may allow water quality trading between a point source and a nonpoint source or between point sources in order to reduce pollutant loading to a water body.

As stated earlier, one of the major deficiencies of the CWA rules is that there is no permitting regulation for nonpoint sources and agricultural runoff is specifically exempted from permitting. Thus, TMDLs often will result in stringent limits for causative pollutants in point source discharges that require permitting, while the nonpoint sources are addressed through voluntary BMPs with no enforcement mechanism.

As EPA pointed out in its “Call to Action” paper (EPA, 2009b), this dichotomy between enforceable permit limits for point sources and voluntary actions by nonpoint sources results in inequitable treatment that is disproportionate to the relative contributions of the two source categories. Point sources can be required to reduce effluent loadings of TN and TP to very low levels by installing expensive treatment (both capital and operating costs are high), even though for receiving water bodies dominated by nonpoint source nutrient loadings these reductions may have essentially no effect on water quality.

Chapter 5—Summary and Conclusions

This analysis was commissioned by API to give member companies and the public a better understanding of the water quality problems associated with nutrient discharges to the nation's surface waters, the current federal and state regulatory responses to nutrient-related water quality problems, the scientific and implementation challenges of nutrient controls, and the petroleum refining industry's relative contribution to nationwide nutrient discharges to surface waters. The principal finding of this analysis is that the overwhelming majority of TN and TP nutrient loadings to surface waters is from nonpoint sources. A significant contribution also comes from municipal wastewater effluents. Petroleum refineries contribute only 0.1 % of the nationwide TN loading and only 0.08 % of the nationwide TP loading to surface waters. Clearly, nutrient control efforts targeting the petroleum industry, though perhaps important in specific circumstances, will not resolve the majority of nutrient impairments of our nation's waters; control efforts must focus on reductions in nonpoint source and municipal nutrient loadings if meaningful gains in water quality are to be achieved.

Nutrient enrichment of U.S. surface waters that leads to excessive growth of aquatic plants is one of the major causes cited by the states and EPA for nonattainment of designated uses and associated water quality standards. Since 2000, EPA has provided numerous reports and guidance documents to assist and pressure states into adopting and implementing numeric water quality standards for nutrients, specifically for TN and TP. Because of the scientific challenges of setting numeric standards states have generally been slow in adopting such standards, and when they do, they are often limited to a subset of the state's surface waters.

Adverse water quality impacts from nutrient enrichment that result in impairment of designated uses for surface waters is a very complex scientific issue that is inherently water body specific. Very few states have followed EPA's recommendation to adopt independently applicable TN and TP standards because there is little scientific support for such an approach. However, because states continue to identify ever increasing numbers of their surface waters as impaired due to nutrient enrichment, EPA will continue to encourage them to adopt numeric nutrient standards, establish water body–specific maximum allowable loadings through the TMDL process for impaired waters, and determine reasonable potential to exceed numeric standards for unimpaired waters.

The overarching problem with controlling nutrient releases to surface waters is that nonpoint source discharges are exempted from permitting under the CWA but constitute, in most watersheds, the most significant sources of nutrients, sometimes by over an order of magnitude compared to point sources. Because point sources must obtain NPDES permits to discharge, they are much easier to regulate than nonpoint sources and may be required to implement expensive treatment that will have minimal effect on the total nutrient loads to a specific water body. The fact that there are treatment technologies for point source effluents that can achieve low effluent concentrations of both TN and TP (typically at a substantial increase in cost compared with existing treatment) renders these point sources candidates for nutrient permit limits that have little cost-benefit justification but that can be identified by EPA and the states' actions taken to reduce nutrient enrichment.

The principal conclusions that result from this evaluation are as follows:

- The type and density of aquatic plant growth in surface water bodies, which includes algae and larger plants, is influenced by the concentration of macronutrients and micronutrients in the water. In most surface water bodies, nitrogen and/or phosphorus are the nutrients that promote or limit aquatic plant growth rates and total density.

- EPA has identified TN and TP as the most appropriate nutrient parameters for assessing and controlling nutrient loadings to surface waters.

- The quantities of TN and TP discharged to, and present in, surface water bodies that result in aquatic plant growth sufficient to impair water quality and designated uses are inherently water body specific.

The physical and chemical characteristics of each water body are important determinants of the type of aquatic plants, their growth rates, and the total density of such growth sufficient to cause an impairment of water quality and one or more designated uses of the water body.

- The inherent water body–specific characteristics of nutrient enrichment have made it difficult for states to establish scientifically sound water quality standards for nutrients. Because of this difficulty, many states rely on narrative water quality standards to address nutrient enrichment.

- EPA continues to issue guidance and put pressure on states to adopt and implement numeric standards for TN and TP, in spite of the absence of a clear relationship between TN and TP and impairment of designated uses.

- EPA's most recent initiative attempts to have states adopt "independently applicable" numeric standards for both TN and TP, regardless of which nutrient is the limiting nutrient in specific surface water bodies. Many states have rejected this approach as not scientifically justified.

- The enrichment of surface waters with the plant nutrients TN and TP causes impairments of water quality and failure to attain designated water uses in a large number of surface water bodies in the United States, according to state assessments of water quality and use attainment.

- There have been some TMDLs adopted by states to address nutrient-impaired surface waters. In all of those completed to date, nonpoint sources have been determined to be predominant over point sources.

- This study of nutrient loading sources has estimated that on a nationwide basis:

    - 84.6 % of the TP loading and 84.1 % of the TN loading on surface waters are due to nonpoint sources.

    - Municipal wastewater effluents (POTWs) account for 14.1 % of the TP loading and 14.6 % of the TN loading.

    - The total industrial point source loadings of TP and TN are estimated at 1.3 % of the national totals.

    - Petroleum refineries contribute 0.08 % and 0.1 % of the nationwide TP and TN loadings on surface waters, respectively.

- These relative loading contributions demonstrate that nutrient control efforts must focus on reductions in nonpoint source nutrient loadings if there are to be any meaningful results in terms of reducing nutrient enrichment in the nation's surface waters.

- This analysis does not mean that point source nutrient contributions are insignificant in all water bodies and is not intended to justify no action in such instances. Rather, each water body must be evaluated by considering its physical, chemical, and biological characteristics; the point and nonpoint sources that contribute nutrients; and the effects of nutrients on aquatic plant growth before establishing limitations on TN and TP for point source discharges.

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Acknowledgments

API gratefully acknowledges the contributions of Mr. Lial Tischler, Tischler/Kocurek, Inc., and Mr. Patrick Bradley, LimnoTech, Inc., to the preparation of this report.

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