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A Strategy to Implement New Dissolved Oxygen Criteria in the Delaware River Estuary

Managing, Protecting and Improving the Water Resources of the Delaware River Basin since 1961

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Background

The tidally influenced portion of the Delaware River, known as the "Delaware River Estuary," extends 133 miles from the head of tide at Trenton, N.J., to the river's outlet to the Atlantic Ocean, between Cape May, N.J., and Cape Henlopen, Del. The Delaware River Estuary, also referred to in this document as "the Estuary," thus includes both the tidal Delaware River (DRBC Water Quality Management Zones[1] 2–5) and the Delaware Bay (Zone 6), and is bordered by the Estuary states of Delaware, New Jersey, and Pennsylvania. The most-urbanized reach of the Estuary, from Philadelphia to Wilmington, Del., spans river miles (RM) 108.4 to 70 (Figure 1). This reach is referred to as the "Fish Maintenance Area" (FMA), because its original water quality standards (WQS) established by the Delaware River Basin Commission (DRBC or "Commission") included as designated uses the "maintenance of resident fish and other aquatic life," and "passage of anadromous fish," but not fish propagation (DRBC, 2022a). While DRBC's WQS also apply to the tidal tributaries within each Zone, the FMA as referenced in this document comprises the mainstem portions of Zone 3, Zone 4, and the upper portion of Zone 5.

Fish, shellfish, and other forms of aquatic life require dissolved oxygen (DO) to survive and grow, making DO among the most critical environmental parameters directly affecting the health of aquatic life. Historically, pollution in the urban corridor of the Delaware River Estuary was so severe that by the mid-1900s, the Estuary between Chester, Pa., and Philadelphia was typically anoxic (i.e., near-zero DO) from May to October. This reach was thus inhospitable to resident and migratory fish. Recognizing that in-stream DO levels that protect fish propagation could not be achieved without applying advanced wastewater treatment technologies deemed impracticable at the time, the DRBC in 1967 adopted aquatic life uses and associated DO criteria in the FMA that did not fully reflect the interim goal in Clean Water Act (CWA) Section 101(a)(2) of "water quality which provides for the protection and propagation of fish, shellfish, and wildlife and provides for recreation in and on the water." The Commission subsequently issued wasteload allocations for carbonaceous biochemical oxygen demand (CBOD) to wastewater treatment facilities discharging to the Estuary. Pursuant to enactment of the CWA in 1972, investments in wastewater treatment facilities to implement DRBC's CBOD wasteload allocations led to steadily improving Estuary DO levels. As a result of the significant DO improvement achieved by these measures, resident and migratory fish populations began to rebound, and intermittent propagation by oxygen-sensitive species has been observed in this portion of the Estuary since the 2000s (DRBC, 2015).

[1] A key to the Water Quality Management Zones assigned by the Delaware River Basin Commission to interstate waters of the Basin comprises page ii (file page 2) of the Water Quality Regulations (DRBC, 2022a).

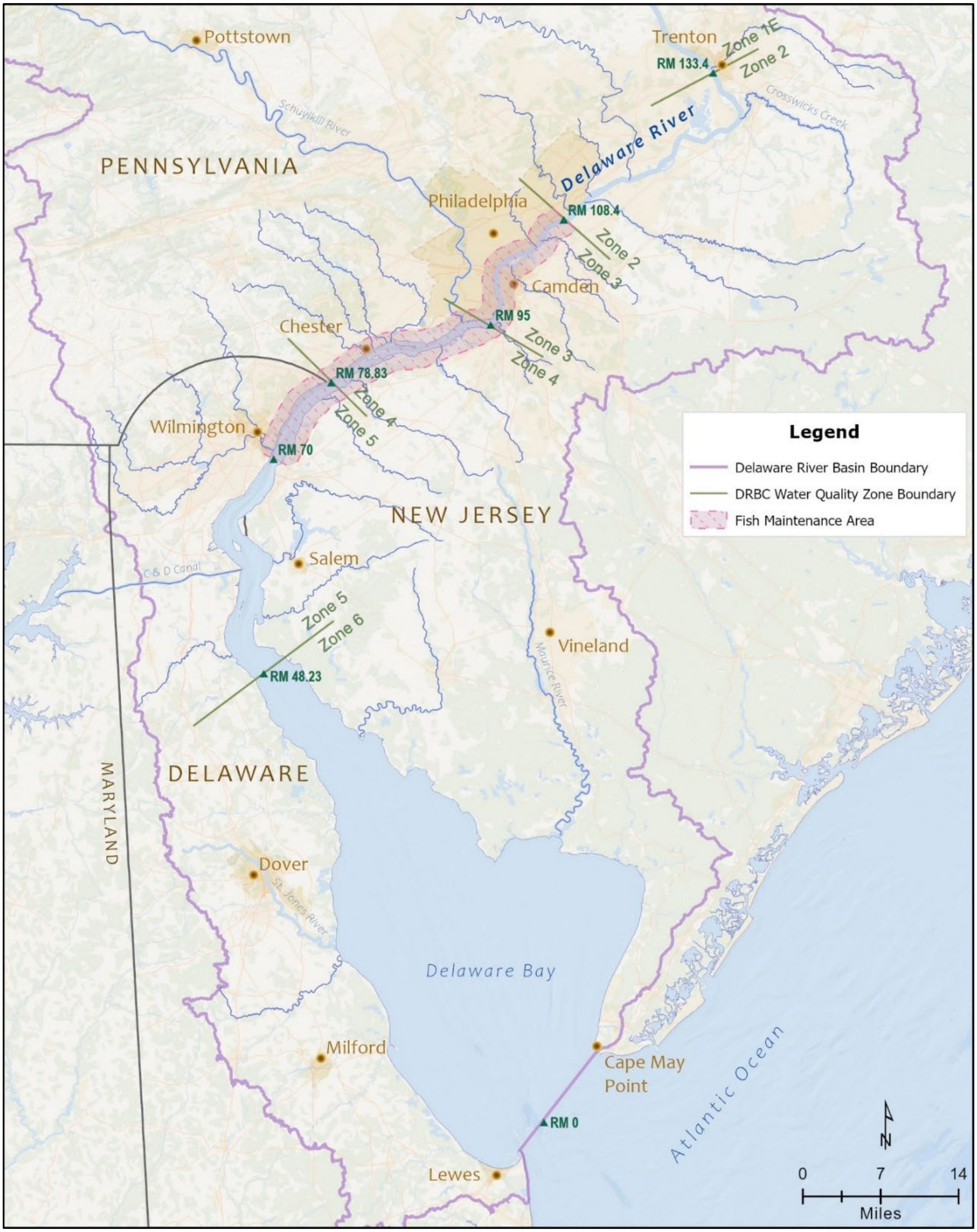

Figure 1: Delaware River Estuary and the Fish Maintenance Area

Despite this progress, DO levels in the FMA remain lower than those in the rest of the Estuary. A "DO sag" is especially pronounced in the FMA during periods of low flow and high temperatures that occur sporadically from July through September. The DRBC has actively worked to identify a pathway for increasing DO in the FMA. Through focused efforts over the course of a decade,[2] DRBC developed a three-dimensional, linked hydrodynamic and water quality model (collectively referred to as the eutrophication model) of the Estuary (Chen et al., 2024; Zheng et al., 2024). A unique and powerful tool, DRBC's model is the only technical tool currently available that can reliably relate pollutant load reductions to expected ambient DO conditions throughout the Estuary, taking into consideration the complex interactions among tides, freshwater inputs, and multiple point and non-point sources. In September 2024, DRBC published a report, *A Pathway for Continued Restoration: Improving Dissolved Oxygen in the Delaware River Estuary*, which applied the eutrophication model to demonstrate how significant improvement in DO levels might be achieved in this vital waterway (Amidon & Beganskas, 2024).

The technical analyses developed by DRBC formed part of the basis for the United States Environmental Protection Agency's (EPA's) 2022 Administrator's determination, pursuant to CWA Section 303(c)(4)(B), that revised WQS are required for the protection of aquatic life in the FMA. EPA's determination specifically concluded that these WQS must include propagation as a designated use and DO criteria to protect that use.[3] One year later, on December 21, 2023, the EPA published a notice of proposed rulemaking entitled "Water Quality Standards to Protect Aquatic Life in the Delaware River" (88 Fed. Reg. 88315) to establish WQS protective of all life stages of oxygen-sensitive species throughout the FMA, including the Atlantic Sturgeon and Shortnose Sturgeon (both of which are listed as endangered under the Endangered Species Act). EPA's final rule, published on September 29, 2025 (90 Fed. Reg. 46483), revises the aquatic life designated uses and DO water quality criteria previously applicable to the mainstem tidal Delaware River within the FMA. DRBC utilized the eutrophication model to provide multiple scenario results to EPA throughout the rule development process.

Importantly, according to EPA, its final rule supplements but does not replace the designated uses in effect for Zone 3, Zone 4, and Upper Zone 5 of the mainstem Delaware River under New Jersey and Pennsylvania regulations. Furthermore, EPA indicates that water quality criteria established by DRBC and the Estuary states for aquatic life uses in the specified zones of the mainstem, other than those for DO, also remain in effect for CWA purposes under the new rule. EPA's newly promulgated DO criteria replace the previously established DO criteria for the specified zones of the mainstem Delaware River in all three Estuary states without, according to EPA, changing any other currently applicable criteria. This strategy addresses only the implementation of EPA's new DO criteria and not any other criteria that may be applicable to the same portion of the Estuary.

EPA's new DO criteria define minimum values for percentiles of daily average DO saturation in each of three seasons: *Spawning and Larval Development* (March 1 through June 30); *Juvenile Development*

[2] https://www.nj.gov/drbc/programs/quality/designated-use.html#11

[3] https://www.nj.gov/drbc/library/documents/AnalysisAttainability/EPApetition/EPA-determination-DRNpetition120122.pdf

(July 1 through October 31); and *Overwintering* (November 1 through February 28/29). During each of these seasons, EPA established a 10th percentile criterion of 66% DO saturation, representing the value below which the average daily DO saturation may not fall for more than 10% of the season (12 days). EPA also established an additional 50th percentile criterion of 74% DO saturation for the *Juvenile Development* season. The EPA's new DO criteria are shown below.

SEASON	MAGNITUDE (% oxygen saturation)	DURATION	EXCEEDANCE FREQUENCY
Spawning and Larval Development (March 1 – June 30)	66%	Daily average	12 days cumulative (10% of 122-day season)
Juvenile Development (July 1 – October 31)	66%	Daily average	12 days cumulative (10% of 123-day season)
	74%	Daily average	61 days cumulative (50% of 123-day season)
Overwintering (November 1 – February 28/29)	66%	Daily average	12 days cumulative (10% of 120/121-day season)

This implementation strategy document outlines a technical approach that DRBC, EPA, and the three Estuary states can use to implement the new DO criteria through the National Pollutant Discharge Elimination System (NPDES) program administered by each state with oversight by EPA under the CWA. Specifically, in accordance with the Commission's Resolution for the Minutes of September 7, 2023 and in close coordination with the Estuary co-regulating states, DRBC will perform a wasteload allocation (WLA) study that will provide a basis for the states to derive and impose valid numerical effluent limitations under their respective permitting authorities in support of EPA's new DO criteria.

Technical Approach

Implementation of the new DO criteria will rely primarily on NPDES point source discharge regulation. Under Section 301 of the CWA, an NPDES permit is required to authorize "the discharge of pollutants from any point source into waters of the United States" (30 C.F.R. § 122.1(b)). NPDES permits control the discharge of pollutants to receiving waters by establishing effluent limitations, which typically consist of a magnitude (concentration or load) and an averaging period (e.g., maximum daily or average monthly). Technology-based effluent limitations (TBELs) require a minimum level of treatment that is attainable based on available treatment technologies (40 C.F.R. § 125.3(a)). For example, the DRBC Special Protection Waters (SPW) program, which protects the 197-mile non-tidal Delaware River, currently requires that any discharge directly to waters DRBC designated as SPW employ best demonstrable technology (BDT) to limit pollutant loads, including ammonia-nitrogen (1.5 mg-N/L) and DO (6.0 mg/L).

Water quality-based effluent limitations (WQBELs) are designed to ensure that the receiving water body meets applicable water quality standards and are required in cases where TBELs do not sufficiently protect water quality (EPA, 2010). To achieve the new DO criteria for the Delaware River Estuary, DRBC and the co-regulating states of Delaware, New Jersey, and Pennsylvania determined that an approach focusing on the derivation of WQBELs is appropriate, because it supports regulators in the derivation of effluent limitations necessary to ensure Estuary waters meet the new DO criteria.

Allocating assimilative capacity among multiple point sources with the goal of meeting WQS in a shared receiving water is analogous to the concept of a total maximum daily load (TMDL). Section 303(d) of the CWA requires that a TMDL be established for water bodies where WQS are not being attained, unless other pollution control requirements may obviate the need for a TMDL. It is expected that under current loads, the new DO criteria will not be attained during the *Juvenile Development* season; based on historical data from the USGS gage in Philadelphia, the new DO criteria would not have been met any of the last 25 years. Thus, the process of assigning WLAs and implementing WQBELs in discharge permits will be necessary to ensure the attainment of the new DO criteria, thereby alleviating the need for a TMDL in the future. The WLA study will closely align with the procedures for deriving WLAs in a TMDL, specifically by: (1) determining the allowable load of a pollutant that may be discharged to the water body without resulting in a violation of the WQS; and then (2) allocating pollutant loads such that the total loading, comprised of point sources and non-point sources (including background levels), remains below that allowable pollutant load (EPA, 2025a). A TMDL analysis often includes a reserve capacity for future growth, and it is anticipated that the WLA study will incorporate this concept as well.

The DRBC's eutrophication model was developed to enhance the Commission's understanding of DO conditions through dynamic (time-varying), long-term simulations of spatial and temporal DO patterns in the Estuary under different loading scenarios. It accounts for many physical, biological and chemical processes that affect ambient DO in the Estuary, including: the impacts of nitrogen and other nutrient loads; phytoplankton photosynthesis, respiration, and decomposition; reaeration; and sediment oxygen demand (SOD). The eutrophication model simulates the entire Delaware River Estuary from the head of tide at Trenton, N.J., to the Atlantic Ocean. The model's computational grid includes nearly 1,900 cells in the horizontal plane with 10 vertical layers in the navigation channel, resulting in an average grid cell resolution in the river upstream of RM 70 of 580 m along-channel by 190 m across-channel.

Previously, the DRBC determined that oxygen depletion in the FMA is driven primarily by summer ammonia-nitrogen loads from a relatively small number of point source discharges. These discharges currently meet DRBC's minimum treatment requirements (applicable to all three Estuary states), which provide that the 30-day average of effluent ammonia-nitrogen concentrations may not exceed 35 mg-N/L for discharges to the Estuary. DRBC's recent modeling work found that reducing ammonia-nitrogen loads could drive significant improvement in ambient DO levels in the FMA (Amidon & Beganskas, 2024).

Since the release of the 2024 reports, DRBC staff have enhanced the eutrophication model to further reduce uncertainty in DO predictions, with guidance from DRBC's model expert panel[4] and water quality modeling consultants.[5] One limitation of the original model was that SOD and nutrient fluxes to and from sediment were prescribed based on observed data, meaning they were assumed to remain constant over time (Zheng et al., 2024). The enhanced model incorporates a sediment diagenesis module that represents exchange at the sediment–water interface and allows for dynamic predictions of SOD rates and nutrient fluxes. A forthcoming supplemental model report will document all model modifications and the new calibration results in detail. The enhanced eutrophication model is expected to be used for the WLA study described below.

For its WLA study, DRBC will use an iterative approach to determine combinations of effluent levels that would lead to attainment of EPA's new DO criteria, aiming to provide a technical basis for Estuary states to assign WQBELs. As described above, the new DO criteria are expressed as seasonal percentiles of daily average DO in units of percent saturation. It is likely that WLAs will be expressed as average monthly concentration and/or load limits for the summer season (May through October).

DRBC's "Change Factor" methodology for estimating DO over space and time based on a combination of model output and gage data will be used to evaluate water quality in the Estuary under different loading conditions (Amidon & Beganskas, 2024, Appendix A). This approach reduces the uncertainty inherent in model output and can be used to predict DO throughout the Estuary for any year with sufficient continuous water quality monitoring data. The eutrophication model was developed and calibrated for three specific years (2012, 2018, and 2019), and with the enhanced eutrophication model and Change Factor methodology, DO for any particular loading scenario can be estimated over 16 years (2008–2024, excluding 2010[6]). DO predictions for each year capture the environmental conditions (i.e., hydrology and temperature) from that year as well as expected impacts of the particular point source loading scenario. The original Change Factor method computed seasonal DO percentiles for each of 500 modeled points in Zones 3 and 4; for the WLA study, the approach will be adjusted so that Upper Zone 5 is also included. For each criterion (e.g., 10th percentile DO saturation percentage over the *Juvenile Development* season), expected compliance will be evaluated spatially across each model point and temporally across 16 years of hydrologic conditions.

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[4] The model expert panel was comprised of nationally recognized water resource scientists and engineers: Dr. Steve Chapra (Emeritus Professor and Berger Chair, Tufts University); Dr. Carl Cerco (Research Hydrologist, US Army Engineer Research and Development Center, ret.); Dr. Bob Chant (Professor, Rutgers University Institute of Marine Sciences); and Tim Wool (USEPA Region 4 Environmental Scientist, ret.).

[5] Victor Bierman (Ph.D.) and Scott Hinz of LimnoTech.

[6] 2010 was excluded from the analysis because the USGS continuous water quality sensors in Zone 3 (at Ben Franklin Bridge) and Zone 4 (at Chester) both malfunctioned for extended periods of time (2 months and nearly one month, respectively) during the critical summer periods of that year.

The WLA analysis will be performed in four steps:

1. Sensitivity analysis: Confirm which effluent constituents have the potential to affect DO in the FMA. Preliminary sensitivity analyses presented in *A Pathway for Continued Restoration* indicate that wastewater discharges of ammonia-nitrogen and effluent DO during the summer have the most potential to impact DO levels in the FMA. A revised sensitivity analysis will be performed to test these conclusions using the enhanced eutrophication model and will determine whether additional sources or constituents, notably CBOD or phosphorus, could significantly affect DO in the FMA.

2. Base case: Develop a framework to evaluate DO criteria compliance. Natural variability in environmental conditions influences DO levels throughout the Estuary and thus may affect compliance with the new DO criteria. The base case will include a baseline model scenario that represents, to the best of present-day knowledge, near-future environmental conditions in the Estuary, including planned and ongoing improvements (e.g., reduction of combined sewer overflows [CSOs]). This model scenario will serve as a baseline on top of which various WLAs will be tested. In addition, the base case will specify the parameters and metrics that will be used to demonstrate DO criteria compliance, reflecting the amount and extent of exempted take as described in the biological opinion by the National Marine Fisheries Service (NMFS, 2024).

3. Reasonable potential analyses: Identify which discharges require effluent limitations. Water quality-based effluent limitations are required for any point source pollutant that is or may be “discharged at a level which will cause, have the reasonable potential to cause, or contribute to an excursion above any State water quality standard” (40 C.F.R. § 122.44(d)(1)(i)). The eutrophication model includes 67 point-source discharges to the Estuary. Using the enhanced model, reasonable potential analyses will be performed based on the co-regulator states’ State Pollutant Discharge Elimination System (SPDES) policies. This analysis will serve as a basis for determining which point sources will require WQBELs to ensure attainment of EPA’s new DO criteria and which point sources do not have the reasonable potential to cause an excursion of the DO criteria and therefore will not require WQBELs.

4. Multiple discharge analysis: Iteratively determine which combination(s) of effluent levels ensure the EPA’s new DO criteria will be attained. This analysis will consider the combined impact of all discharges to the Estuary, as well as background levels from non-point sources. The objective is to find which combination(s) of effluent limitations allow the new DO criteria to be attained efficiently and equitably, within institutional and legal constraints.

The EPA designates 19 methods for allocating the maximum point source load among multiple discharges; the most commonly used are equal percent removal and equal effluent concentration (EPA, 1991). DRBC’s Water Quality Regulations (Section 3.10.4.E) require that allocation of assimilative capacity respect the doctrine of equitable apportionment. Indeed, fairness is a governing principle in selecting an allocation procedure, such that all dischargers contributing to water quality impairment receive an equitable burden of treatment requirements. The DRBC, in close coordination with the co-regulating Estuary states, will determine the allocation methodology to be applied in this study.

A portion of the point source loading capacity will be set aside in reserve for future growth. Section 4.30.7(A.4) of DRBC's Water Quality Regulations allows the Commission to set aside a portion of the waste assimilative capacity of a water body to accommodate new discharges or major changes that occur after the initial allocation or any reallocation (DRBC, 2022a).

Process

DRBC staff will perform the WLA analysis in coordination with the Delaware Department of Natural Resources and Environmental Control, the New Jersey Department of Environmental Protection, the Pennsylvania Department of Environmental Protection, and the EPA. Additionally, input will be solicited from DRBC's Water Quality Advisory Committee (WQAC) as the analysis progresses. In addition to representatives from the referenced state and federal agencies, the WQAC includes representatives from the regulated community (municipal and industrial), academia, the U.S. National Park Service, a local watershed organization, and an environmental group.

Regulatory Impacts

Pursuant to 40 C.F.R. § 131.21, where a WQS in effect under state law is applicable for CWA purposes, if the EPA promulgates a more stringent standard for that state, then the EPA-promulgated standard becomes the applicable standard for CWA purposes. As such, the WQS in the EPA's final rule are effective for CWA purposes in Zone 3, Zone 4, and Upper Zone 5 of the mainstem Delaware River without further action by the DRBC or any of the three Estuary states. Importantly, DRBC and state aquatic life criteria for parameters other than DO remain in effect for CWA purposes in all three states—not only in the region covered by the EPA's final rule, but in regions of the Delaware River that already include propagation of aquatic life as a designated use. These regions include Zone 2, Lower Zone 5, and Zone 6.

With the promulgation of the EPA's rule, a mix of state and federal WQS will apply to the specified zones for CWA purposes. The new WQS will appear in EPA's web-based compilation of the state-adopted and federally promulgated standards in effect for CWA purposes in each state (EPA, 2025b). For transparency and to avoid misunderstanding, DRBC, Delaware, New Jersey, and Pennsylvania may choose to annotate the WQS set forth in their respective administrative codes by directing readers to the Federal Register notice for the EPA's final rule (90 Fed. Reg. 46483).

As noted above, implementation of the new DO criteria will primarily be the responsibility of the Estuary states, through their respective NPDES programs. Although states retain the option of adopting common measures or approaches, they are expected to individually manage the implementation of effluent limits and compliance schedules in coordination with the affected dischargers. Where implementation challenges arise, the Estuary states, DRBC, and EPA will work collaboratively with dischargers to identify solutions that facilitate permit compliance and WQS attainment.

Although the EPA promulgated a revised aquatic life designated use and protective DO criteria for Zone 3, Zone 4, and Upper Zone 5 of the mainstem Delaware River, each state—and the states jointly through DRBC—retains the option to adopt a revised designated use and DO criteria supporting that use. If each of the Estuary states, or the states jointly through DRBC, adopts WQS as stringent as (or more stringent than) EPA's, and if EPA approves the WQS as consistent with the requirements of the CWA, then the EPA will conduct a ministerial rulemaking to withdraw the use and/or DO criteria it promulgated (40 C.F.R. § 131.21(c)) and the state standards will become the applicable WQS. Similarly, if one state adopts and submits revised WQS to the EPA, and the EPA approves those WQS, then the EPA will conduct a rulemaking to withdraw the federally promulgated WQS for that state. If Delaware, New Jersey, and/or Pennsylvania were to adopt DO criteria less stringent than the federally promulgated criteria for the Estuary, and if the EPA were to approve those less-stringent criteria, then the state criteria would become the applicable criteria for CWA purposes only after the EPA withdraws its federally promulgated criteria for the relevant state(s).

Under Sections 305(b) and 303(d) of the CWA, states are required to identify waters that do not meet applicable WQS based on monitoring and assessment. The DRBC assesses attainment of mainstem WQS set forth in its Water Quality Regulations (incorporated by reference at 18 C.F.R. § 410) and will also assess against the new DO criteria for states' use. As it will take time for DRBC to prepare a WLA study, the Estuary states to establish updated WQBELs in permits, and permittees to upgrade wastewater treatment plants to meet their new WQBELs, it is likely that monitoring by the DRBC and/or states will find that EPA's new DO criteria are not consistently being met. In that event, it is anticipated that states will list the Delaware River Estuary as a "Category 4b" water for DO on their respective Section 303(d)/305(b) Integrated Reports, a classification applicable to impaired waters for which a TMDL is not necessary because other required control measures are expected to result in WQS attainment within a reasonable period of time (Monschein & Mann, 2007).

Funding

Precise WLAs, the individual WQBELs needed to effectuate the WLAs, and the costs of achieving the WQBELs are currently unknown. However, previous analyses indicate that for the most impactful discharges, achieving the ammonia-nitrogen limits required to achieve the EPA's final aquatic life WQS for Zone 3, Zone 4, and Upper Zone 5 of the mainstem Delaware River will be costly. For instance, the combined total annualized cost for the wastewater improvements identified in *A Pathway for Continued Restoration* and cited in the Potential Costs section of EPA's final rule are $185.6M/yr in 2024 dollars,[7] a figure that includes $3.1B of capital investment as well as annual operation and maintenance (DRBC, 2021). Ratepayers for several large NPDES permittees are likely to bear a portion of these costs. An affordability analysis for the scenario referenced above concluded that the distributed cost increase to ratepayers would not increase their affordability burden category as defined by either the EPA (Residential Indicator) or the American Water Works Association, National Association of Clean Water Agencies, and Water Environment Federation (Household Affordability metric) (DRBC, 2022b).

[7] The figures presented in *A Pathway for Continued Restoration* are in 2019 dollars. An inflation factor of 1.2 was applied to those figures to present them here in 2024 dollars (ENR, 2025).

The capital, operations, and maintenance costs associated with the wastewater treatment upgrades that will likely be necessary to ensure compliance with EPA's WQS are significant. Furthermore, the utilities that would need to make these upgrades are facing a host of equally costly compounding regulatory requirements and associated infrastructure upgrades. Given this reality, progress toward improving DO levels in the Estuary will require a collective and strategic approach to leverage both traditional and new funding programs and financing mechanisms to reduce the burden on ratepayers. Existing funding opportunities such as the municipal bond market and State Revolving Funds will need to be leveraged along with any public or private grant programs that can be secured through the collaboration of all stakeholders.

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