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DRAFT

ANALYSIS OF ATTAINABILITY: IMPROVING DISSOLVED OXYGEN AND AQUATIC LIFE USES IN THE DELAWARE RIVER ESTUARY

Technical Report No. 2022-X

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

Delaware River Basin Commission
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UNITED STATES OF AMERICA

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Editors' Note

The DRBC has requested comments on the draft report from: WQAC members, Estuary co-regulator agencies, Tier 1 dischargers, and DRBC Commissioners, after which the draft report will be revised to address substantive issues. The Commission also intends to contract with an engineering firm to expand feasibility and cost evaluations for effluent DO concentrations of 4, 5, and 6 mg/L. The highest attainable DO condition may be revised in the final report based on these expanded feasibility and cost evaluations.

DRBC is releasing the following supplemental draft documents in support of this draft report:

1. Modeling Eutrophication Processes in the Delaware River Estuary: Three-Dimensional Hydrodynamic Model (DRBC, 2021 Draft)

2. Modeling Eutrophication Processes in the Delaware River Estuary: Three-Dimensional Water Quality Model (DRBC, 2022a Draft)

3. Social and Economic Factors Affecting the Attainment of Aquatic Life Uses in the Delaware River Estuary (DRBC, 2022b Draft)

4. Linking Aquatic Life Uses with Dissolved Oxygen Conditions in the Delaware River Estuary (DRBC, 2022c forthcoming)

ACKNOWLEDGEMENTS

This report would not have been possible without the collaboration, cooperation and contributions of many individuals and organizations, including the following.

- The Delaware River Estuary co-regulator agencies, including staff and experts from the: Delaware Department of Natural Resources and Environmental Control (DNREC); New Jersey Department of Environmental Protection (NJDEP); Pennsylvania Department of Environmental Protection; (PADEP) and United States Environmental Protection Agency (EPA).
- Members of the DRBC Water Quality Advisory Committee.
- The Delaware River Estuary wastewater dischargers, and especially the “Tier 1” dischargers (Table 4-4), that provided valuable data throughout the study.

The DRBC staff is grateful for the technical support and direction provided by the Model Expert Panel, composed of internationally renowned engineers and scientists: Steven C. Chapra (Ph.D.), Emeritus Professor at Tufts University; Carl Cerco (Ph.D.), US Army Corps of Engineers (ret.); Robert Chant (Ph.D.), Rutgers University; and Tim Wool, USEPA Region 4 (ret.). DRBC acknowledges with appreciation the invaluable guidance received from its water quality modeling consultants, Victor Bierman (Ph.D.) and Scott Hinz of LimnoTech.

In addition to the technical study leads named on page i, DRBC staff who made valuable contributions to the study efforts at various stages of the project included Jacob Bransky, Elaine Panuccio, Fanghui Chen (Ph.D., P.E.) and Vince DePaul (on loan from USGS’s New Jersey Science Center).

Vital funding for the analysis of attainability and supporting studies consisted in part of the following:

- DRBC signatory member funding by the States of Delaware, New Jersey, and New York and the Commonwealth of Pennsylvania;
- Grant funding from the New Jersey Department of Environmental Protection and the Pennsylvania Department of Environmental Protection;
- Grant funding from EPA under Section 106 of the Clean Water Act; and
- Grant funding from the William Penn Foundation Delaware Watershed Research Fund.

EXECUTIVE SUMMARY

The Delaware River Basin Compact (Section 5.2) provides the Delaware River Basin Commission (DRBC or Commission) with the authority to “assume jurisdiction to control future pollution and abate existing pollution in the waters of the basin, whenever it determines . . . that the effectuation of the comprehensive plan so requires” and empowers the Commission to “[m]ake and enforce reasonable rules and regulations for the effectuation, application and enforcement of this compact . . . .” (Section 14.2). This report represents a significant milestone for the DRBC’s work under Resolution No. 2017-4, by which the Commissioners instructed the staff to initiate rulemaking to control pollution and improve water quality by revising the designated aquatic life uses in a 38-mile reach of the Delaware River Estuary consistent with the results of a series of studies to be performed in consultation with co-regulators and dischargers, and consistent with the goals of the federal Clean Water Act, 33 U.S.C. § 1251.

When the DRBC was created in 1961, for periods of up to six months each year, little or no dissolved oxygen (DO) was present in portions of the Delaware Estuary, the tidal section of the Delaware River extending from the head of tide at Trenton, NJ, to the mouth of Delaware Bay. In 1967, when DRBC established water quality standards for the Estuary, it effectively created two tiers of standards, both of which were aspirational. Dissolved oxygen concentrations sufficient to support “fish propagation,” a use that includes reproduction and juvenile development, were not deemed attainable within the 38-mile reach extending from Northeast Philadelphia to Wilmington, Delaware, encompassing DRBC water quality Zones 3 and 4 and upper Zone 5. Within this densely urbanized reach, the standards DRBC established thus included maintenance of resident fish and passage of migratory fish, but excluded propagation. Upstream in Zone 2 and downstream in Zones 5 and 6, the designated aquatic life uses included fish maintenance, passage *and* propagation.

Improvements in Estuary water quality and fish populations in the decades since have been remarkable, thanks in part to DRBC’s regulation in 1968 of carbonaceous biochemical oxygen demand (the driver of low dissolved oxygen in the river at that time) discharged by treatment plants; significant federal grants and subsequent investment in wastewater treatment infrastructure following adoption of the Clean Water Act in 1972; coordinated interstate and federal water quality management on an ongoing basis; and practical improvements by wastewater treatment plant engineers and operators. As a result of these efforts, DO levels in the Delaware River Estuary steadily improved, to the point where the designated uses and the oxygen levels (numeric DO criteria) established to support those uses have been achieved.

The question for the Commission, the basin states and EPA today is whether the water quality standards, consisting of designated uses and criteria to protect those uses, should now be upgraded within Zones 3 and 4 and upper Zone 5, referred to in this report as the “Fish Maintenance Area” (FMA). Under current conditions, DO levels in the FMA support fish maintenance at all times of the year, but a DO “sag” occurs during the summer months, making conditions unsuitable for propagation of certain DO-sensitive species in some years.

In summary, the work comprising this analysis of attainability, together with supporting studies, including those performed by the DRBC and those it commissioned, shows that:

- The addition of technically feasible advanced treatment by nine major wastewater treatment plants discharging to the Estuary will significantly improve the level of dissolved oxygen that can be achieved, and that water quality supporting the aquatic life use of “fish propagation” is attainable throughout the Estuary, including in the FMA.
- The capital, operations, and maintenance costs of advanced treatment associated with the recommended scenario (AA08) are significant; however, analyses using metrics developed by the EPA and by the utility industry (AWWA), respectively, indicate that the cost of adding such treatment will not increase the affordability burden category, as defined by either method, for households within the service areas of the affected treatment plants.
- The Commission should proceed with rulemaking to add fish propagation as a designated use within the reach of the Estuary currently designated for fish maintenance, and that it should adopt revised DO water quality criteria that support the new use.

This report is the culmination of five years of intensive study involving scientific and technical expertise across multiple disciplines. It was conducted in cooperation with the DRBC’s state and federal co-regulators and stakeholders, and with a high degree of transparency. Each phase of the Commission’s monitoring, modeling and analytical effort, including methodologies, assumptions and management scenarios, was presented to DRBC’s Water Quality Advisory Committee (WQAC), on which dischargers, the scientific community, environmental groups, and co-regulators are represented. The study results are supported by robust and defensible data, state-of-the-art hydrodynamic and water quality models, and cost and socioeconomic evaluations. Model development benefited from the guidance of a panel of experts who have unanimously endorsed the models developed by the DRBC team and fully endorsed the staff’s scenario results, technical findings and work products. This report is being delivered on time and in accordance with the Commission’s 2017 directive as amended in 2020.

In an early phase of this work, DRBC staff studied the existing aquatic life uses in Zones 3, 4 and 5 with respect to resident and anadromous fish species and prepared the report, *Existing Use Evaluation for Zones 3, 4, & 5 of the Delaware Estuary Based on Spawning and Rearing of Resident and Anadromous Fishes* (DRBC, 2015). Based on the results, the Commission: 1) determined that a deliberative, scientific process was needed before any change could be made to the designated aquatic life uses for Zones 3 and 4 and the upper portion of Zone 5; and 2) adopted Resolution No. 2017-4, which established a set of studies comprising an analysis of attainability (AA) to be performed, together with a schedule for their completion. The Commission has prioritized this effort, moving as quickly as possible consistent with sound scientific practices and the directive that it proceed “in close collaboration with member states, EPA Regions 2 and 3, and municipal and industrial dischargers both public and private."[1] The AA recommends a suite of pollutant reductions from among a range of tested scenarios. The recommended scenario relies primarily upon advanced wastewater treatment to reduce ammonia loads to the Estuary, which will achieve the highest attainable dissolved oxygen (HADO) condition within the FMA.

The work presented in this document identifies the pollutant reductions needed to achieve the HADO condition, with the objective of supporting fish propagation throughout the Delaware River Estuary including in areas where propagation is not currently designated as an aquatic life use. The HADO condition was determined based on wastewater treatment feasibility and resultant DO improvement in the FMA.

A fundamental step in the Commission's analysis of attainability was developing a Baseline simulation, or design condition, against which to compare scenarios. The design condition was developed to reflect point source effluent characteristics based on recent (2018–2019) data; current channel bathymetry; and environmental conditions for the year 2012, which resulted in the lowest Estuary DO condition in more than twelve years. DO conditions in the Delaware River Estuary are dynamic, varying both temporally and spatially. Staff developed multiple metrics to objectively compare scenarios and to communicate their attributes to stakeholders. Wastewater discharges were simulated at their permitted flow rates, reflecting maximum allowable wastewater loads.

After the Baseline DO condition for the entire Estuary was developed under the design conditions described above, DO sensitivity simulations for individual sources and source categories were performed. Thirteen wastewater discharges out of the 67 included in the linked hydrodynamic and water quality (eutrophication) model were identified as impactful and manageable sources based on initial screening sensitivity tests. Sequential model simulations were used to evaluate the incremental and cumulative impacts of wastewater discharges on DO in the Estuary. Through this process, nine wastewater discharges from among the thirteen were identified as contributing to low DO in the FMA. Together, these nine wastewater discharges contribute 96 percent of the total ammonia nitrogen load discharged to the Estuary by wastewater treatment point sources.

In addition to the Baseline scenario, eight load reduction scenarios were developed and characterized in terms of resultant DO improvement, estuary-wide cost, and facility-specific affordability. Of the nine scenarios evaluated, the study recommended pollutant reduction scenario AA08. This scenario includes:

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[1] DRBC, Resolution No. 2017-4 (Sept. 13, 2017), available at: www.state.nj.us/drbc/library/documents/Res2017-04_EstuaryExistingUse.pdf.

1) reduction of effluent ammonia nitrogen to 1.5 mg/L by seven wastewater treatment plants[2] located in the FMA; and 2) reduction of effluent ammonia nitrogen to 5 mg/L by two wastewater treatment plants[3] located upstream of the FMA, the discharges from which impact DO in the FMA.

The HADO condition (AA15) associated with scenario AA08 was developed incorporating: 1) full implementation of CSO long-term control plans, 2) effluent DO concentrations of 4 mg/L, 3) assumed seasonal variations of ammonia effluent levels based upon expected treatment performance, and 4) a ten percent reserve capacity for future growth. The HADO simulation results showed substantial DO improvement in the FMA. The minimum DO at the lowest point of the sag moved upstream by 10 miles and increased by approximately 2.3 mg/L, a biologically significant enhancement of the minimum DO conditions that typically occur between July and September. The DRBC's analysis, including the resulting HADO condition in the FMA, supports including propagation as an attainable designated use in the FMA.

The pre-rulemaking studies required by Resolution No. 2017-4 have been completed. A linked, three-dimensional hydrodynamic and water quality model of eutrophication processes in the Delaware River Estuary was developed, calibrated, and utilized to evaluate potential DO improvements associated with various pollutant control scenarios. Multiple sensitivity and future condition test scenario simulations were performed to identify key variables and sources to reduce the DO sag in the area near Camden and Philadelphia and to enhance overall DO conditions in the FMA. The AA not only identifies achievable DO conditions in the FMA utilizing a state-of-the-art three-dimensional water quality model under critical hydrologic and loading conditions, but also identifies the feasible treatment technologies for reducing effluent ammonia loads from specific discharges and provides cost estimates and affordability impacts.

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[2] The seven municipal wastewater treatment plants discharging within the FMA are the Philadelphia Water Department's Northeast Water Pollution Control Plant (PWD NE), Southeast Water Pollution Control Plant (PWD SE), and Southwest Water Pollution Control Plant (PWD SW), and plants operated by the Camden County Municipal Utilities Authority (CCMUA), Gloucester County Utility Authority (GCUA), Delaware County Regional Water Quality Control Authority (DELCORA), and City of Wilmington Wastewater Treatment Plant.

[3] The two wastewater treatment plants discharging within Zone 2, upstream of the FMA, are the Hamilton Township Water Pollution Control Facility and the plant operated by Lower Bucks County Joint Municipal Authority (Lower Bucks JMA).

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF ACRONYMS/ABBREVIATIONS

2D	two-dimensional (model)
3D	three-dimensional (model)
AA	analysis of attainability (aka attainability analysis)
BAF	biological aerated filter
C	carbon
CBOD	carbonaceous biochemical oxygen demand (CBODU indicates ultimate CBOD)
CCMUA	Camden County Municipal Utilities Authority
cfs	cubic feet per second
CSO	combined sewer overflow
Δ	delta (difference)
DE	Delaware
DELCORA	Delaware County Regional Water Quality Control Authority
DO	dissolved oxygen
DRBC	Delaware River Basin Commission (or Commission)
EFDC	Environmental Fluid Dynamics Code
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
FMA	Fish Maintenance Area
GCUA	Gloucester County Utilities Authority
HA	Household Affordability metric
HADO	highest attainable dissolved oxygen
IFAS	integrated fixed film activated sludge
LBCJMA	Lower Bucks County Joint Municipal Authority
MGD	million gallons per day
MS4	municipal separate storm sewer system
N	nitrogen
NJ	New Jersey
NH34	ammonia-nitrogen (aka ammonia)
NO3	nitrate-nitrogen (aka nitrate)
NPDES	National Pollutant Discharge Elimination System
NPS	non–point source

O2	Oxygen
P	phosphorus
PA	Pennsylvania
PWD	Philadelphia Water Department
RI	Residential Indicator metric
RM	river mile
RSI	Relative Stress Index metric
TN	total nitrogen
WASP	Water Quality Analysis Simulation Program
USGS	U.S. Geological Survey
Zone	DRBC water quality management Zone

1. BACKGROUND AND PURPOSE

1.1 HISTORICAL PERSPECTIVE

Water quality standards establish water body uses to be protected, as well as water quality criteria necessary to protect those uses. The water quality standards program of the Delaware River Basin Commission (DRBC or Commission) is based upon authority conferred by the Delaware River Basin Compact, the 1961 statute that created the DRBC. Section 3.2 of the Compact directs the Commission to adopt "a comprehensive plan . . . for the immediate and long range development and uses of the water resources of the basin" and to adopt "a water resources program, based upon the comprehensive plan, which shall include a systematic presentation of the quantity and quality of water resources needs of the area . . . ." Section 5.2 allows the Commission to "assume jurisdiction to control future pollution and abate existing pollution in the waters of the basin, whenever it determines . . . that the effectuation of the comprehensive plan so requires." And Section 14.2 empowers the Commission to "[m]ake and enforce reasonable rules and regulations for the effectuation, application and enforcement of this compact . . . ."

The Delaware River Estuary[4] (Figure 1-1) is divided into five water quality assessment and management Zones, numbered 2 through 6. Zones have been designated by the DRBC as sections of the Delaware River mainstem and the tidal portions of the tributaries thereto, from the mouth of Delaware Bay between Cape Henlopen and Cape May (River Mile [RM] 0.0) to the head of tide at Trenton, NJ (RM 133.4). Zone 2 extends from RM133.4 to RM 108.4, just downstream of the Pompeston Creek outlet. Zone 3 extends from RM 108.4 to RM 95.0 at Horseshoe Bend, 1/2-mile downstream of the Big Timber Creek outlet. Zone 4 extends from RM 95.0 to RM 78.8, just upstream of Marcus Hook, and Zone 5 extends from RM 78.8 to the head of Delaware Bay at Liston Point (RM 48.2). Zone 6 includes the Delaware Bay from RM 48.2 to its mouth (RM 0.0). Zones 2 to 4 are bordered by the State of NJ and Commonwealth of PA, while Zones 5 and 6 are bordered by the States of DE and NJ. The Delaware River Estuary includes the tidal Delaware River (Zones 2 to 5) and Delaware Bay (Zone 6).

Dissolved oxygen (DO, gaseous oxygen dissolved in water) levels within the Delaware River Estuary have historically been problematic in the tidal river from Philadelphia, PA, to Wilmington, DE. By the mid-1900s, pollution in the Estuary near Philadelphia and Camden was so severe that in the summer and early fall, the Delaware River was typically anoxic (i.e., near-zero DO). Aquatic life use DO to respire (breathe), and

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[4] The coastal water body where freshwater from rivers and streams mixes with salt water from the ocean is called an estuary. The estuary formed by the Delaware River, referred to interchangeably in this document as the "Delaware River Estuary," the "Delaware Estuary," or the "Estuary," consists of both a tidal river and a bay. The Delaware River Estuary therefore includes both the tidal Delaware River (Zones 2–5) and the Delaware Bay (Zone 6).

their DO requirements vary for different types of species (e.g., migratory or resident) and for different life stages (e.g., juvenile or adult).

To address aquatic life needs, the Commission adopted designated uses and supporting water quality criteria (in DRBC parlance, "stream quality objectives") in 1967 that were deemed protective of resident fish and the passage of migratory fish in Zones 3, 4 and 5 (DRBC, 2013a). "Faced with technical and financial challenges, these 1967 standards included a compromise position for 38 miles of the 133-mile-long estuary: a limited 'use' for Zones 3, 4, and upper Zone 5 that did not include 'propagation' along with lower dissolved oxygen water quality criteria" (DRBC, 2015). These objectives were established with the understanding that they could be achieved via wasteload allocation for carbonaceous biochemical oxygen demand (CBOD) among wastewater dischargers to the Estuary, through a process equivalent to implementing a total maximum daily load (TMDL) under the Federal Water Pollution Control Act Amendments of 1972, commonly referred to as the Clean Water Act. The Estuary states under their state and Clean Water Act authorities have established water quality standards (designated uses and criteria) for interstate waters, including the Delaware River Estuary, by deferring or referring to DRBC's water quality standards.

By the late 1980s, with the assistance of federal grants provided under the Clean Water Act, significant new investment had been made to improve municipal wastewater treatment facilities in the Delaware River Basin to control pollution loads and meet DRBC-directed wasteload allocations. As a result, DO levels in the Delaware Estuary steadily improved and now meet the established water quality criteria. Figure 1-2 shows daily-average DO during July and August from 1965–2022 based on continuous data collected at the Penn's Landing United States Geological Survey (USGS) Station (previously called the Ben Franklin Bridge station)[5], compared with the 24-hour average DO criteria established in 1967. Each box[6] shows the central 50% of daily averages in July and August, with the horizontal line representing the median value. The recovery of DO in the Delaware Estuary over decades has been extraordinary. As a result of this

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[5] Dissolved oxygen has been measured at this long-term monitoring location (USGS 01467200) since October 1961, and water level measurements back to 1949. The monitoring location is 2,500 ft downstream from Ben Franklin Bridge, at Penn's Landing, PA. Prior to January 2020, the monitoring devices at this location were located at end of Pier 12 about 150 ft upstream of Ben Franklin Bridge. Prior to July 1988, they were located on the edge of Pier 11 about 300 ft downstream of Pier 12.

[6] The box and whisker plot is a graphical illustration of numerical data to show the distribution of data through their quartiles (box) and data ranges (whiskers and circles). This report employed the standard box and whisker plot definition to summarize the data spread. The structure of each box indicates the following: bottom edge of the box = the first quartile (Q1 or 25th percentile); mid-point line on box = median (50th percentile); uppermost edge of the box = the third quartile (Q3 or 75th percentile); entirety of the box = interquartile range (IQR, the distance between Q3 and Q1). The whiskers are based on the IQR: the upper (lower) whisker is drawn to: 1) the largest (smallest) observed data point from the dataset if that point falls within a distance of 1.5 × the IQR above Q3 (below Q1); or 2) the full distance 1.5×IQR above Q3 (below Q1), if the largest (smallest) observed data point falls beyond this distance. Any observed data points beyond the whisker boundaries are plotted as circles.

Figure 1-1: Delaware River Estuary

historic DO improvement, resident fish populations in this region of the Estuary, as well as migratory fish, have returned.

Following incomplete attempts to reevaluate designated aquatic life uses in the 1990s, and in response to a United States Environmental Protection Agency (EPA) initiative on nutrients, the Commission's Water Quality Advisory Committee (WQAC) in 2007 renewed efforts to evaluate nutrient and DO conditions in the Delaware Estuary. DRBC staff developed a Nutrient Criteria Plan (DRBC, 2013b) that includes components addressing DO criteria in the Estuary and nutrient criteria in both the non-tidal and tidal waters of the Delaware River. The initial focus of this plan was to ". . . address dissolved oxygen directly, particularly the direct effects on oxygen from BOD loading, and [to] include an evaluation of the uses currently falling below Clean Water Act goals." In Fall 2013, the WQAC recommended that staff evaluate the existing uses of Zones 3 and 4 and the upper portion of Zone 5 for propagation of resident and anadromous fish species.

That evaluation resulted in the report *Existing Use Evaluation for Zones 3, 4 & 5 of the Delaware Estuary Based upon Spawning and Rearing of Resident and Anadromous Fishes* (DRBC, 2015). While evidence of propagation was presented in the 2015 Report, the report concluded that "[f]ull attainment of a 'maintenance and propagation' use has not been demonstrated now based on the data available and examined for this existing use evaluation."

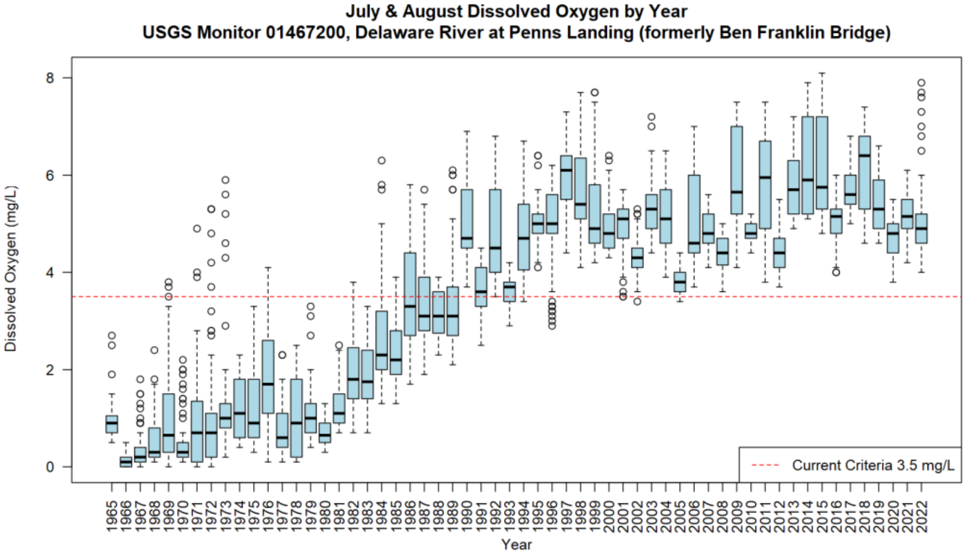

Figure 1-2: DO at Ben Franklin Bridge during July and August from 1965–2022

1.2 RESOLUTION NO. 2017-4

Following review, input, and deliberation by the WQAC and Estuary co-regulators[7], the Commission recognized by adopting Resolution No. 2017-4 that evidence supported further study on the inclusion of propagation as a designated use in Zones 3 and 4 and the upper portion of Zone 5. Resolution No. 2017-4 further directed the Executive Director to initiate a rulemaking process, with the understanding that before new rules could be proposed or finalized, additional studies were needed to establish designated uses and determine the criteria required to support these uses in the three zones. The Commission recognized the vital importance of determining the appropriate aquatic life use designations and water quality criteria, and it underscored the importance of reaching these determinations through a collaborative process informed by technical studies and specialized scientific and engineering expertise. The Commissioners unanimously approved Resolution No. 2017-4,[8] including a description of the required studies, a schedule, and the following goals:

- The improved conditions and uses we collectively have achieved should be protected.
- The path of continuous water quality improvement in these shared waters must continue.
- Water quality standards, including designated uses and water quality criteria, should be updated consistent with Clean Water Act goals as quickly as possible and practicable.
- Early actions based on optimizing the use of our existing infrastructure should be promoted and implemented pending final actions on water quality standards and revised permits or dockets.
- Stakeholders, including the regulated community, should be consulted in the DRBC rulemaking process and in the concurrent development of strategies for implementing the proposed water quality standards.

As discussed above, the Delaware River Estuary has experienced a remarkable recovery from water quality conditions that for many decades prevented the successful reproduction of resident and anadromous fish such as the American shad, Striped bass and Atlantic sturgeon. This achievement was the result of: significant past and ongoing efforts by state and federal agencies to implement and administer the Clean Water Act; public entities and private industry constructing and effectively operating wastewater treatment works; continuing scientific work by regulatory agencies and academic institutions to document water quality improvements and the return of fish and other aquatic life; and the public's support for restoration and protection of the Delaware Estuary, a vital shared resource.

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[7] The term "Estuary co-regulators" is used by the DRBC to refer to the regulatory apparatus of its member states (Delaware, New Jersey and Pennsylvania) and Regions 2 and 3 of the EPA.

[8] DRBC, Resolution No. 2017-4 (Sept. 13, 2017), available at: https://www.state.nj.us/drbc/library/documents/Res2017-04_EstuaryExistingUse.pdf.

DRBC Resolution No. 2017-4 directs the Commission staff to perform the technical studies[9] shown in Figure 1-3 and to provide an "analysis of attainability" (AA) report that synthesizes the findings and recommendations from each study. The technical studies focus on: fish and DO relationships, data collection, development and calibration of a eutrophication (linked hydrodynamic and water quality) model, and a social and economic impact evaluation pursuant to EPA's Clean Water Act regulations at 40 C.F.R. 131.10(g)(6). DRBC completed all the technical studies that Resolution No. 2017-4 directed DRBC to perform. DRBC staff worked in cooperation with co-regulators from NJ, DE, PA, and the EPA, and with members of the Commission's WQAC, and incorporated guidance from DRBC's technical consultant LimnoTech, Inc. and a panel of scientific experts, to determine the methodologies, assumptions, and scenarios involved in the AA, as described in this report.

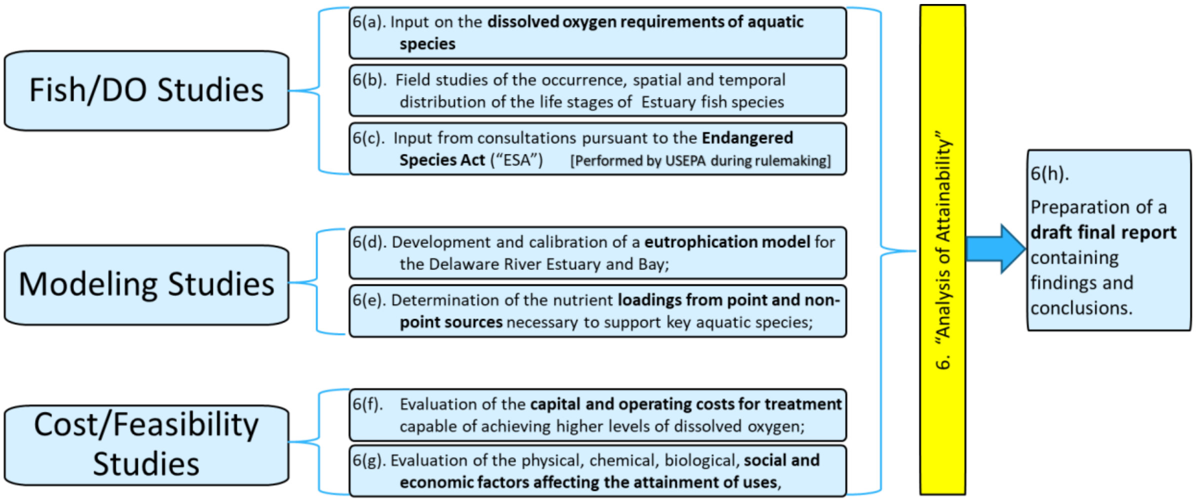

Figure 1-3: DRBC Resolution No. 2017-4 studies required before rulemaking

During public meetings from 2010–2020, the Commission adopted the numbered resolutions (subject to public hearing) and resolutions for the Minutes (not requiring public hearing) listed in chronological order below:

- Resolution No. 2010-5: Nutrient monitoring of point-source discharges to the Estuary and Bay
- Resolution No. 2012-7: Formation of Model Expert Panel
- Resolutions Nos. 2013-6 and 2017-5: Analysis of primary productivity by University of Maryland
- Resolution No. 2014-9: Study of effects of low DO and the presence of PCBs on the early life stages of the Atlantic sturgeon

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[9] One of the seven studies, "Consultation pursuant to Endangered Species Act (ESA)," is expected to be performed by the EPA in consultation with the National Marine Fisheries Service during the water quality standards adoption process. The other six studies have been completed by DRBC and its consultants.

- Resolution for the Minutes of Mar. 15, 2017: Consultation services from LimnoTech
- Resolution No. 2017-4: Studies to be undertaken in consultation with co-regulators and dischargers; DRBC to initiate rulemaking to revise the designated aquatic life uses consistent with the results of the identified studies and objectives and goals of the Clean Water Act
- Resolution for the Minutes of Sept. 13, 2017: Monitoring of effluent from Estuary point-source discharges for two years
- Resolution No. 2018-6: Feasibility and cost evaluation of effluent ammonia reduction from key point-source dischargers by Kleinfelder
- Resolution for the Minutes of June 12, 2019: Consultation services for enhancement of source code for the hydrodynamic model (EFDC) from GHD
- Resolution for the Minutes of Dec. 11, 2019: Analytical services for algal composition from Academy of Natural Sciences, Drexel University
- Resolution for the Minutes of Sept. 10, 2020: Revision of AA study period as defined in Resolution No. 2017-4 due to COVID 19 and budget constraints
- Resolution No. 2021-05: Collection of additional information essential to the evaluation of social and economic factors affecting the attainment of uses in the Delaware River Estuary
- Resolution for the Minutes of March 9, 2022: Agreement for professional services with the Environmental Finance Center at the University of Maryland

The results of work performed pursuant to these resolutions were used to support one or more of the studies enumerated above.

1.3 EXISTING REGULATIONS

Each zone of the Delaware River Estuary has multiple designated uses and water quality criteria to support those uses. The water quality standards applicable to aquatic life uses, including numeric DO criteria, were adopted in 1967 by the Commission and are summarized in Table 1-1 below.

Propagation of resident fish is not a designated use for the 38-mile reach comprising Zones 3 and 4 and the upper portion of Zone 5, where the DO criteria is 3.5 mg/L as a 24-hour average. While the Commission and co-regulators recognized that this level of DO would not be sufficient to fully restore and protect aquatic life, the Commission adopted criteria deemed feasible at the time, based on the DRBC's engineering evaluation. Also based on that evaluation, the Commission assigned wasteload allocations for carbonaceous biochemical oxygen demand to Estuary point-source dischargers in 1968.

Table 1-1: Applicable aquatic life uses and DO criteria for the Delaware River Estuary

Zone	River Mile	Aquatic Life Uses[1]	DO criteria[2]
2	108.4–133.4	Maintenance and propagation of resident fish and other aquatic life	24-hour average of 5.0 mg/L Seasonal average of 6.5 mg/L
3	95.0–108.4	Maintenance of resident fish and other aquatic life	24-hour average of 3.5 mg/L Seasonal average of 6.5 mg/L
4	78.8–95.0	Maintenance of resident fish and other aquatic life	24-hour average of 3.5 mg/L Seasonal average of 6.5 mg/L
5	70.0–78.8	Maintenance of resident fish and other aquatic life	24-hour average of 3.5 mg/L Seasonal average of 6.5 mg/L
	59.5–70.0	Maintenance and propagation of resident fish and other aquatic life	24-hour average of 4.5 mg/L Seasonal average of 6.5 mg/L
	48.2–59.5	Maintenance and propagation of resident fish and other aquatic life	24-hour average of 6.0 mg/L Seasonal average of 6.5 mg/L
6	0.0–48.2	Maintenance and propagation of resident fish and other aquatic life Maintenance and propagation of shellfish	24-hour average of 6.0 mg/L Not less than 5.0 mg/L at any time unless due to natural conditions

Notes: [1] Aquatic life uses for Zones 2–6 also include passage of anadromous fish and wildlife.

[2] For seasonal average DO criteria for Zones 2–5, the season is defined as "During periods from April 1 to June 15, and September 16 to December 31".

In this report, Zone 3, Zone 4, and the upper part of Zone 5 (RM 108.4–70), within which the current designated aquatic life use is "maintenance of resident fish and other aquatic life, passage of anadromous fish," are collectively referred to as the Fish Maintenance Area (FMA). The designated aquatic life use in Zone 2 and the remainder of Zone 5 is "maintenance *and propagation* of resident fish and other aquatic life, passage of anadromous fish" [emphasis added].

In accordance with Resolution No. 2017-4, DRBC is performing this evaluation pursuant to its authority under the Delaware River Basin Compact. However, DRBC's goal is not simply to develop new standards under its unique authority, but to work with co-regulators to support their responsibilities under the Clean Water Act for interstate waters.

As described in the DRBC's report *Linking Aquatic Life Uses with Dissolved Oxygen Conditions in the Delaware River Estuary* (DRBC, 2022c), at least eight resident fish species in the Delaware Estuary are sensitive to DO levels. Among these DO-sensitive fish is the Atlantic sturgeon, a federally-listed endangered species. While some degree of propagation has been documented to occur under current conditions (DRBC, 2015), the population of Atlantic sturgeon in the Delaware Estuary is small and fragile (White *et al.*, 2022). Fish face many challenges, including salinity, temperature, ship strikes, cooling water intakes, prey availability, and spawning habitat; however, it is widely understood that, at times, the current summer seasonal DO condition in the Delaware Estuary may limit propagation for Atlantic sturgeon and other DO-sensitive species.

DRBC is therefore identifying the level of fish propagation that is attainable as the degree of propagation associated with a particular DO condition. The current state of science does not allow us to know in advance exactly what degree of propagation will be associated with a particular DO condition; we can say with certainty that, within a range in which fish are sensitive to DO, more DO is better. Based on a comprehensive assessment of the available literature (DRBC, 2022c), that range appears to be approximately 4.3 mg/L to 7.0 mg/L. In other words, the occurrence of DO levels below 4.3 mg/L will not support propagation of one or more DO-sensitive species in the Delaware River Estuary, and there appears to be no incremental benefit for fish propagation associated with DO levels above 7.0 mg/L. Between 4.3 mg/L and 7.0 mg/L DO, the degree of propagation attained will depend on the timing, frequency, and duration of exposure to particular DO levels (in addition to the factors unrelated to DO). The process of translating the range of protective DO concentrations into numeric criteria will be performed in collaboration with co-regulators and with input from the Commission's WQAC. A final proposal will be the subject of rulemaking, in which DRBC will propose a revised designated use and draft water quality criteria to protect that use. The process will be one in which all stakeholders and members of the public will have an opportunity to provide their input and perspectives.

1.4 PURPOSE

The purpose of this analysis of attainability is to synthesize the various studies performed pursuant to Resolution No. 2017-4 to provide an analysis of the degree to which the aquatic life uses and water quality criteria to support those uses may be attained in the FMA. The work will inform rulemaking to amend the Commissions' water quality standards for Delaware Estuary aquatic life.

This analysis identifies the highest attainable dissolved oxygen (HADO) condition in the FMA (within which propagation is not currently designated as an aquatic life use) based on pollutant loading sensitivity and treatment feasibility. The attainable degree of propagation is that associated with the HADO condition. The word "condition" is important, because DO is dynamic in space throughout the Estuary and in time throughout the year. DRBC's report *Linking Aquatic Life Uses with Dissolved Oxygen Conditions in the Delaware Estuary* (DRBC, 2022c) identifies the range of DO concentrations protective of propagation for the Estuary's DO-sensitive species. The analysis of attainability is supported by the development, calibration and technically appropriate use of an Estuary eutrophication model. The costs and socioeconomic impacts of the pollutant reduction recommendations are evaluated in supporting studies. Section 2 of this report documents the methodology and process for determining feasible management scenarios to achieve the HADO condition within the FMA.

2. ANALYSIS OF ATTAINABILITY METHODOLOGY

2.1 WATER QUALITY MODEL

In support of the overall evaluation of highest attainable dissolved oxygen[10] (HADO) conditions, the DRBC developed a three-dimensional dynamic model of eutrophication processes[11] throughout the Delaware River Estuary from the head of tide at Trenton, NJ, to the ocean (DRBC 2022a). This effort entailed: 1) engagement of an expert panel to guide development, calibration, and use of the eutrophication model; 2) a two-year monitoring program to obtain data on nutrient loadings from tributaries and, in cooperation with wastewater utilities, from point sources; 3) field studies on primary productivity and DO gradients; and 4) development and calibration of the eutrophication model, comprised of linked hydrodynamic and water quality models. The eutrophication model was designed to estimate ambient DO levels that can be expected for various pollutant reduction scenarios using a dynamic (time-varying), long-term simulation of diurnal DO patterns.

Modeling eutrophication in the Delaware River Estuary requires an understanding of complex interactions among many processes including: tidal dynamics and water circulation; temperature, salinity, and algal dynamics; nutrient cycling and transformation; and solute exchange across the air/water and sediment/water interfaces. To adequately capture these dynamics, the DRBC developed and linked a hydrodynamic model of the system, using Environmental Fluid Dynamics Code (EFDC), with a water quality model, using Water Quality Analysis Simulation Program (WASP8). The linked hydrodynamic and water quality models utilize the same numerical grid domain, which extends from the mouth of the Delaware Bay (RM 0) to just upstream of the head of tide at Trenton, NJ (RM 135). The numerical grid consists of 1,876 horizontal grid cells, 10 vertical layers in the navigation channel, and 11,490 water segments in total. Detailed calibration results are documented in the hydrodynamic model report (DRBC, 2021) and water quality model report (DRBC, 2022a). In addition to the full 3D eutrophication model, a 2D version with only one vertical layer was also developed and utilized for testing and sensitivity purposes; the 2D model takes about 4 hours to complete a one-year simulation, whereas the 3D model takes about 35 hours. The eutrophication model has significantly enhanced the DRBC's and the basin community's understanding of the impact of carbon, nitrogen and phosphorus loads on DO conditions in the Delaware River Estuary, as well as reaeration, sediment oxygen demand, and phytoplankton photosynthesis and respiration.

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[10] DO condition throughout this report is measured and assessed in terms of water column concentration (mg/L). DO as a percent of saturation level, which is affected by water temperature and salinity, is certainly relevant for fish, which extract DO from the water column through their gills. The eutrophication model of course accounts for all these variables, but concentration is used to assess and compare DO conditions for various scenarios throughout this report.

[11] In this context "eutrophication processes" refers to the physical, chemical and biological processes that impact (and are impacted by) nutrients and dissolved oxygen, including those driven by algal growth, respiration, photosynthesis, and death. A "eutrophication model" is one that incorporates eutrophication processes.

The primary purpose of the eutrophication modeling study was to develop a modeling tool appropriate for conducting forecast simulations of future pollutant reductions to determine the resulting ambient DO conditions in the Estuary, and particularly in the FMA. The model was specifically calibrated and endorsed by the expert panel for this intended use. By providing a quantitative means of evaluating management options for improving DO, namely by establishing pollutant loading targets for point and non–point sources to achieve specific DO improvements, the eutrophication model provides the scientific and engineering basis for the DRBC to determine the highest attainable DO condition and the attainable aquatic life use in the FMA.

2.2 ELEMENTS OF THE ANALYSIS OF ATTAINABILITY

Figure 2-1 shows the basic elements of the AA process employed by the DRBC in accordance with Resolution No. 2017-4. As discussed in Section 2.1 above, the Commission's analysis was conducted using a complex eutrophication model to dynamically compute the DO conditions that would result from candidate test scenarios.

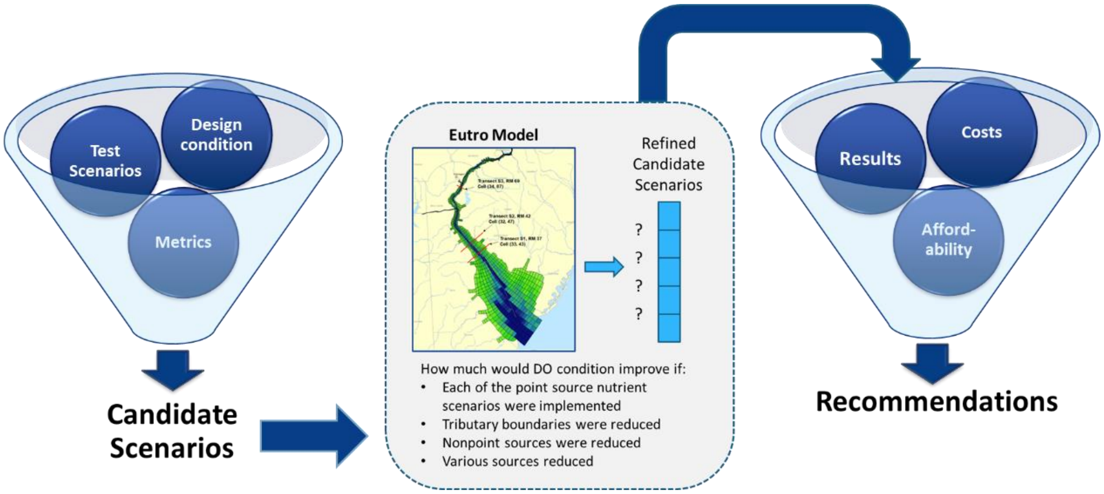


Figure 2-1: Elements of analysis of attainability

To select candidate scenarios, a design condition, test scenarios, and metrics must be defined. The design condition (Section 2.4 below), which simulates the impact of wastewater facilities discharging their permitted flows at their current treatment levels and under critical environmental conditions, provides a baseline from which to develop other test scenarios and against which to compare these scenarios using specific metrics. Test scenarios fall into two general types: pollutant source sensitivity scenarios and pollutant load reduction scenarios. Source sensitivity scenarios are not meant to be realistic or feasible, but instead are designed to assess the relative impacts of pollutant source categories such as wastewater discharges, tributaries, and combined sewer overflows (CSOs). Pollutant load reduction scenarios (Section 2.5 2.5below), on the other hand, capture the impact of specific management scenarios, such as the use of advanced treatment on wastewater discharges. Metrics (Section 2.3 below) provide the analytical basis for comparing one scenario with another. Since DO varies over time and space throughout the Estuary, metrics are needed to compare the results and identify the highest attainable DO condition.

To prepare recommendations, test scenarios were characterized in terms of feasible and attainable DO improvement. Costs were evaluated and considered by estimating the capital and operating costs for individual facilities and combining them to provide an estimate of the total cost under each management scenario. Affordability (Section 0) was also evaluated to consider the potential burden of the DO improvement on customers in each service area that would be impacted by additional utility costs. For example, for the Philadelphia Water Department (PWD), the costs were determined for additional treatment at three wastewater treatment plants. The affordability analysis reflected increases in the affordability burden on ratepayers for the entire PWD service area.

2.3 METRICS TO COMPARE SCENARIOS

Several metrics were developed to compare modeled DO under different scenarios. Because model output comprises 2-hour DO time series within each model cell (thousands of locations), this output needed to be processed before scenarios could be compared effectively. Each metric described below is designed to characterize the distribution, magnitude, frequency, and/or duration of low-DO values throughout the Estuary. Each metric was evaluated for the period from May 1 to October 15, the “critical propagation season.” This “summer” season reflects the temporal overlap between historically low DO events and important stages in juvenile development in which fish may be particularly vulnerable to low DO concentrations (DRBC, 2022c).

2.3.1 Longitudinal Plots: DO Percentiles and “Percent-Above”

A longitudinal plot depicts modeled changes in water quality from just upstream of the head of tide at Trenton, NJ, (RM 135) on the right-hand side of the plot to where the Delaware Bay meets the Atlantic Ocean (RM 0) on the left (Figure 2-2). Each value plotted represents a cross-section of the model in space (all cells at the same transect, or along-channel, coordinate) over a period of time (the critical propagation season). Two metrics are presented using longitudinal plots.

- **DO Percentiles.** A percentile DO value represents the distribution of DO concentration results during the critical propagation season. The 1st percentile DO is the value for which 1% of modeled DO values are lower and 99% are higher. In this study, the 1st, 10th, 25th and 50th percentile values are presented to characterize the lower end of predicted DO distributions for each scenario and the 1st percentile DO generally characterizes the minimum DO at a particular transect.
- **Percent time above.** The duration of low-DO events during the critical propagation season was evaluated using the percent of time that modeled DO concentration is above 4, 5, 6 and 7 mg/L.

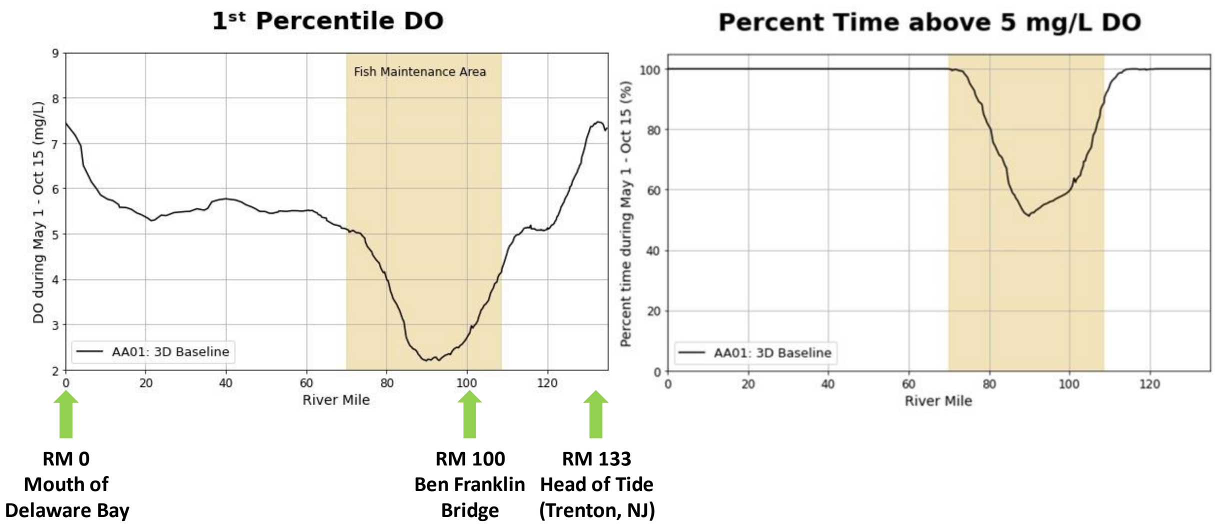


Figure 2-2: Example longitudinal plots for the 3D Baseline scenario

1st percentile DO (left) and percent time above 5 mg/L (right) plotted against River Mile for the 3D Baseline scenario (see Section 2.4). The Fish Maintenance Area is shaded in yellow.

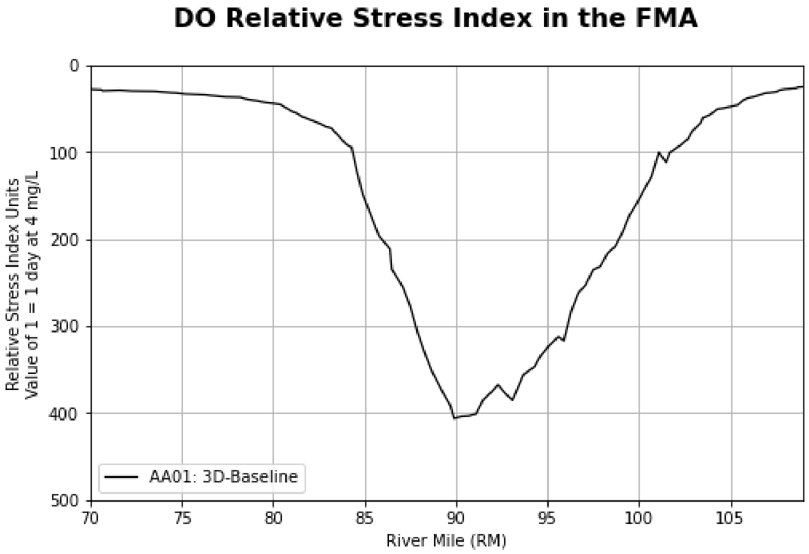


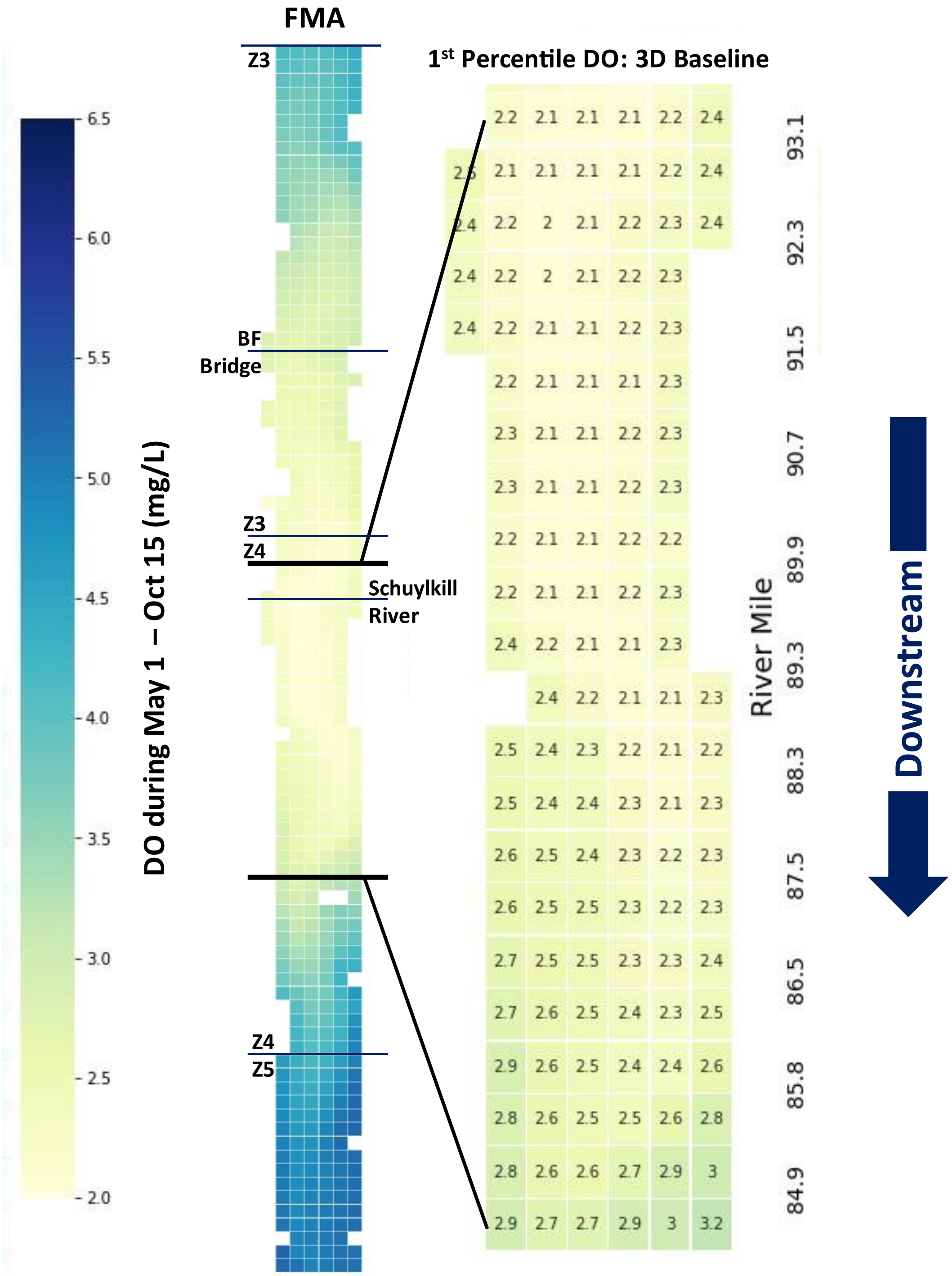
Figure 2-3: Example DO Relative Stress Index plot for the 3D Baseline scenario

2.3.2 DO Relative Stress Index

The DO Relative Stress Index (RSI) was developed by DRBC to compare the potential stress to aquatic life from low DO under different scenarios by capturing the frequency, magnitude, and duration of low-DO events in a single number. This metric is intended only for scenario comparison; it compares, rather than absolutely quantifies, potential stress to aquatic life. The calculation was designed such that lower DO values represent exponentially more "stress" than higher DO values. For example, a DO increase from 3.5 mg/L to 4.0 mg/L would represent a bigger decrease in RSI than a DO increase from 4.0 mg/L to 4.5 mg/L. RSI results were also plotted longitudinally by river mile; however, these plots show only the FMA (RM 70–108.4), as RSI values are typically low outside of the FMA during all scenarios. An example RSI plot is shown in Figure 2-3.

2.3.3 Tabular Maps

To visualize spatial patterns in DO not apparent in longitudinal plots (e.g., variation within a cross-section), tabular maps were generated. These maps display each model coordinate within the FMA as a square, colored according to the 1st percentile from the DO time-series at that location. Figure 2-4 displays results from the 3D Baseline scenario.



	2.2	2.1	2.1	2.1	2.2	2.4
2.5	2.1	2.1	2.1	2.1	2.2	2.4
2.4	2.2	2	2.1	2.2	2.3	2.4
2.4	2.2	2	2.1	2.2	2.3	
2.4	2.2	2.1	2.1	2.2	2.3	
	2.2	2.1	2.1	2.1	2.3	
	2.3	2.1	2.1	2.2	2.3	
	2.3	2.1	2.1	2.2	2.3	
	2.2	2.1	2.1	2.2	2.2	
	2.2	2.1	2.1	2.2	2.3	
	2.4	2.2	2.1	2.1	2.3	
		2.4	2.2	2.1	2.1	2.3
	2.5	2.4	2.3	2.2	2.1	2.2
	2.5	2.4	2.4	2.3	2.1	2.3
	2.6	2.5	2.4	2.3	2.2	2.3
	2.6	2.5	2.5	2.3	2.2	2.3
	2.7	2.5	2.5	2.3	2.3	2.4
	2.7	2.6	2.5	2.4	2.3	2.5
	2.9	2.6	2.5	2.4	2.4	2.6
	2.8	2.6	2.5	2.5	2.6	2.8
	2.8	2.6	2.6	2.7	2.9	3
	2.9	2.7	2.7	2.9	3	3.2

Figure 2-4: Example tabular maps for the 3D Baseline scenario

Left: Each cell location in the FMA colored by 1st percentile DO during May 1–October 15, 3D Baseline scenario. Zone boundaries, Ben Franklin Bridge, and the Schuylkill River confluence are labelled. Right: Zoom in to a 10-mile section at the lowest part of the DO sag.

2.4 DESIGN CONDITION

The design condition is a baseline model simulation against which to compare a range of future condition test scenarios. It represents ambient water quality with wastewater facilities discharging their permitted flows at their current treatment levels and under critical environmental conditions. “Critical” in this context means a combination of temperature, hydrology and other environmental factors that produce a particularly low DO condition that is a “conservative” condition for design purposes. 2D and 3D model versions of the Baseline design condition were constructed, incorporating the following components, each discussed in more detail within this section:

- Hydrologic conditions from 2012, including: (1) tributary and watershed inflows and concentrations, (2) tidal inputs at the mouth of the Bay and the C&D Canal, and (3) weather inputs.
- Permitted flow rates for all point source (wastewater treatment plant) discharges.
- Seasonal median effluent concentrations for wastewater discharges, calculated using model-interpolated concentrations assigned based on intensive data collection during the 2018–2019 calibration period.
- River channel bathymetry based upon the deepening of the navigation channel completed in 2016. Numerical tests demonstrate that the deepened navigation channel has insignificant effects on DO concentrations in the Delaware Estuary; nevertheless, post-2016 bathymetry was implemented in both 2D and 3D models.

2.4.1 Hydrologic Conditions

Figure 2-5 and Figure 2-6 present box and whisker plots of DO concentrations at Penn’s Landing, PA (USGS 01467200, formerly known as the “Ben Franklin Bridge” station) and Chester, PA (USGS 01477050) from 2010–2022 during July and August, when DO in the Delaware River Estuary usually reaches its annual minimum. During the period 2010–2022, the lowest DO in the Delaware River Estuary occurred during 2012.

Figure 2-7 and Figure 2-8 depict flow rates for the Delaware River at Trenton, NJ, (USGS 01463500) and the Schuylkill River at Philadelphia, PA, (USGS 01474500) during July and August from 2010–2021. The flow rates during summer 2012 were approximately 3,000 and 800 cubic feet per second (cfs), respectively, and are the second- and third-lowest summer flow rate at each station. A minimum flow objective of 3,000 cfs at Trenton, NJ was established and codified in the Delaware River Basin Water Code (DRBC, 2013c) to maintain freshwater inflow into the Estuary under normal conditions. Low flows in summer 2012 coincided with low precipitation (Figure 2-9), as 2012 was the third driest summer during the past decade. Monthly total July precipitation from 2010–2021 was lowest in 2012 (Figure 2-10).

The dry weather and low flow from tributaries in 2012 brought lower DO in the Estuary, likely due to less dilution by ambient waters and longer residence time for the consumption of oxidizable organic material than during other years over the last decade. This provides the justification for selecting the 2012 hydrologic condition as a conservative baseline for assessing DO improvement.

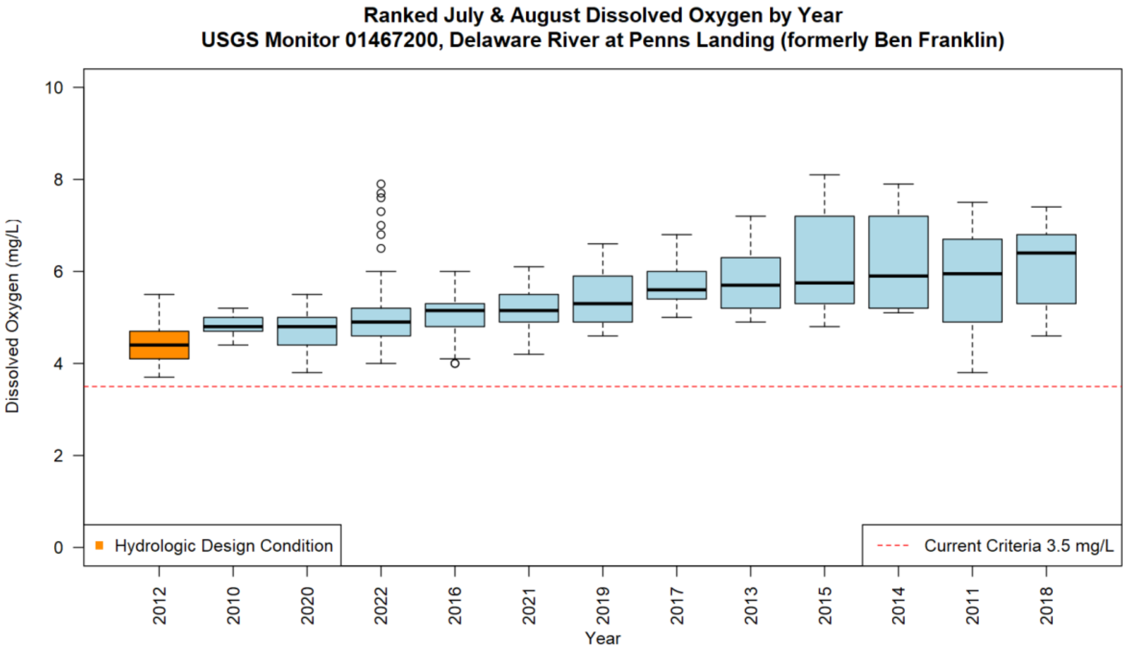


Figure 2-5: Dissolved oxygen at Penn's Landing during July and August from 2010–2022

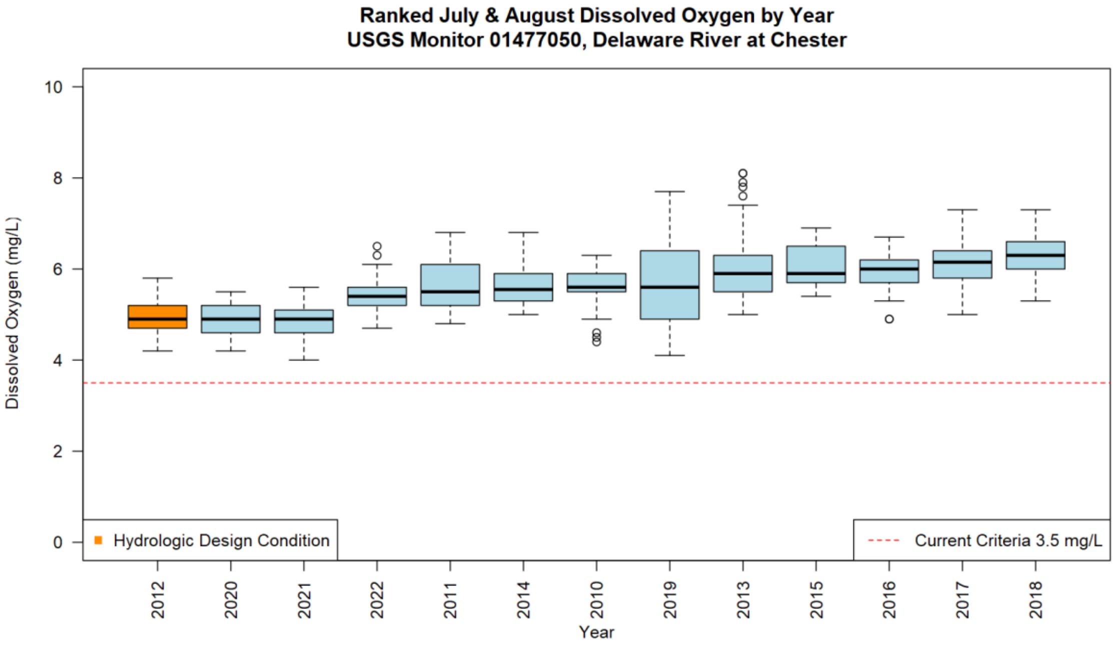


Figure 2-6: Dissolved oxygen at Chester during July and August from 2010–2022

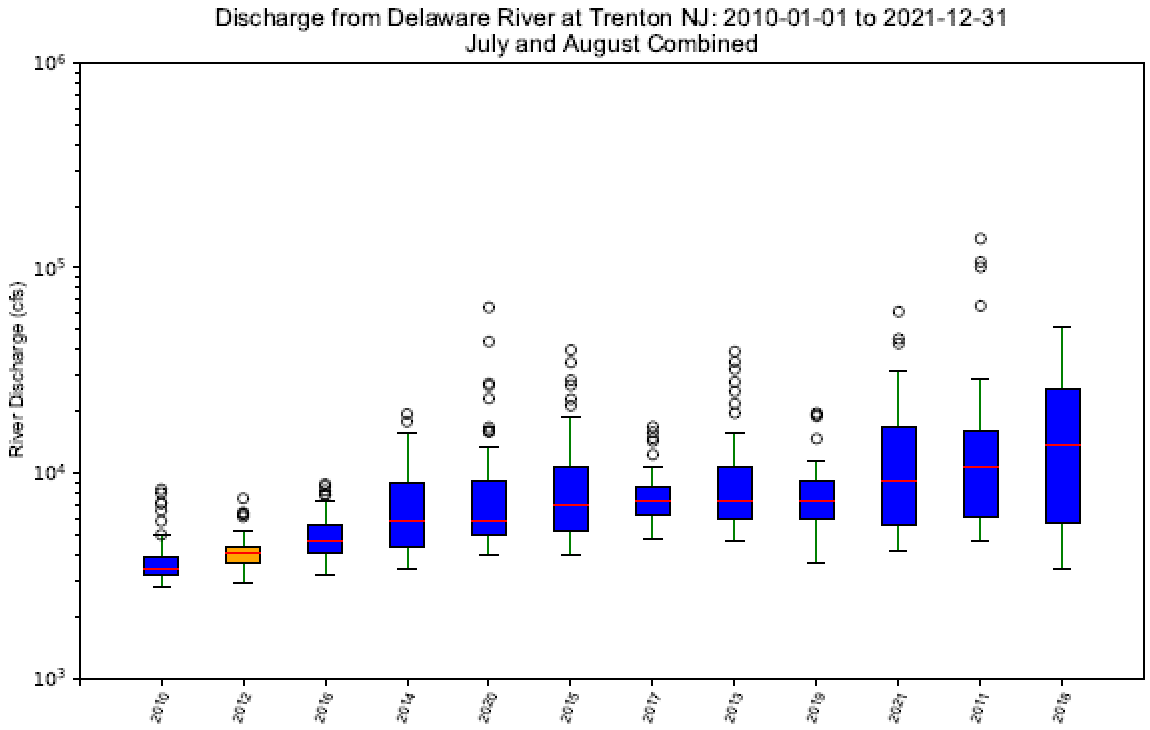


Figure 2-7: Daily flow at Trenton during July and August from 2010–2021

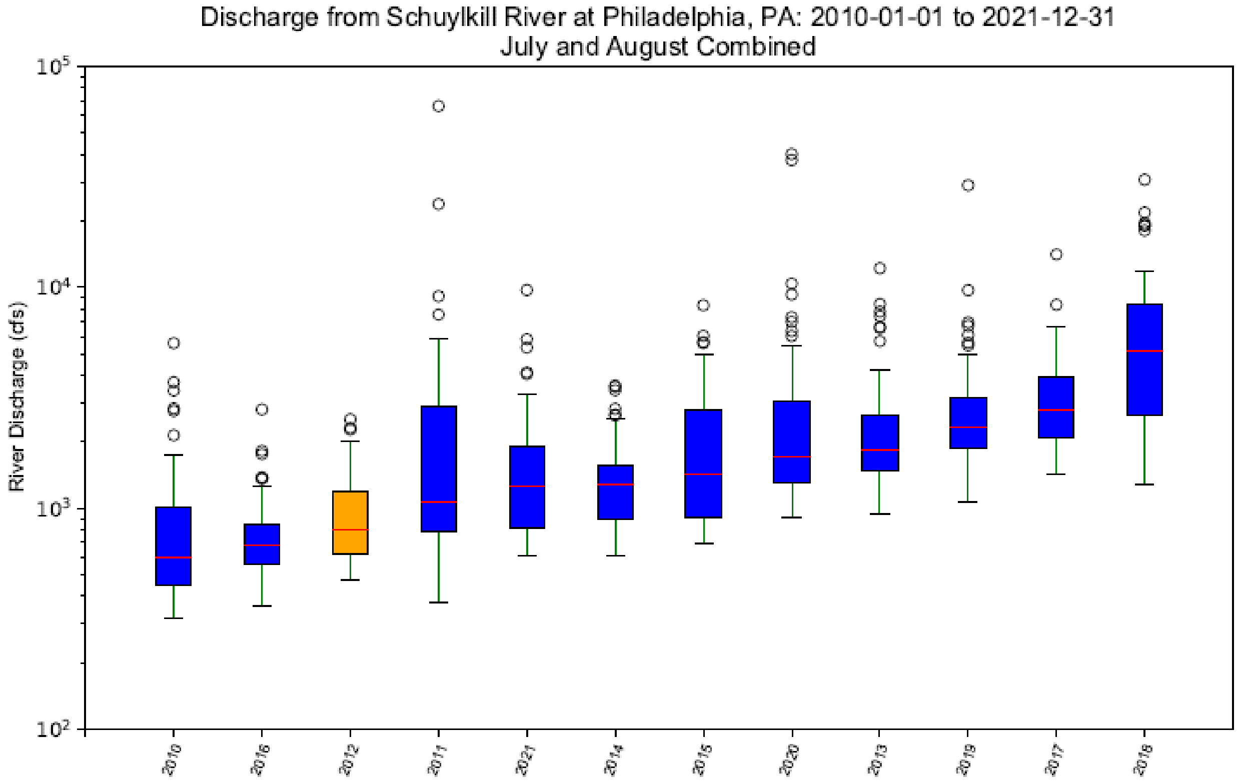


Figure 2-8: Daily flow in Schuylkill River during July and August from 2010–2021

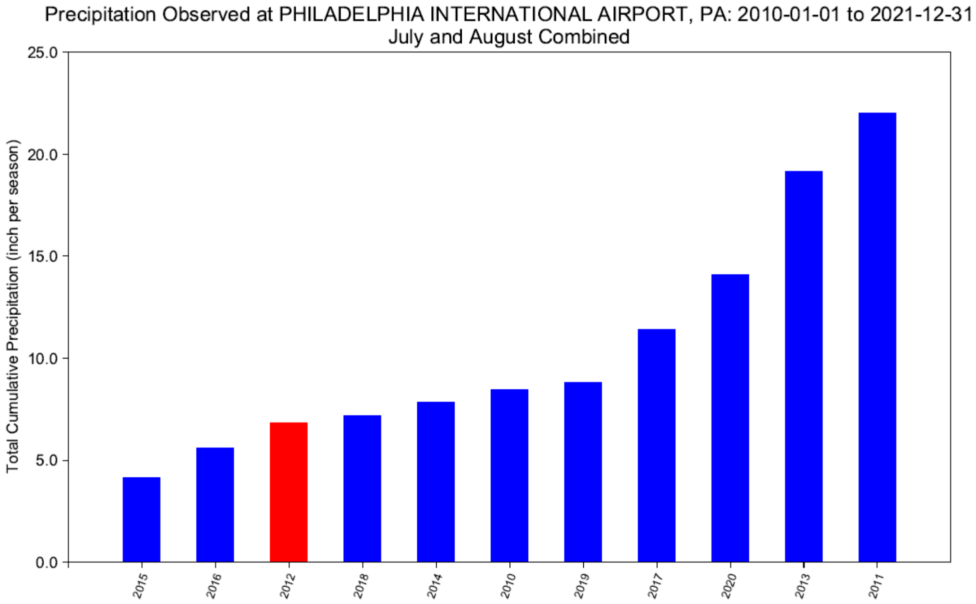


Figure 2-9: Precipitation at Philadelphia International Airport during July and August from 2010–2021

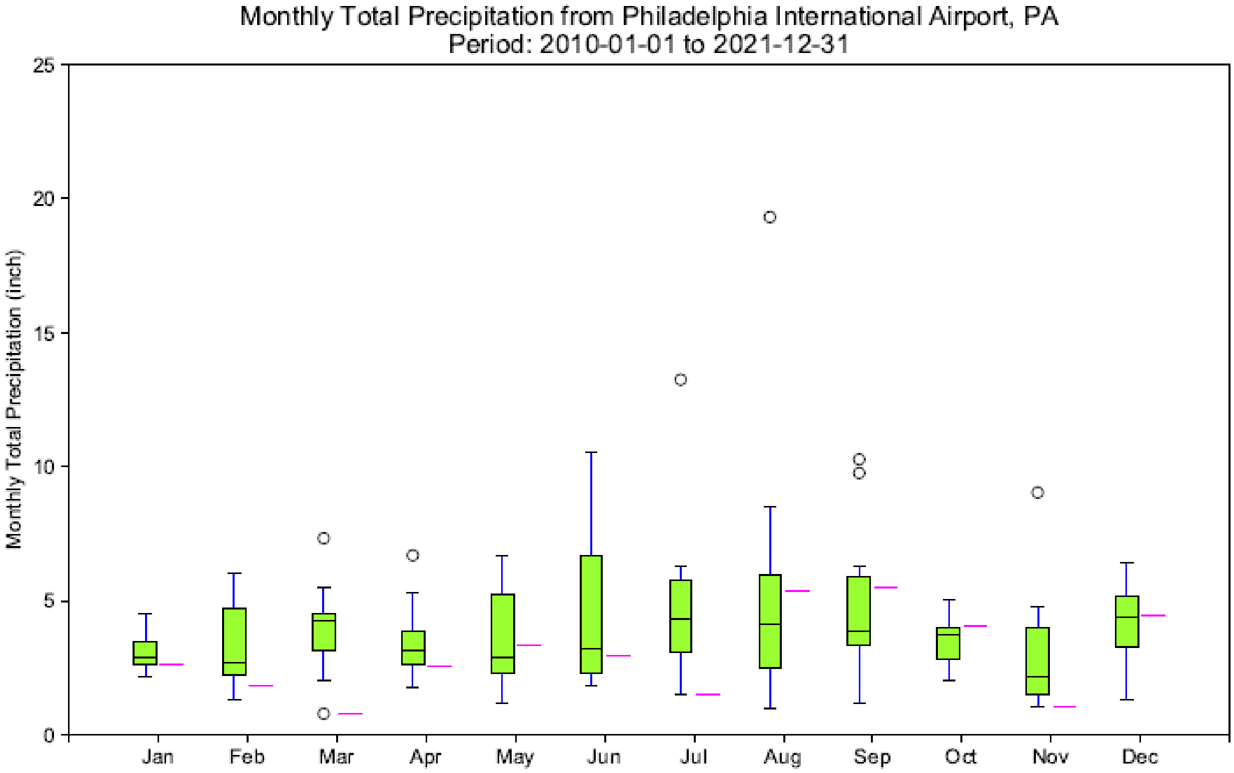


Figure 2-10: Historical monthly total precipitation statistics at Philadelphia for 2010–2021

Monthly precipitation in 2012 (pink lines) is shown for comparison with the distribution of monthly precipitation values from 2010 to 2021 (green boxes and whiskers).

2.4.2 Wastewater Characteristics

Typically, wastewater treatment plants discharge well below their permitted flow rates; however, wastewater plants may lawfully discharge at the permitted flow level at any time. The permitted flow rates established by individual NPDES permits were used to characterize wastewater discharges in the design condition. Effluent concentrations were set to “summer” (May–October) and “winter” (November–April) median values calculated based on model-interpolated concentrations assigned based on intensive data collection during the 2018–2019 calibration period (DRBC, 2022a). Permitted flows and key effluent concentrations for the Baseline condition for discharges identified as potential candidates for load reduction are summarized in Table 2-1 (summer) and Table 2-2 (winter). Figure 2-11 and Figure 2-12 present the load distributions of ammonia nitrogen and CBOD summarized by flow type for Zones 2–5 in the design Baseline condition.

Table 2-1: Baseline permitted flows and key pollutant effluent concentrations, May–October

Discharge Name	NPDES # Outfall #	Flow (MGD)	NH34 (mg-N/L)	Phosphate (mg-P/L)	CBODU (mg-O2/L)	DO (mg-O2/L)
PWD Northeast Water Pollution Control Plant	PA0026689-001	210	4.4	0.1	9.6	5.4
Camden County Municipal Utilities Authority	NJ0026182-001A	80	17.3	1.4	8.6	5.1
PWD Southeast Water Pollution Control Plant	PA0026662-001	112	8.6	0.1	9.4	4.9
PWD Southwest Water Pollution Control Plant	PA0026671-001	200	19.0	0.1	10.5	5.1
Gloucester County Utilities Authority	NJ0024686-001A	27	23.9	2.2	11.9	7.6
DELCORA	PA0027103-001	70	3.8	1.4	14.7	6.7
City of Wilmington Wastewater Treatment Plant	DE0020320-001	134	9.5	0.6	10.9	5.5
Hamilton Twp Water Pollution Control Facility	NJ0026301-001A	16	27.0	3.5	25.7	7.2
Lower Bucks County Joint Municipal Authority	PA0026468-001	10	19.7	1.7	12.2	3.7
Morrisville Borough Municipal Authority	PA0026701-201	7.1	9.7	2.3	10.4	7.6
Trenton Sewer Utility	NJ0020923-001A	20	5.4	1.9	12.3	8.5
Willingboro Water Pollution Control Plant	NJ0023361-001A	5.22	1.4	0.8	18.2	7.4
Cinnaminson Sewerage Authority	NJ0024007-001A	2	16.0	2.4	9.6	0.5
City of Millville Sewage Treatment Authority	NJ0029467-001A	5	26.2	2.0	11.2	7.4
Cumberland County Utilities Authority	NJ0024651-001A	7	4.7	0.5	10.3	7.4
Logan Township Municipal Utilities Authority	NJ0027545-001A	2.75	6.4	1.6	9.9	6.9
Florence Township Sewage Treatment Plant	NJ0023701-001A	2.5	5.9	1.2	27.9	7.9
Penns Grove Sewerage Authority	NJ0024023-001A	0.75	19.5	0.6	13.8	8.4
Beverly Sewerage Authority	NJ0027481-001	1	14.5	4.0	16.0	4.0

Table 2-2: Baseline permitted flows and key pollutant effluent concentrations, November–April

Discharge Name	NPDES # Outfall #	Flow (MGD)	NH34 (mg-N/L)	Phosphate (mg-P/L)	CBODU (mg-O2/L)	DO (mg-O2/L)
PWD Northeast Water Pollution Control Plant	PA0026689-001	210	5.6	0.1	10.8	5.8
Camden County Municipal Utilities Authority	NJ0026182-001A	80	15.6	0.8	10.7	5.9
PWD Southeast Water Pollution Control Plant	PA0026662-001	112	8.0	0.1	10.6	5.9
PWD Southwest Water Pollution Control Plant	PA0026671-001	200	19.0	0.1	12.8	6.8
Gloucester County Utilities Authority	NJ0024686-001A	27	20.7	1.8	13.7	7.5
DELCORA	PA0027103-001	70	9.1	0.8	17.3	7.5
City of Wilmington Wastewater Treatment Plant	DE0020320-001	134	13.2	0.4	13.1	5.6
Hamilton Twp Water Pollution Control Facility	NJ0026301-001A	16	25.2	2.7	26.0	7.9
Lower Bucks County Joint Municipal Authority	PA0026468-001	10	20.6	1.7	14.7	4.0
Morrisville Borough Municipal Authority	PA0026701-201	7.1	9.1	1.4	14.2	9.8
Trenton Sewer Utility	NJ0020923-001A	20	6.4	1.3	10.6	8.5
Willingboro Water Pollution Control Plant	NJ0023361-001A	5.22	3.3	0.9	19.6	9.0
Cinnaminson Sewerage Authority	NJ0024007-001A	2	18.2	1.8	12.3	0.5
City of Millville Sewage Treatment Authority	NJ0029467-001A	5	28.5	1.5	15.6	7.9
Cumberland County Utilities Authority	NJ0024651-001A	7	9.2	1.2	13.1	7.6
Logan Township Municipal Utilities Authority	NJ0027545-001A	2.75	6.4	1.6	9.9	6.9
Florence Township Sewage Treatment Plant	NJ0023701-001A	2.5	3.1	1.3	25.3	8.9
Penns Grove Sewerage Authority	NJ0024023-001A	0.75	19.5	0.6	13.8	8.4
Beverly Sewerage Authority	NJ0027481-001	1	14.5	4.0	16.0	4.0

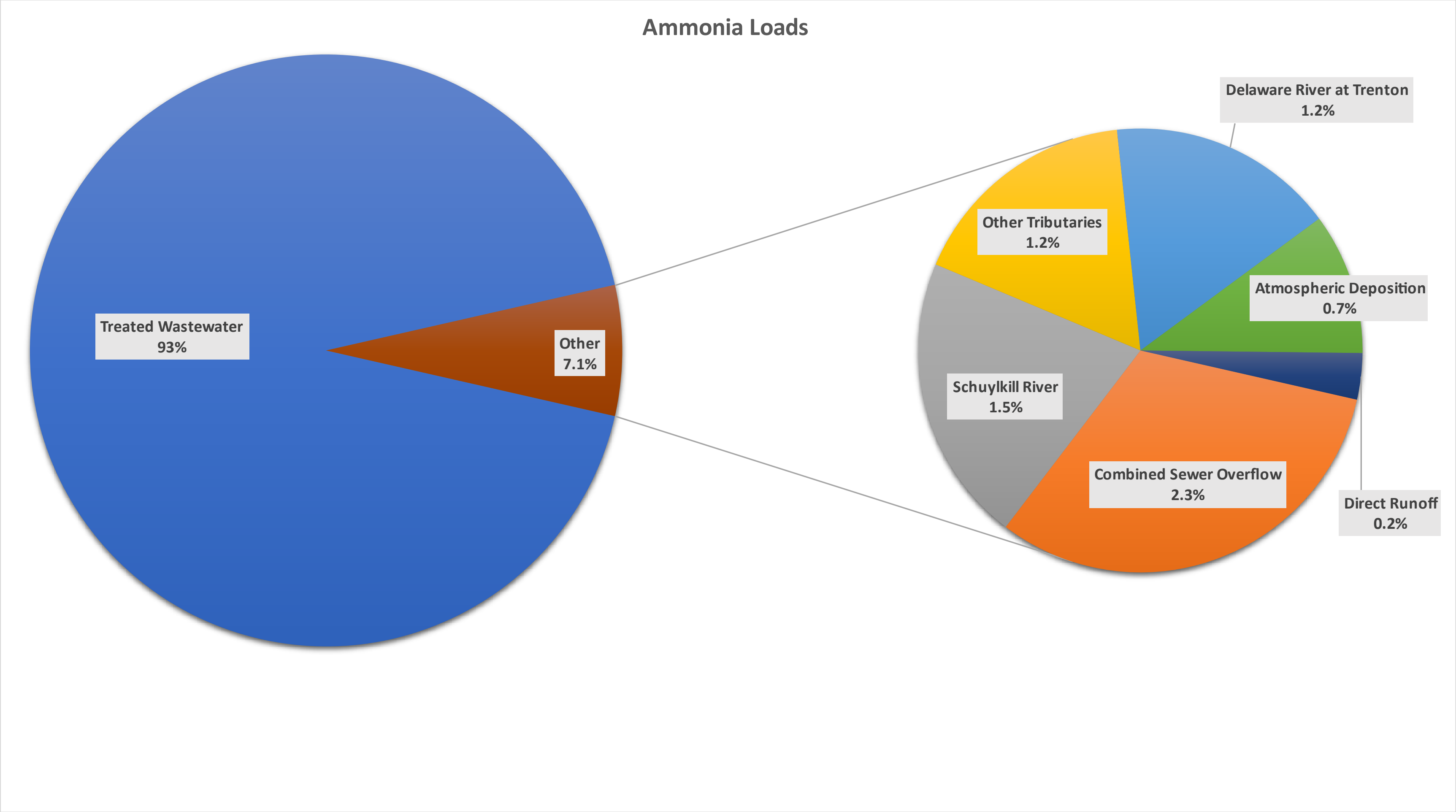


Figure 2-11: Ammonia loading composition in design condition

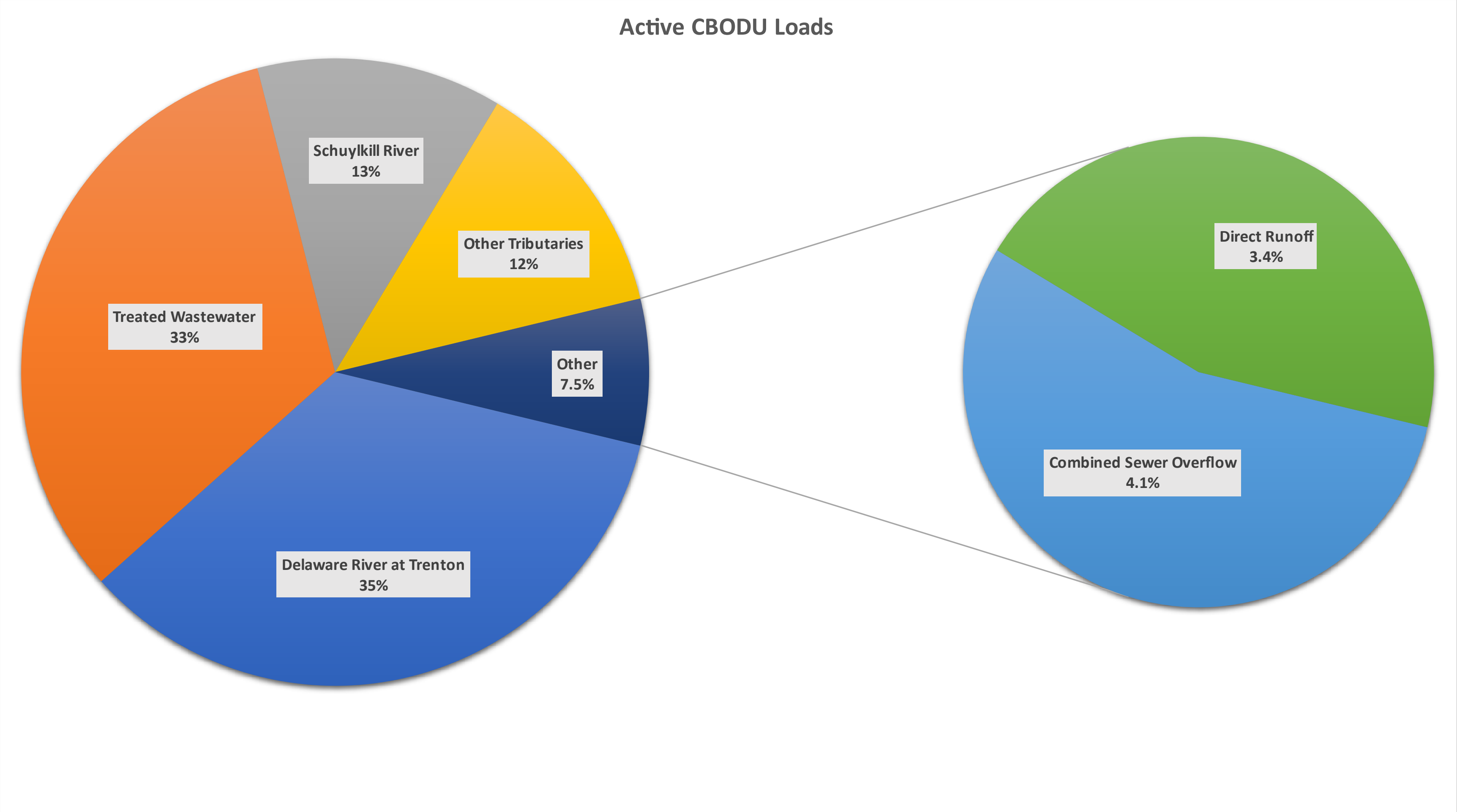


Figure 2-12: Active CBODU loading composition in design condition

2.4.3 Sensitivity of DO to Effluent Flow Rates

A series of modeling tests were conducted to address uncertainty in results due to differences between the permitted wastewater flow rates used in the design condition and "actual" wastewater discharge flow rates, which are generally lower than the permitted rate. First, two 3D simulations were performed using the same effluent pollutant loads but different flow rates for wastewater plants. One was assigned permitted flow rates (as in the design condition) and the other, actual flow rates from 2012. Two different sets of constant concentrations were assigned to each simulation, such that, accounting for their different flows, the total annual loads were identical. The goal for this test was to confirm that the hydrodynamic differences between actual (variable and generally lower) and permitted (constant and generally higher) effluent flows were not causing a difference in DO independent of the nutrient loads delivered. The 1st percentile results are almost identical between the two simulations (Figure 2-13: Comparison between scenarios with same wastewater load but different flows), indicating that that hydrodynamics caused by differences in effluent flows are not consequential to ambient DO in the Estuary.

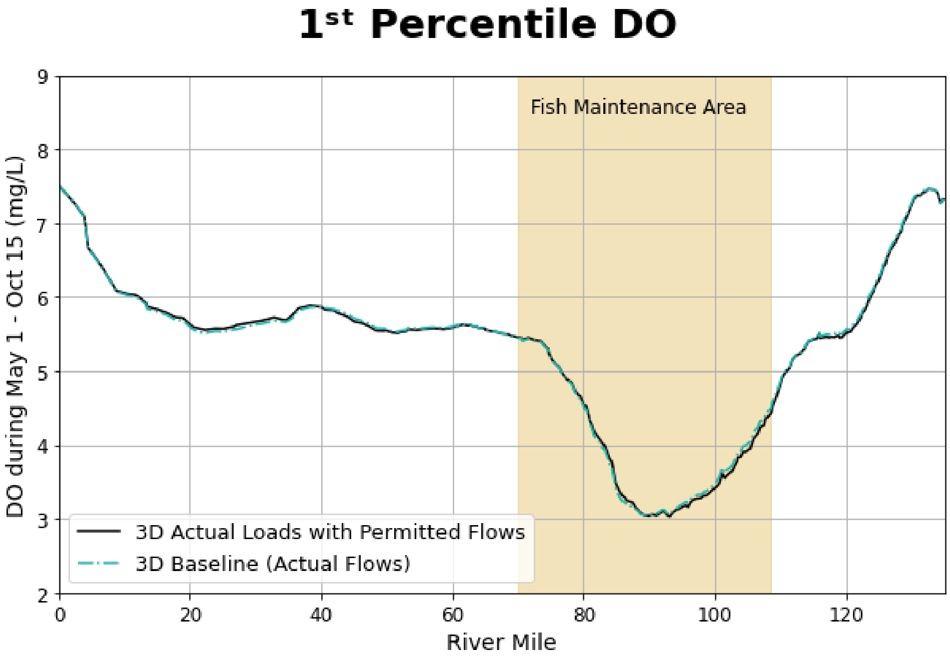


Figure 2-13: Comparison between scenarios with same wastewater load but different flows

Second, comparisons between the 2D Baseline condition and a scenario with effluent ammonia from select discharges reduced to 1.5 mg/L were prepared (Figure 2-14) using: (1) permitted wastewater flow rates (upper panel) from 2012; and (2) actual wastewater flow rates from 2012 (lower panel). For this test, the twelve (12) Tier 1 wastewater treatment plants were selected. Tier 1 discharges were identified based on two years of effluent loading data collected during the 2010s; the Tier 1 discharges together constitute 95% of total point source nutrient load.

In Figure 2-14, the predicted low (1st percentile) DO concentrations from the permitted-flows Baseline are lower than those from the actual-flows Baseline; this was expected, since the permitted-flow Baseline, with higher flows and equal concentrations, results in a higher ammonia load to the Estuary. However, the predicted low DO concentrations for the reduced-ammonia scenarios were more similar between permitted and actual flows, especially within the FMA. This result suggests that the conservative use of permitted effluent flows, which accounts for anticipated increases in effluent discharge rates over time, is less significant for load reduction scenarios compared to the Baseline scenario.

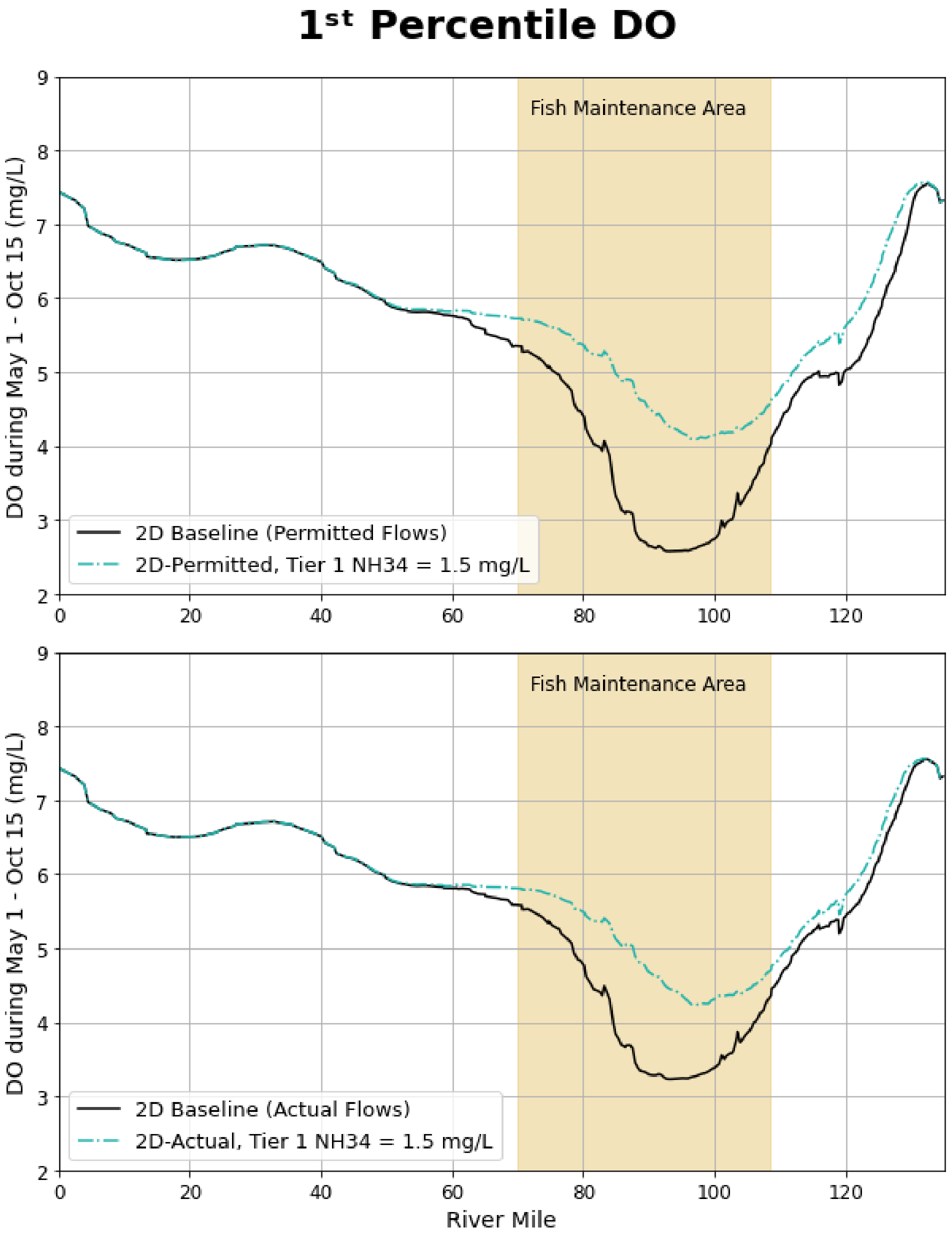


Figure 2-14: 2D scenario comparisons using permitted and actual wastewater flows

2.5 POLLUTION LOAD REDUCTION SCENARIOS

As described above, two types of test scenarios—source sensitivity scenarios and load reduction scenarios—were used to explore the sensitivity of DO in the FMA to various pollutant sources. The load reduction scenarios tested management scenarios defined by combinations of feasible point source wastewater treatment and the associated reductions in pollutant effluent concentrations.

As part of the AA under Resolution No. 2017-4, the DRBC commissioned a Nitrogen Reduction Cost Estimation Study (Kleinfelder, 2021). In this study, Kleinfelder developed planning-level cost estimates for four levels of reduced effluent ammonia and total nitrogen concentrations for each of the twelve Tier 1 wastewater treatment plants discharging to the Estuary: ammonia levels of 10, 5.0 and 1.5 mg/L, and a total nitrogen level of 4.0 mg/L. The evaluation results were presented to the WQAC on August 24, 2017.

Kleinfelder identified three broad categories of existing wastewater treatment types among the Tier 1 dischargers. These include pure oxygen activated sludge, fixed film, and conventional activated sludge. Kleinfelder further identified proven treatment technologies with long-term records of performance to ensure a reasonable degree of confidence in plant upgrade performance and the ability to appropriately estimate construction and operating costs for achieving the four effluent nitrogen levels for each of the existing treatment types. Specifically, Kleinfelder identified addition of a biological aerated filter (BAF) along with other process modifications for the pure oxygen activated sludge and fixed film plants, and conversion to an Integrated Fixed Film Activated Sludge (IFAS) process with other process modifications for the conventional activated sludge plants.

According to the Kleinfelder report, for pure oxygen activated sludge plants and fixed film plants to achieve an effluent ammonia concentration of 1.5 mg/L, the entire plant effluent flow must be treated by a fully nitrifying BAF. For those two types of plants, 1.5 mg/L ammonia represents full treatment. Conventional activated sludge effluent ammonia treatment with IFAS may be adjusted to achieve different effluent ammonia targets depending on the quantity of IFAS media added. But the Kleinfelder report highlights significant treatment bottlenecks and challenges that limit the practical treatment of effluent ammonia. As a result, DRBC understands 1.5 mg/L ammonia to be a practical lower treatment limit for conventional activated sludge.

EPA’s guidance for NPDES permit writers recognizes that wastewater influent flow and concentration are highly variable and that effluent concentration will also be variable. As such, although day to day effluent concentrations may be lower or higher than 1.5 mg/L ammonia, 1.5 mg/L ammonia represents an attainable level consistent with EPA guidance.

Load reduction scenarios were prepared by assigning constant effluent concentrations during the “summer” (May 1–October 31) to the discharges being tested. Ammonia was set to the level being tested, while nitrate (NO3) and carbonaceous biochemical oxygen demand (CBOD) were adjusted accordingly, as shown in Table 2-3. When a particular scenario required a reduction in summer ammonia concentration, the difference was added to nitrate to keep the total nitrogen level constant. This approach assumes that ammonia would be reduced in the wastewater by nitrification, resulting in additional nitrate. Associated CBOD reductions were assumed for Tier 1 dischargers based on the cost and feasibility study (Kleinfelder, 2021); essentially, these reductions represent the decrease in ultimate CBOD that would be expected for a particular level of ammonia treatment. Note that for simulating a total nitrogen concentration of 4.0, the following composition of nitrogen components was assumed: 1.5 mg/L ammonia, 1.5 mg/L nitrate, 0.75 mg/L organic nitrogen, and 0.25 mg/L detrital nitrogen.

Table 2-3: Summer effluent CBOD and nitrate adjustments

	Baseline			NH34 ≤ 10 mg/L		NH34 ≤ 5 mg/L		NH34 = 1.5 mg/L		TN ≤ 4 mg/L	
Discharge	NH34	NO3	CBOD	NO3	CBOD	NO3	CBOD	NO3	CBOD	NO3	CBOD
PWD Northeast WPCP	4.4	2.7	9.6	NC	NC	NC	NC	5.6	5.9	1.5	5.6
Camden County MUA	17.3	1.5	8.6	8.8	6.2	13.8	5.5	17.3	5.0	1.5	5.0
PWD Southeast WPCP	8.6	0.3	9.4	NC	NC	3.9	7.4	7.4	6.3	1.5	3.1
PWD Southwest WPCP	19	1.3	10.5	10.3	9.6	15.3	9.4	18.8	9.2	1.5	9.2
Gloucester County UA	23.9	1.8	11.9	15.7	10.2	20.7	8.5	24.2	6.9	1.5	5.0
DELCORA	3.8	6.5	14.7	NC	NC	NC	NC	8.8	9.5	1.5	5.2
City of Wilmington WWTP	9.5	3.4	10.9	NC	NC	7.9	7.2	11.4	5.4	1.5	5.5
Hamilton Twp WPCF	27	4.8	25.7	21.8	10.3	26.8	6.2	30.3	3.3	1.5	3.3
Lower Bucks County JMA	19.7	2.4	12.2	12.1	10.0	17.1	7.7	20.6	5.4	1.5	6.8
Trenton Sewer Utility	5.43	7.2	12.3	NC	NC	7.63	6.33	11.13	2.12	1.5	2.12
Morrisville BMA	9.7	12.7	10.4	12.4	6.03	17.4	4.04	20.9	2.65	1.5	2.65
Willingboro WPCP	1.4	15.4	18.2	NC	NC	NC	NC	NC	NC	1.5	4.74
Cumberland County UA	4.7	2.8	10.3	NC	NC	NC	NC	6.0	NC*	1.5	NC*
Logan Township MUA	6.43	2.0	9.9	NC	NC	3.43	NC*	6.93	NC*	1.5	NC*
Florence Township STP	5.9	3.8	27.9	NC	NC	4.7	NC*	8.2	NC*	1.5	NC*
Penns Grove SA	19.5	0.4	13.8	9.9	NC*	14.9	NC*	18.4	NC*	NC	NC
Beverly SA	14.5	5.5	16.0	10	NC*	15	NC*	18.5	NC*	1.5	NC*
Cinnaminson SA	16.0	3.7	9.6	9.7	NC*	14.7	NC*	18.2	NC*	1.5	NC*
City of Millville STA	26.2	0.16	11.1	16.4	NC*	21.4	NC*	24.9	NC*	NC	NC

NC	No change (Baseline values were used);
NC*	CBOD values were adjusted for the 12 Tier 1 discharges only.

3. FACTORS THAT CAN IMPROVE DISSOLVED OXYGEN IN THE FISH MAINTENANCE AREA

3.1 SENSITIVITY OF SOURCE CATEGORIES

A series of 2D model sensitivity test scenarios were designed to evaluate which pollutant sources to the Estuary may substantially impact DO improvement in the FMA. The following source categories were evaluated: individual wastewater discharges (NH34, TN, CBOD, DO), CSOs (NH34, CBOD), non–point sources, municipal separate storm sewer systems (MS4s), and source contributions from major tributaries including the non-tidal mainstem Delaware River (C, N, and P). Longitudinal results for 1st percentile DO and DO Relative Stress Index (see Section 2.5) from each sensitivity scenario were compared against results from the 2D Baseline scenario (Figure 3-1). Table 3-1 summarizes findings from the sensitivity tests described below.

- **Ammonia from individual wastewater discharges:** Sensitivity test scenarios included reducing effluent ammonia to 1.5 mg/L for the four largest discharges individually (PWD Southwest WPCP, PWD Northeast WPCP, PWD Southeast WPCP, and Camden County MUA) and for the 12 Tier 1 discharges with largest NH34 and CBOD loading together (Figure 3-1A,B). Reducing effluent ammonia loads from these discharges resulted in substantial DO improvement in the FMA. Further testing showed that reducing summer ammonia loads alone contributed to this effect; reducing winter ammonia loads did not measurably improve DO in the FMA. Section 3.2 describes further efforts to evaluate individual wastewater discharges.
- **DO, CBOD, and TN from individual wastewater discharges:** For the same 12 discharges, effluent DO was set to a minimum value of 6 mg/L and CBOD was decreased to 10 mg/L (Figure 3-1C,D). Increasing effluent DO had a modest beneficial impact on DO in the FMA, while decreasing CBOD did not have a substantial impact. Limiting effluent TN to 4 mg/L did not provide additional benefit to DO in the FMA relative to only reducing ammonia levels (while keeping TN constant).
- **Ammonia and CBOD from CSOs:** Reducing ammonia and CBOD concentrations by 85% in CSO inflows to the Estuary resulted in modest improvements to DO in the FMA (Figure 3-1E,F). Decreasing these concentrations by 85% was intended as a sensitivity test, not a realistic reduction scenario. Expected reductions from CSO long term control plans were implemented in the HADO simulation described in Section 5.
- **Non–point sources (NPS) and municipal separate storm sewer systems (MS4):** Removing nitrogen and carbon from NPS and MS4 runoff did not result in substantial improvement to DO in the FMA (Figure 3-1G,H).

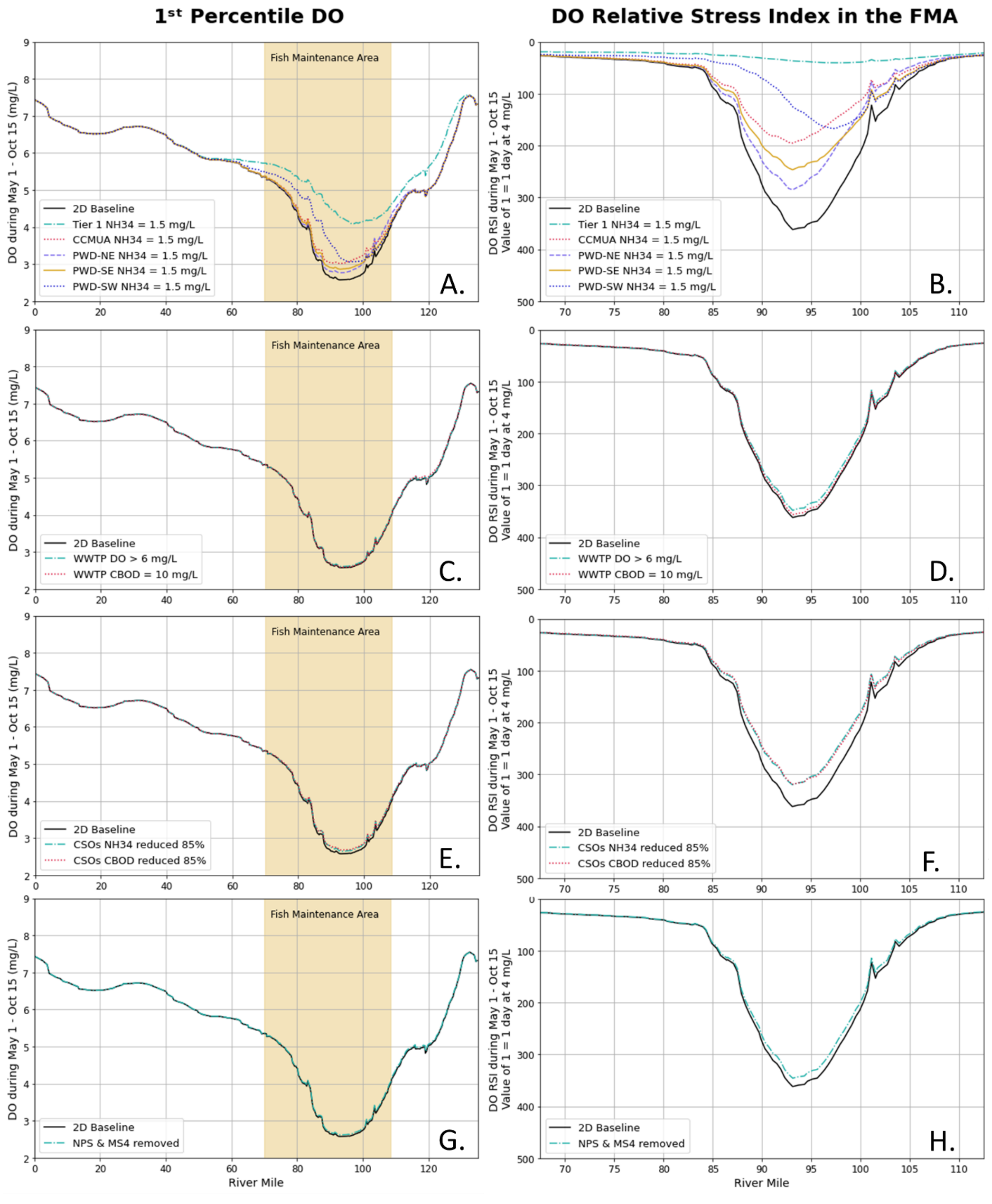
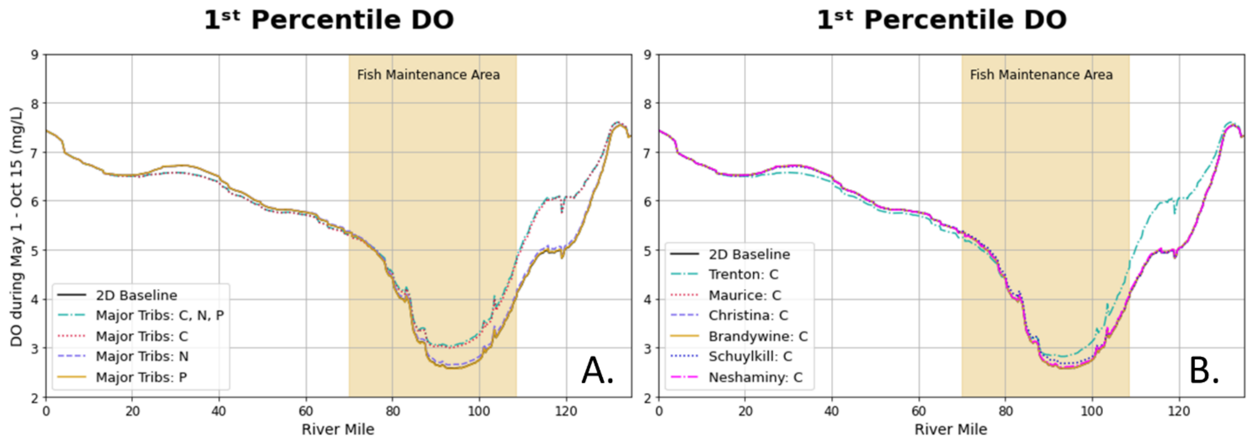


Figure 3-1: Source category sensitivity tests

Results from sensitivity tests are compared to the 2D Baseline scenario. Individual wastewater discharge NH34 reduced to 1.5 mg/L (A,B). Effluent DO set to a minimum of 6 mg/L and CBOD set 10 mg/L (C,D). CSO ammonia and CBOD reduced by 85% (E,F). N and C from NPS and MS4 eliminated (G,H).

- **Nutrient loads from tributaries:** Nutrient concentrations from the six largest tributary boundaries (Delaware River at Trenton, Schuylkill River, Christina River, Brandywine Creek, Neshaminy Creek, and Maurice River) were reduced to minimal concentrations. Reduced nitrogen (N) and phosphorus (P) loads from these tributaries did not have a substantial impact on DO in the FMA (Figure 3-2A). The low-DO response to reduced tributary carbon (C) is due almost entirely to impact from the Delaware River at Trenton, with carbon from the Schuylkill River contributing a minor impact (Figure 3-2B). It is important to note that these tributary carbon impacts are due to the large flows at these boundaries; the carbon concentrations are reflective of background conditions and would not be subject to regulatory control.


1st Percentile DO

1st Percentile DO

Figure 3-2: Tributary load sensitivity tests

A. Four test scenarios where C, N, and/or P from six major tributaries (Delaware River at Trenton, Schuylkill River, Maurice River, Christina River, Brandywine Creek, and Neshaminy Creek) were set to minimal values. B. Six test scenarios where C was reduced from each major tributary individually.

Table 3-1: Summary of 2D source sensitivity results

Factors that can most improve DO in the FMA	Factors that can slightly improve DO in the FMA	Factors that cannot measurably improve DO in the FMA
Summer (May–Oct) ammonia loads from specific point-source discharges Carbon loads from Delaware River at Trenton and Schuylkill River	Combined sewer overflows (CSOs) DO concentration in treated effluent from the largest point-source discharges Carbon loads from Schuylkill River	Nutrient (C, N, P) loads from tributaries, except C loads from Delaware River at Trenton and Schuylkill River Winter (Nov–Apr) ammonia, CBOD, and TN from all point-source discharges Summer (May–Oct) ammonia loads from many point-source discharges Direct stormwater runoff into the Estuary

3.2 CLASSIFICATION OF WASTEWATER DISCHARGES

3.2.1 Wastewater Discharge Screening using 2D Model

The nineteen wastewater discharges with the largest summer ammonia loads were selected for screening analysis (Table 3-2). A 2D model scenario was developed for each of these discharges in which the effluent from the individual discharge only was modeled with a maximum ammonia concentration of 1.5 mg/L. TN was kept constant by adding the difference between the original ammonia concentration and 1.5 mg/L to nitrate. No other adjustments were made. Three metrics were developed to evaluate the individual impact of each discharge's effluent ammonia concentration on DO in the Estuary:

- **Summer ammonia load**: The ammonia load from each discharge was calculated as the product of the discharge's permitted flow and the seasonal median effluent ammonia concentration (Table 2-1). Discharges that contribute 95% of the total load to the Delaware Estuary were selected for further analysis in the 3D model (Table 3-2).
- **Volume with ΔDO = 1 mg/L**: The extent of each discharge's impact within the total volume of the Estuary was evaluated with this metric. At each model cell, the difference between scenario DO and Baseline DO was determined. Only time steps where the Baseline DO was ≤ 7 mg/L and the DO difference was > 0.05 mg/L were considered. In each cell, the average DO difference was weighted by the cell's median volume and resulting values for all cells were summed to yield the equivalent volume in the Delaware Estuary where the DO increased by 1 mg/L. Discharges that impacted a volume > 100,000 m^3 according to this metric were selected for further analysis in the 3D model (Table 3-2).
- **Percent Reduction in DO Stress within FMA**: For each scenario, the total DO Stress in the FMA was calculated by summing the DO Relative Stress Index for each cell in the FMA (see Section 2.5.3). Discharges that reduced DO Stress in the FMA by > 5% were selected for further analysis in the 3D model (Table 3-2).

Table 3-2: Screening results for the 19 wastewater discharges with the greatest ammonia load

Values that warrant further analysis are highlighted with bold text. Discharges with a highlighted value in any column were selected.

Point Source Name	Summer NH34 Load (kg N/day)	% Cumulative NH34 Load	Vol. with ΔDO = 1 mg/L (m^3)	% Reduction DO RSI in FMA
PWD Southwest WPCP	**14354**	**36.5%**	**3.16E+08**	**51.7%**
Camden County MUA	**5241**	**49.9%**	**1.38E+08**	**36.9%**
City of Wilmington WWTP	**4807**	**62.1%**	**6.98E+07**	1.3%
PWD Southeast WPCP	**3626**	**71.4%**	**7.92E+07**	**25.2%**
PWD Northeast WPCP	**3535**	**80.4%**	**7.80E+07**	**20.4%**
Gloucester County Utilities Authority	**2438**	**86.6%**	**4.45E+07**	**10.6%**
Hamilton Twp WPCF	**1634**	**90.7%**	**5.24E+07**	2.6%
DELCORA	**1014**	**93.3%**	4.73E+04	0.8%
Lower Bucks County JMA	**747.6**	**95.2%**	**1.71E+07**	1.8%
City of Millville STA	495.4	96.5%	**1.95E+06**	0.3%
Trenton Sewer Utility	411.2	97.5%	**1.10E+07**	1.0%
Morrisville BMA	261.8	98.2%	**8.68E+06**	0.9%
Cumberland County Utilities Authority	124.7	98.5%	0.00E+00	0.0%
Cinnaminson Sewerage Authority	120.8	98.8%	**2.69E+06**	0.8%
Willingboro WPCP	96.8	99.1%	0.00E+00	0.3%
Logan Township MUA	66.9	99.2%	0.00E+00	0.0%
Florence Township STP	56.2	99.4%	3.87E+01	0.3%
Penns Grove Sewerage Authority	55.4	99.5%	0.00E+00	0.3%
Beverly Sewerage Authority	54.9	99.7%	0.00E+00	0.2%

3.2.2 Sequential Testing of Discharges using 3D Model

The thirteen (13) point source wastewater discharges identified from 2D model testing were included in a sequence of 3D model test scenarios to evaluate their cumulative impact on low DO in the Estuary. Table 3-3 lists a subset of scenarios that were part of this analysis; for each scenario, one or more discharge(s) were added to those included in the previous scenario in the sequence. Figure 3-3 shows 1st percentile DO and percent time above 5 mg/L for the scenarios in Table 3-3. Results from these cumulative scenarios were used to identify how strongly each discharge impacts low DO and DO improvement in the FMA.

- **PWD Southwest, PWD Southeast, PWD Northeast, and Camden County MUA (Run 89).** These four discharges are located between RM 90 and RM 104, in the heart of the "DO sag". They have a large impact on low DO in the FMA. Reducing effluent ammonia to 1.5 mg/L for these four discharges increases the minimum 1st percentile DO by ~2 mg/L relative to the Baseline scenario (Figure 3-3A) and results in DO staying above 5 mg/L at least 80% of the time throughout the Estuary (Figure 3-3B).
- **Gloucester County UA (GCUA) (Run 81).** Adding the reduction of effluent ammonia from GCUA brings additional benefit to low DO in the FMA relative to Run 89 (Figure 3-3A). Both 1st percentile DO and percent time above 5 mg/L show substantial improvement over RMs 80–95 (Figure 3-3B).
- **City of Wilmington WWTP and DELCORA (Run 85).** These two discharges are located at the downstream end of the FMA DO sag, between RM 70 and 80. Reducing their effluent ammonia results in additional benefit to low DO in this part of the FMA, with 1st percentile DO increasing 0.2 to 0.3 mg/L relative Run 81 (Figure 3-3C). Note that percent time above 5 mg/L does not show a benefit from the addition of these two discharges because in Run 81, DO is always above 5 mg/L in this part of the FMA (Figure 3-3D).
- **Hamilton Twp WPCF and Lower Bucks JMA (Runs 85 and 86).** These discharges are located upstream of the FMA. Adding these and reducing their effluent ammonia has the biggest impact on low DO in Zone 2, near RM 120, though the impacts carry downstream into the FMA; this is especially apparent in terms of percent time above 5 mg/L in the upper FMA (Figure 3-3D).
- **Trenton Sewer Utility, Morrisville BMA, Cinnaminson SA, and City of Millville STA (Runs 77, 87, and 88).** These discharges are located outside of the FMA. Reducing their effluent ammonia does not have a measurable impact on low DO in the FMA relative to Run 86 (Figure 3-3, E&F).

Based on these results, the 13 dischargers were divided into three classes that would each be tested as a group in the AA (Table 3-4, Figure 3-4). The classes are defined as follows:

- **Class A':** Discharges that have a major impact on low DO in the FMA. The biggest DO response to effluent ammonia reductions is located within the FMA, the discharge is located within the FMA, and low DO in the FMA is sensitive to the level of ammonia reduction.

- **Class A:** Discharges that have a marginal impact on low DO in the FMA. Low DO within the FMA is impacted, but the biggest DO response to effluent ammonia reductions is located outside of the FMA. The discharge is not located within the FMA, and low DO in the FMA is less sensitive to the level of ammonia reduction.
- **Class B:** Discharges that do not have a measurable impact on low DO in the FMA.

Table 3-3: A subset of sequential 3D model scenarios that were tested

For each scenario, effluent ammonia was reduced to 1.5 mg/L for the discharges listed. Discharge names in bold italics indicate that these were added to the list from the previous run. Results from these runs are shown on Figure 3-3.

Run #	Discharges with effluent ammonia = 1.5 mg/L
3D Baseline	None
89	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA
81	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA, ***Gloucester County UA***
85	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA, Gloucester County UA, ***City of Wilmington WWTP, DELCORA, Hamilton Twp WPCF***
86	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA, Gloucester County UA, City of Wilmington WWTP, DELCORA, Hamilton Twp WPCF, ***Lower Bucks JMA***
87	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA, Gloucester County UA, City of Wilmington WWTP, DELCORA, Hamilton Twp WPCF, Lower Bucks JMA, ***Trenton Sewer Utility***
88	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA, Gloucester County UA, City of Wilmington WWTP, DELCORA, Hamilton Twp WPCF, Lower Bucks JMA, Trenton Sewer Utility, ***Morrisville BMA***
77	PWD Southwest WPCP, PWD Southeast WPCP, PWD Northeast WPCP, Camden County MUA, Gloucester County UA, City of Wilmington WWTP, DELCORA, Hamilton Twp WPCF, Lower Bucks JMA, Trenton Sewer Utility, Morrisville BMA, ***Cinnaminson SA, City of Millville STA***

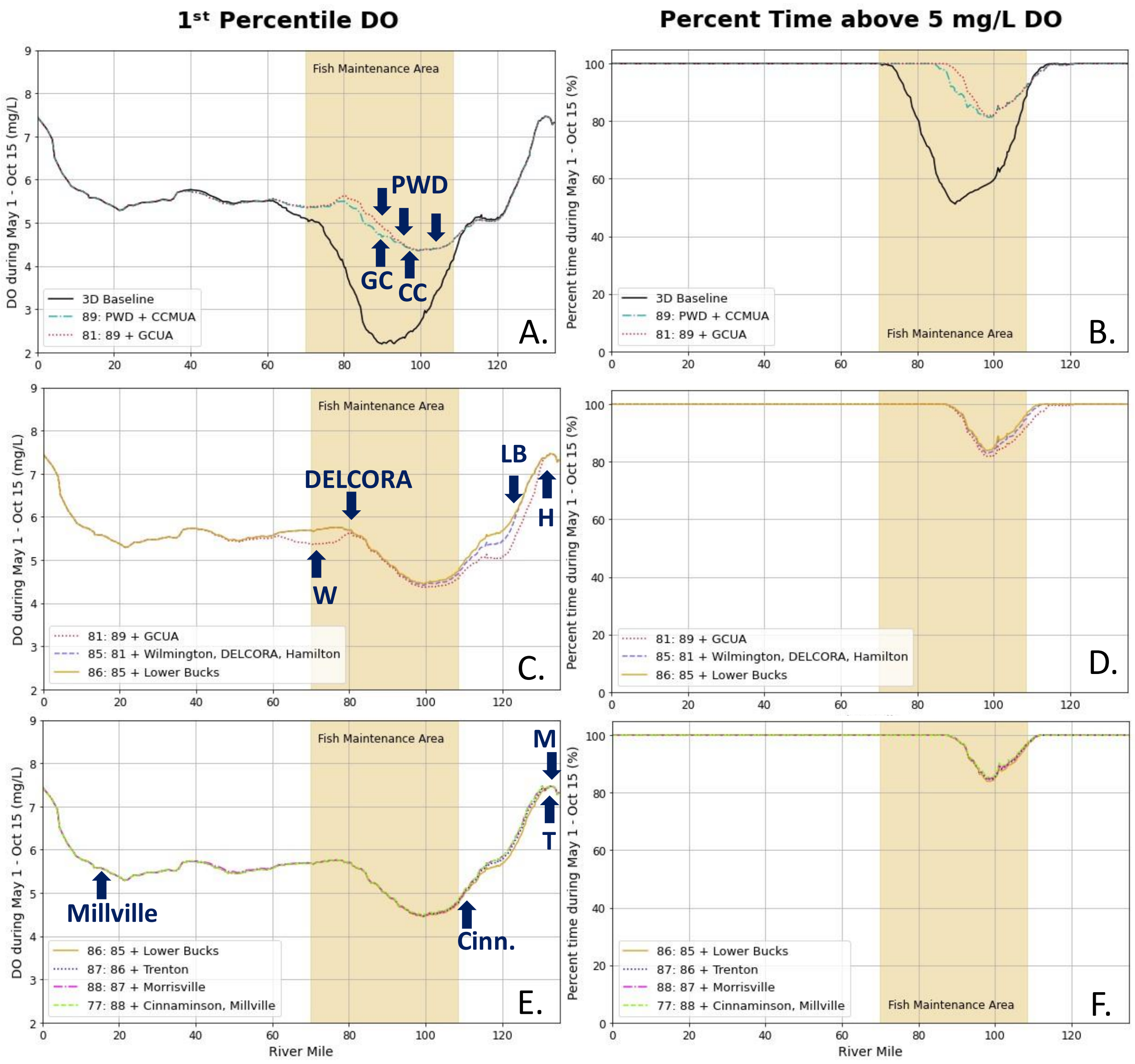


Figure 3-3: 3D model results from sequential testing of effluent NH34 reductions

Each discharge's approximate location is indicated with an arrow on the 1st percentile plot (left column).

Table 3-4: Discharge classification results

Zone	River Mile	State	Point Source NPDES#	Point Source Name	Class
4	90.7	PA	PA0026671-001	PWD Southwest Water Pollution Control Plant	A’
3	97.9	NJ	NJ0026182-001A	Camden County Municipal Utilities Authority	
5	71.6	DE	DE0020320-001	City of Wilmington Wastewater Treatment Plant	
3	96.7	PA	PA0026662-001	PWD Southeast Water Pollution Control Plant	
3	103.9	PA	PA0026689-001	PWD Northeast Water Pollution Control Plant	
4	89.9	NJ	NJ0024686-001A	Gloucester County Utilities Authority	
4	80.4	PA	PA0027103-001	DELCORA	
2	121.9	PA	PA0026468-001	Lower Bucks County Joint Municipal Authority	A
2	128.4	NJ	NJ0026301-001A	Hamilton Twp Water Pollution Control Facility	
6	15.2	NJ	NJ0029467-001A	City of Millville Sewage Treatment Authority	B
2	131.8	NJ	NJ0020923-001A	Trenton Sewer Utility	
2	132.5	PA	PA0026701-201	Morrisville Borough Municipal Authority	
2	108.7	NJ	NJ0024007-001A	Cinnaminson Sewerage Authority	

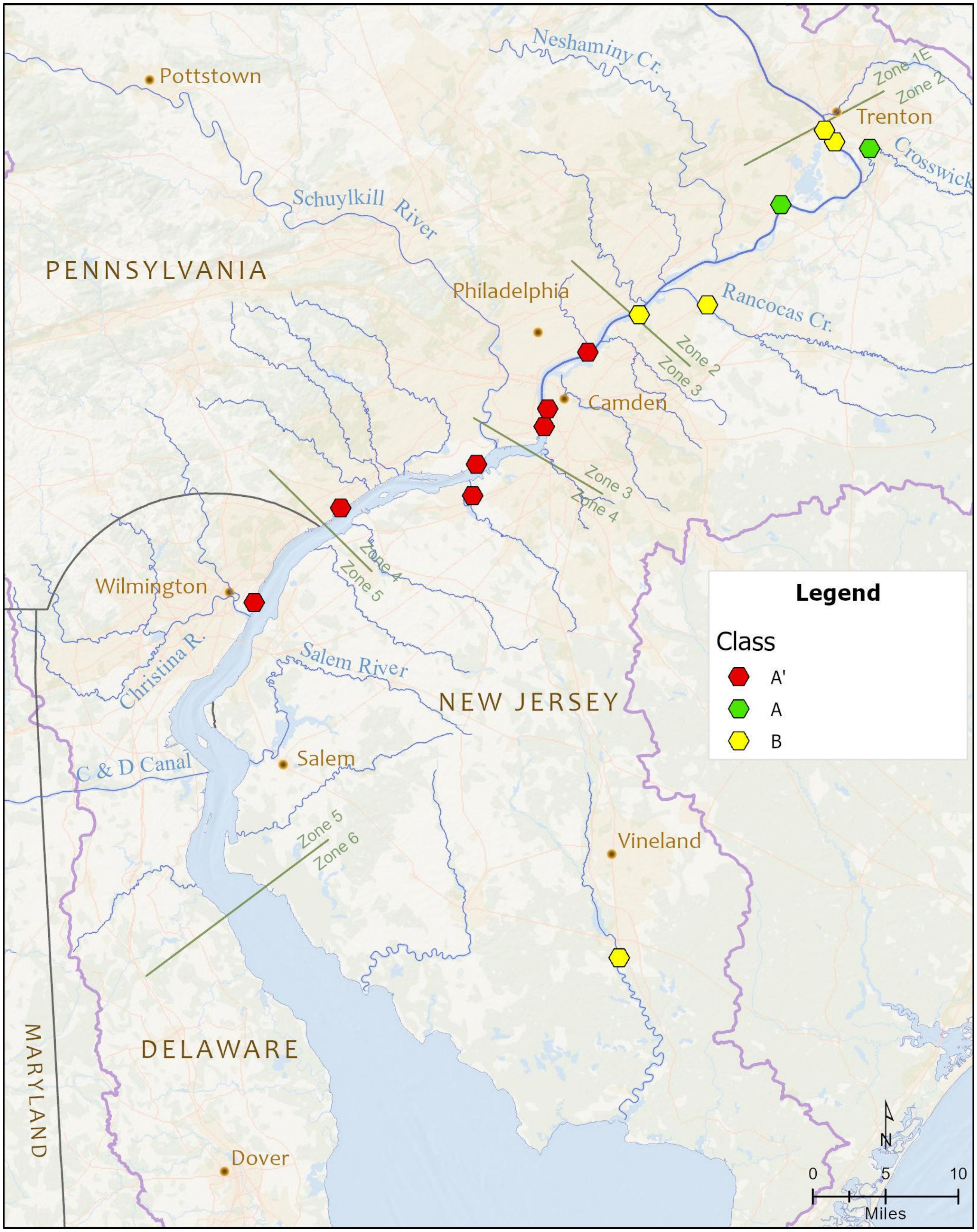


Figure 3-4: Map of Class A', A and B wastewater discharges

4. ANALYSIS OF ATTAINABILITY RESULTS

4.1 WASTEWATER NUTRIENT REDUCTION AA SCENARIOS

Candidate analysis of attainability scenarios (“AA scenarios”) were designed based on source sensitivity results (Section 3.1) and wastewater discharge classification (Section 3.2). As described in Section 2.4, the Baseline design condition that is the foundation for the AA scenarios represents existing water quality under critical conditions. Table 4-1 lists the AA wastewater nutrient (ammonia and total nitrogen) reduction scenarios that were prepared and simulated in the 3D model.

Table 4-1: Analysis of attainability scenarios

Scenario ID	Description
AA01	3D Baseline (Current conditions)
AA02	Class A' + A: Summer NH34 ≤ 10 mg/L
AA03	Class A' + A: Summer NH34 ≤ 5.0 mg/L
AA04	Class A' + A: Summer NH34 = 1.5 mg/L
AA05	Class A' + A: Summer TN ≤ 4.0 mg/L
AA06	All Tier 1: Summer NH34 = 1.5 mg/L
AA07	Class A' only: Summer NH34 = 1.5 mg/L
AA08	Class A': Summer NH34 = 1.5 mg/L Class A: Summer NH34 = 5 mg/L
AA10	Class A': Summer NH34 = 1.5 mg/L Class A: Summer NH34 = 10 mg/L

The AA scenarios differ only in: 1) which discharge classes were assigned reduced effluent nutrient concentrations; and 2) the level of reduction. For example, scenario AA02 caps summer ammonia at 10 mg/L for discharges in Classes A’ and A. For each discharge in Classes A’ and A, if the summer seasonal median ammonia (Baseline value) is greater than 10 mg/L, ammonia was reduced to 10 mg/L and nitrate and CBOD were adjusted accordingly (Table 2-3). Whenever summer effluent ammonia was reduced, summer effluent DO was reduced to 2 mg/L or the discharge’s existing permit limit. As in the Baseline design condition, NH34, NO3, CBOD, and DO were set to constant values for May through October. For these AA scenarios, CSOs were not adjusted from the Baseline design condition and no reserve capacity was included.

Scenarios AA02 through AA05 test a range of nutrient effluent reduction conditions for Classes A' and A together. Figure 4-1 presents comparative results of these test scenarios and the Baseline (AA01), showing: 1) 1st percentile DO, representing critically low values that are exceeded 99% of the time; and 2) the percentage of time the DO is above 5 mg/L. For the Baseline scenario, the minimum 1st percentile DO is 2.2 mg/L at RM 90 (Figure 4-1A), and at the lowest point of the DO sag (RM 90), DO is above 5 mg/L 51% of the time (Figure 4-1B).

As the effluent ammonia from all Class A' and A discharges was reduced from 10 mg/L (AA02) to 5 mg/L (AA03) to 1.5 mg/L (AA04), the minimum 1st percentile DO increases and moves upstream to 2.9 mg/L (RM 96), 3.4 mg/L (RM 96), and 4.0 mg/L (RM98), respectively (Figure 4-1A). Wastewater ammonia levels need to be reduced to 1.5 mg/L before DO in the FMA remains consistently above 4 mg/L. Similarly, minimum percent time above 5 mg/L increases from 51% (AA01) to 59% (AA02), 63% (AA03), and 74% (AA04) and the spatial extent that experiences DO < 5 mg/L decreases from 50 mi (AA01) to 37.5 mi (AA02), 33 mi (AA03), and 28 mi (AA04) (Figure 4-1B). Technically feasible reductions to 1.5 mg/L effluent ammonia have measurable and significant benefit towards achieving improved DO in the FMA.

In scenario AA05, reducing the total nitrogen (TN) to 4 mg/L (with NH34 = 1.5 mg/L) provides almost identical results to scenario AA04 (Figure 4-1A,B). While reducing total nitrogen to 4 mg/L is feasible, it provides no measurable benefit to DO improvement in the FMA; as such, this candidate scenario was eliminated from further consideration

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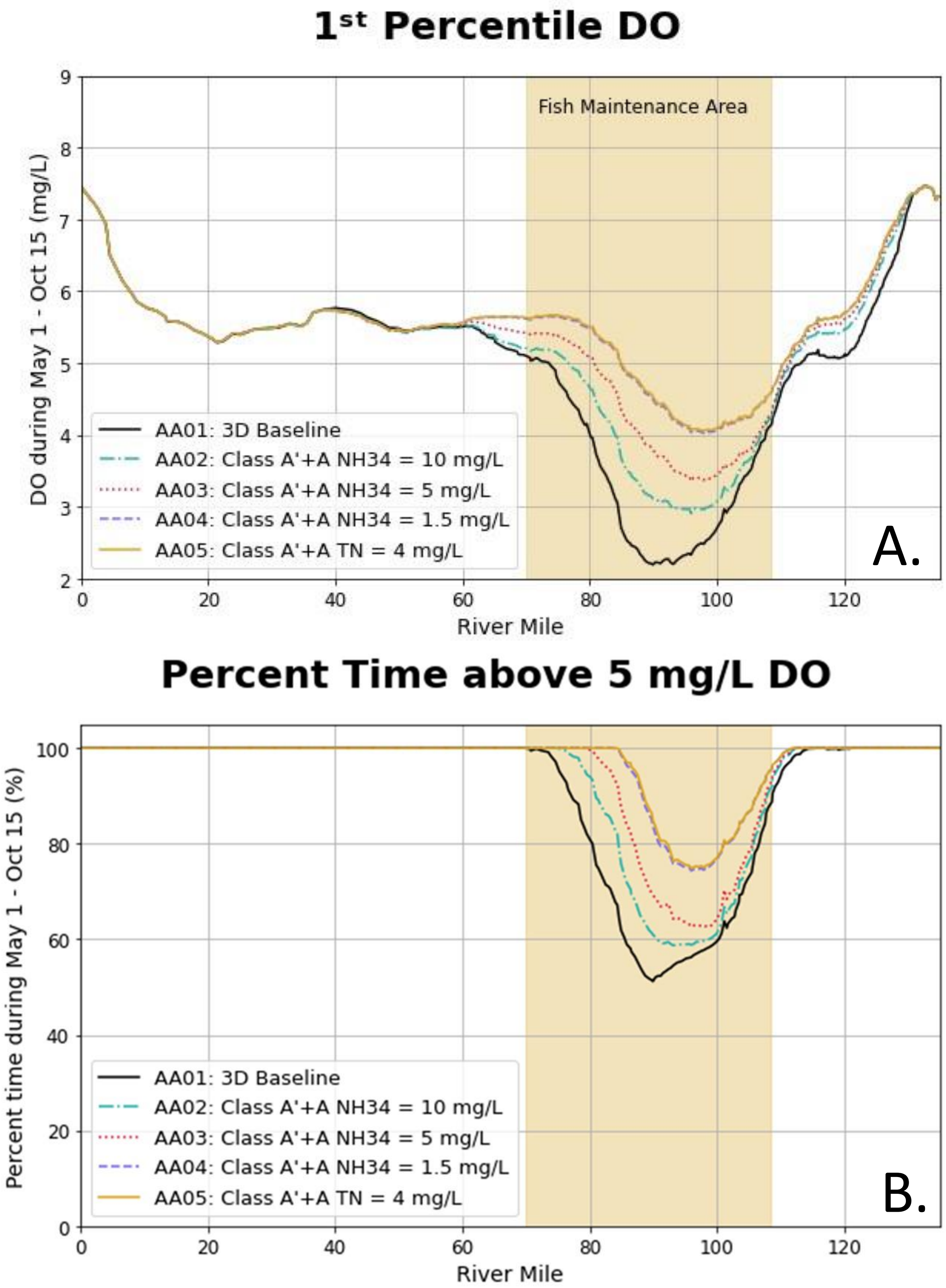


Figure 4-1: AA results for scenarios AA01–AA05

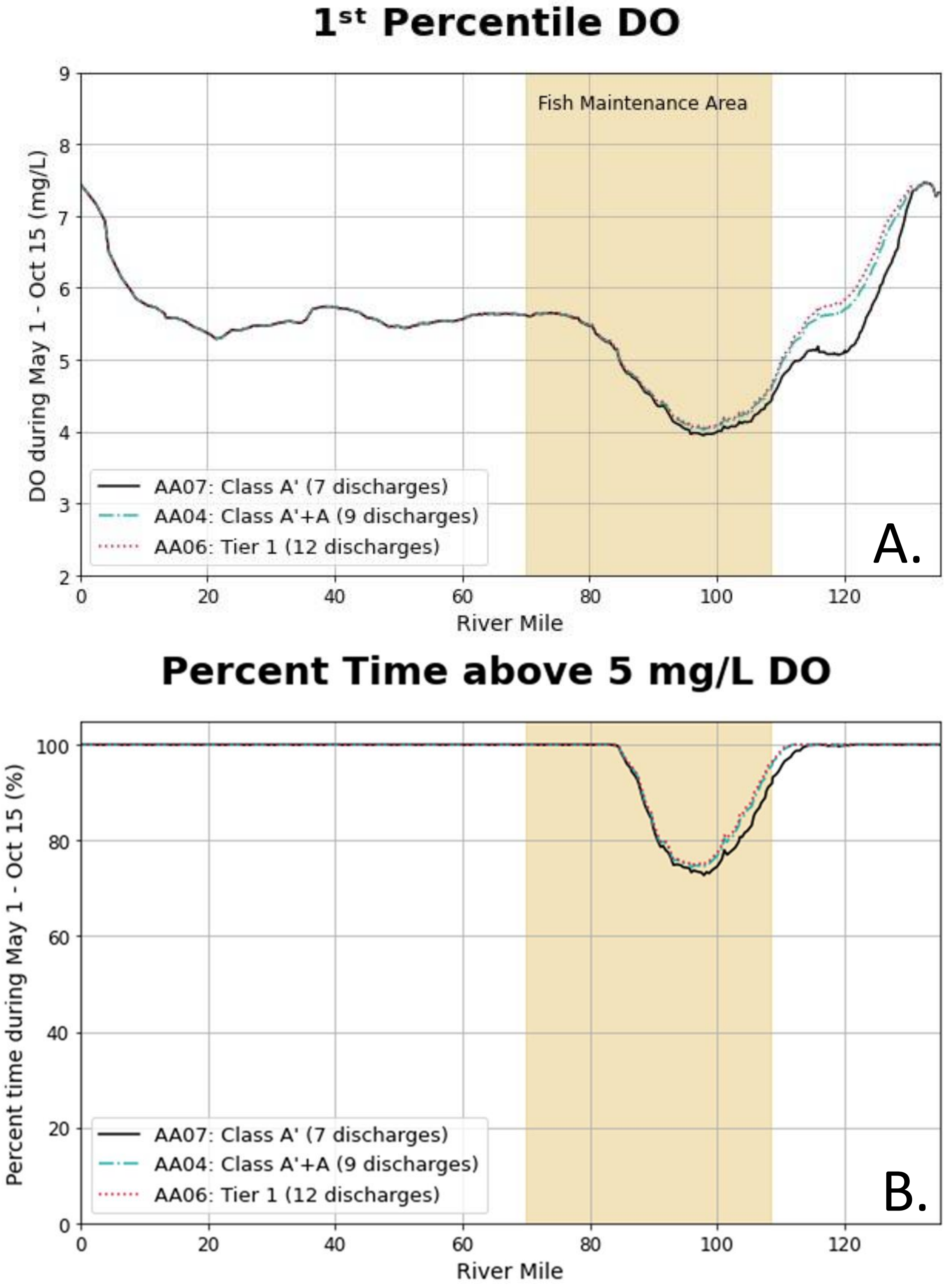


Figure 4-2: AA results for scenarios AA04, AA06 and AA07

Figure 4-2 compares scenarios AA04, AA06 and AA07, evaluating a reduction of effluent ammonia concentrations to 1.5 mg/L for the following groups of candidate discharges:

- AA07: The seven (7) wastewater discharges identified as Class A’ that have a major impact on low DO in the FMA.
- AA04: The nine (9) wastewater discharges identified as Class A’ and Class A.
- AA06: The twelve (12) wastewater discharges originally identified as “Tier 1” discharges. Tier 1 wastewater treatment plants were identified based on two-year effluent loading data collected in early 2010s whose key nutrients loads were contributing top 95% cumulative loads. Tier 1 discharges were included in the Kleinfelder costs study.

Using the seven discharges in Class A’ as the baseline (AA07), including two additional Class A discharges (AA04) brings measurable improvement in low DO and percent of time above 5 mg/L to the upper FMA. However, including 3 additional Tier 1 discharges (AA06) does not bring additional benefit over Scenario AA04. These results support including Class A and A’ discharges and eliminating other point-source discharges from future consideration.

Scenarios AA04, AA07, AA08 and AA10 represent a range of effluent ammonia reduction scenarios for Class A discharges (Table 4-1). In each scenario, the Class A’ discharges have effluent ammonia concentrations set to 1.5 mg/L. There is demonstrated benefit to low DO from reducing effluent ammonia for Class A discharges; as scenarios AA04, AA08, and AA10 have minimum 1st percentile DO ~0.1 mg/L higher, and a spatial extent experiencing DO < 5 mg/L ~10 mi lower, than AA07. However, DO improvement in the FMA is less sensitive to the level of ammonia reduction for the Class A discharges. Reducing Class A effluent ammonia to 10, 5 and 1.5 mg/L increases the minimum 1st percentile DO by 0.05, 0.06 and 0.08 mg/L, respectively, relative to AA07. Appendix A contains additional longitudinal plots showing 1st, 10th, 25th and 50th percentiles, as well as percent time over 4, 5, 6 and 7 mg/L from the groups of AA scenarios presented in Figures 4-1, 4-2, and 4-3.

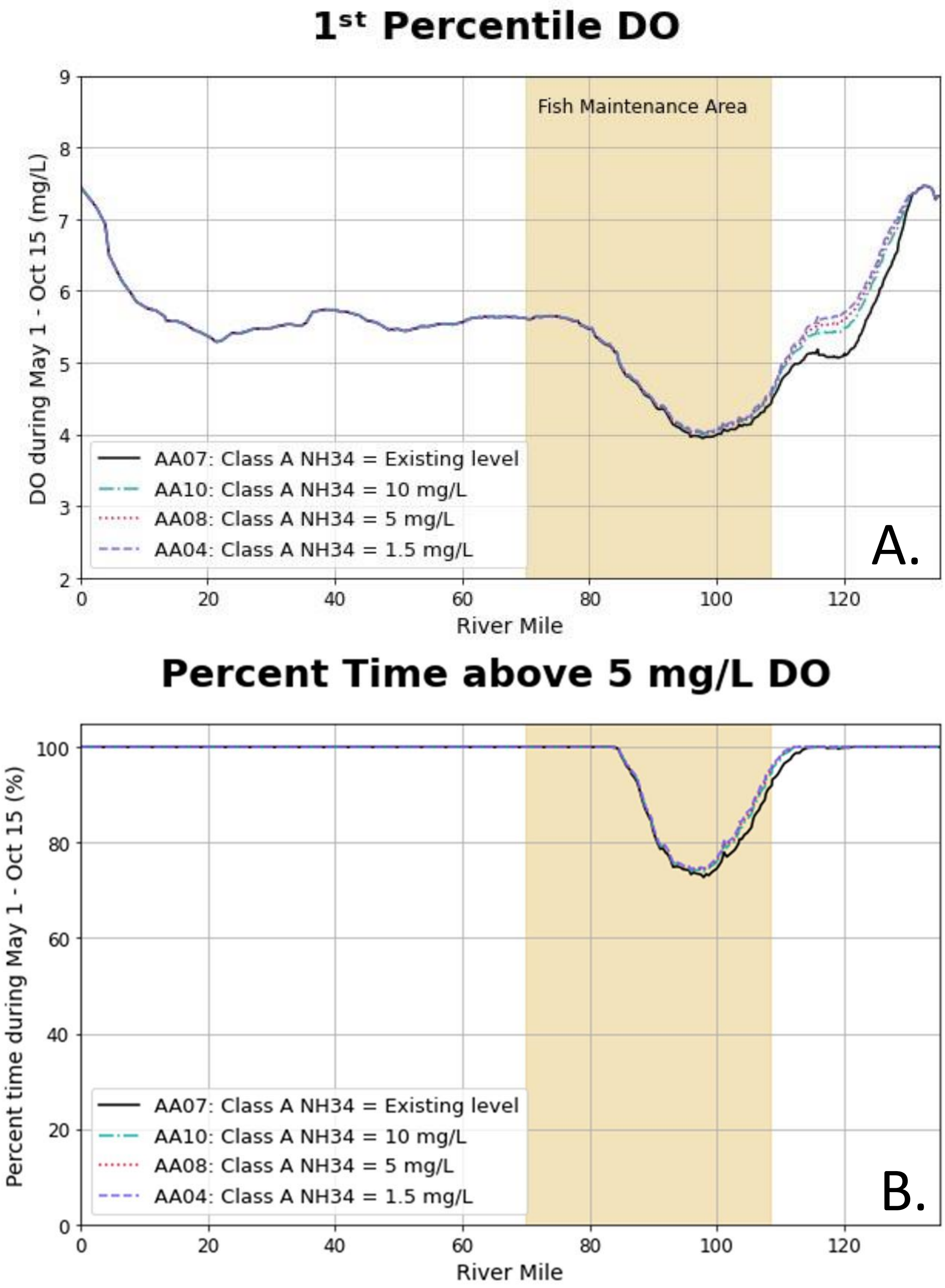
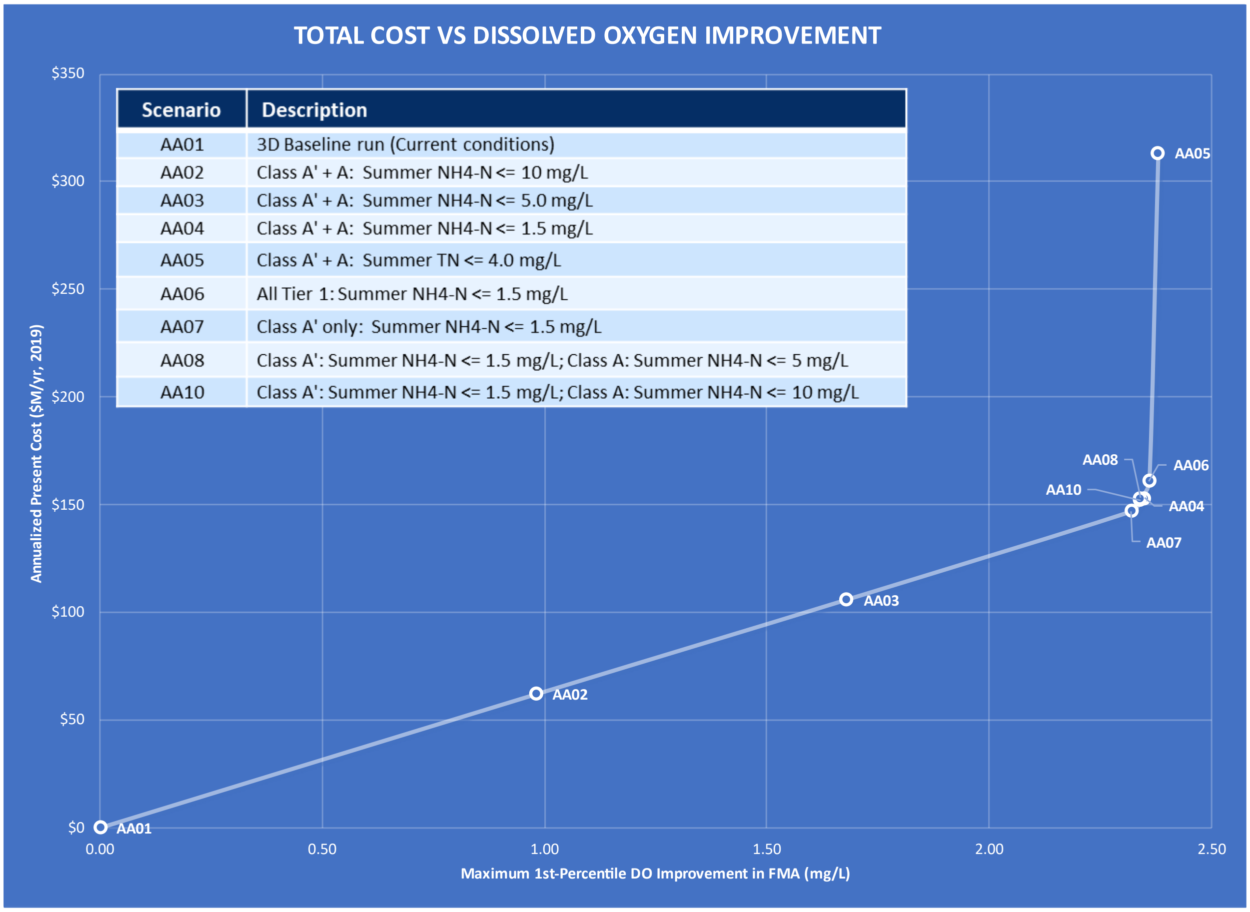


Figure 4-3: AA results for scenarios AA04, AA07, AA08 and AA10

4.2 WASTEWATER TREATMENT COSTS AND DO IMPROVEMENTS

An analysis of costs versus DO improvements is shown in Figure 4-4. Costs are presented as annualized present value in 2019 dollars and are taken directly from the feasibility and cost study (Kleinfelder, 2021) as applied to each AA scenario. The DO improvement between the Baseline (AA01) and each scenario varies in time and space, but is distilled into a single value by plotting the maximum improvement in the 1st percentile DO within the FMA. This metric was obtained by calculating the difference in 1st percentile DO at every longitudinal cell (i.e., RM coordinate) within the FMA, and then taking the maximum of those differences.



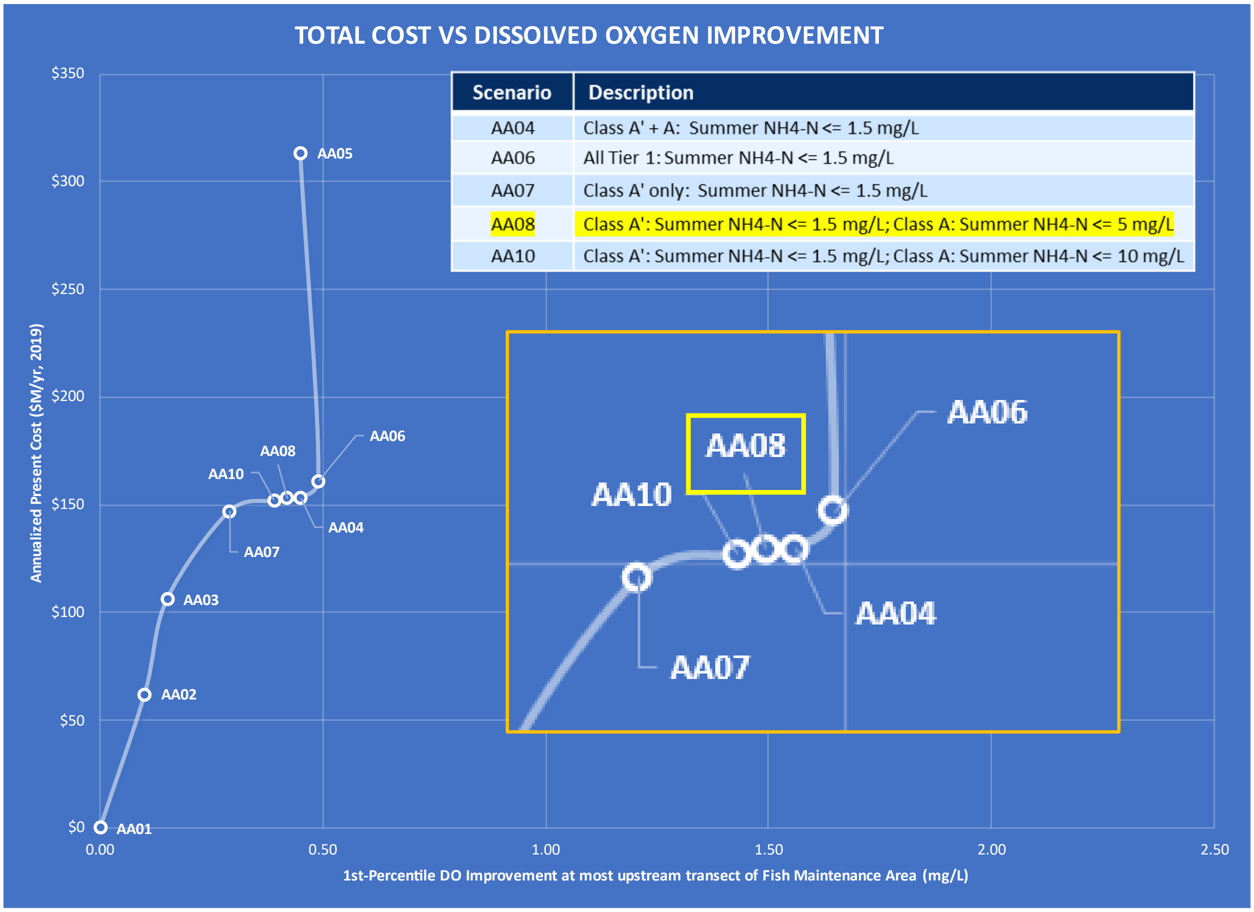
Scenario	Description
AA01	3D Baseline run (Current conditions)
AA02	Class A' + A: Summer NH4-N <= 10 mg/L
AA03	Class A' + A: Summer NH4-N <= 5.0 mg/L
AA04	Class A' + A: Summer NH4-N <= 1.5 mg/L
AA05	Class A' + A: Summer TN <= 4.0 mg/L
AA06	All Tier 1: Summer NH4-N <= 1.5 mg/L
AA07	Class A' only: Summer NH4-N <= 1.5 mg/L
AA08	Class A': Summer NH4-N <= 1.5 mg/L; Class A: Summer NH4-N <= 5 mg/L
AA10	Class A': Summer NH4-N <= 1.5 mg/L; Class A: Summer NH4-N <= 10 mg/L

Figure 4-4: Cost versus DO improvement within the FMA for each AA scenario

The resultant curve in Figure 4-4 shows a linear improvement in DO as wastewater ammonia concentrations decrease, and then a sharp inflection point going from an ammonia concentration of 1.5 mg/L to a total nitrogen concentration of 4.0 mg/L. This reflects the fact that, after reducing ammonia to the limit of technology through nitrification, removing nitrate would incur a high cost with no improvement in DO (AA05). Overall, this systemwide characterization of cost versus DO improvement points to the inflection point as the region where infrastructure investments can yield a significant benefit in terms of enhanced DO in the FMA. There are several AA scenarios clustered near the inflection point, which are discussed in Section 4.3 below.

4.3 RECOMMENDED SCENARIOS

Scenarios AA04, AA06, AA07, AA08, and AA10 are clustered around the inflection point, which essentially represents the point of vanishing returns in terms of infrastructure investment. Scenarios AA06 and AA07 differ in the number of discharges simulated at 1.5 mg/L ammonia: AA07 includes only the seven Class A' dischargers, while AA06 includes all twelve Tier 1 discharges. Scenarios AA04, AA08, and AA10 simulate the seven Class A' discharges at 1.5 mg/L ammonia, but simulate the two Class A discharges at ammonia levels of 1.5, 5.0 and 10 mg/L, respectively. Since the Class A discharges are both in Zone 2, upstream of the FMA, it makes sense to evaluate these scenarios at the region of the FMA where they exert their greatest impact, namely the most upstream transect of the FMA (i.e., the most upstream transect in Zone 3). Figure 4-5 does just that, plotting the annualized cost against the improvement in 1st percentile DO at the most upstream transect within the FMA.



Scenario	Description
AA04	Class A' + A: Summer NH4-N <= 1.5 mg/L
AA06	All Tier 1: Summer NH4-N <= 1.5 mg/L
AA07	Class A' only: Summer NH4-N <= 1.5 mg/L
AA08	Class A': Summer NH4-N <= 1.5 mg/L; Class A: Summer NH4-N <= 5 mg/L
AA10	Class A': Summer NH4-N <= 1.5 mg/L; Class A: Summer NH4-N <= 10 mg/L

Figure 4-5: Cost versus DO improvement at upstream-most transect in the FMA for each AA scenario

Notice that the overall magnitude of DO improvement is smaller in the most upstream transect (Figure 4-5) compared to the transect with the maximum improvement (Figure 4-4), which occurs near the center of the FMA where the current DO sag is largest. Also notice that scenario AA07, in which only the seven Class A’ discharges are simulated at a reduced ammonia concentration of 1.5 mg/L, leaves significant additional DO improvement at this transect in the FMA. It would not be possible to characterize that scenario as the one that would produce the HADO, since additional DO improvement in the FMA can be achieved for a relatively small investment on a systemwide basis. The opposite is true for scenario AA06, which simulates all 12 Tier 1 discharges with ammonia at 1.5 mg/L. Clearly this scenario lies on the vertical portion of the curve, in which costs increase quickly with no incremental improvement in DO.

This leaves scenarios AA04, AA08, and AA10, which differ only in the effluent concentrations assumed for the two Class A discharges. While the DO differences among these scenarios are not significant, the cost differences are also insignificant. DRBC therefore recommends implementation of scenario AA08, in which the two Class A discharges in Zone 2 are assigned ammonia concentrations of 5.0 mg/L.

It is important to recognize that the recommended AA scenario, and the resultant HADO condition, were based solely on technological feasibility, natural conditions, and the sensitivity of DO improvement to further load reduction. Cost and affordability were both quantified and considered, but no socio-economic constraints drove the selection of the recommended AA scenario. Technological feasibility also played a minimal role, as the impact on DO from further ammonia reductions, even if they were possible, would be minimal. Furthermore, the study demonstrated that the reduction of other nutrient sources, such as total nitrogen from wastewater, would not yield any further improvement in the low DO condition in the Estuary. Implementation of the wastewater load reductions simulated in recommended scenario AA08 would result in an overall future ammonia load reduction of 87% (based on design conditions) from the nine wastewater discharges that would be impacted, as shown in Table 4-2Table 4-2: Recommended below.

Table 4-2: Recommended ammonia load reductions under design conditions

Wastewater Discharge	**Summer Ammonia Load (kg/day)**		
	Baseline Scenario	**Recommended (AA08)**	**Percent Reduction**
PWD Southwest WPCP	14,400	1,140	92%
Camden County MUA	5,240	454	91%
City of Wilmington WWTP	4,810	761	84%
PWD Southeast WPCP	3,630	636	83%
PWD Northeast WPCP	3,540	1,190	66%
Gloucester County UA	2,440	153	94%
Hamilton Twp WPCF	1,630	91	94%
DELCORA	1,010	397	61%
Lower Bucks County JMA	748	57	92%
Total	37,448	4,879	87%

4.4 SOCIO-ECONOMIC EVALUATION

DRBC evaluated the socio-economic factors affecting the attainment of uses, as required by Resolution No. 2017-4. Details of the affordability evaluation are documented in a separate report entitled *Social and Economic Factors Affecting the Attainment of Aquatic Life Uses in the Delaware River Estuary* (DRBC, 2022b).

During 2022, DRBC became aware that DELCORA sought to increase the permitted flow of its plant from 50 million gallons per day (MGD) to 70 MGD. DRBC commissioned Kleinfelder to develop an addendum to its 2021 report (Kleinfelder, 2021) with updated cost estimates for DELCORA reflecting the new proposed permitted flow (Kleinfelder, 2022). This evaluation utilized the updated cost estimate for DELCORA. The effluent levels for Tier 1 Utilities and annualized costs (in $M, 2019 dollars) are shown in Table 4-3 below.

Table 4-3: Annualized cost in 2019 $M/yr. to achieve reduced effluent levels

Utility	New Effluent Concentration			
	Ammonia 10 mg/L	Ammonia 5 mg/L	Ammonia 1.5 mg/L	Total Nitrogen 4 mg/L
Wilmington	6	20	26	49
CCMUA	12	15	18	35
City of Trenton	0.1	2	3	6
Hamilton Twp WPCF	3	4	4	7
Willingboro WPCF	0	0	2	3
DELCORA	4	11	14	27
Morrisville	2	2	3	5
LBCJMA	2	2	2	5
GCUA	3	4	5	11
PWD (SW, SE, & NE)	32	50	84	179

Two guidance documents were utilized to evaluate the social and economic impact of these potential costs on the affected communities.

- EPA. *Proposed 2022 Clean Water Act Financial Capability Assessment Guidance*. February 2022.
- AWWA et al. *Developing a New Framework for Household Affordability and Financial Capability Assessment in the Water Sector*. April 17, 2019.

Although numerous metrics were evaluated as part of the overall socio-economic evaluation, two key resulting affordability metrics are presented: the Household Affordability (HA) metric from the AWWA guidance and the Residential Indicator (RI) from the EPA guidance. These two metrics allow for the comparison of different future scenarios to each other and to the Baseline. All results are presented by utility service area. The affordability burden factors presented here should not be interpreted as a service area rate study. Final costs to taxpayers or rate payers will depend upon many factors, including the availability and use of federal, state and local programs that can improve affordability for utilities, communities, and individual households.

The combined total annualized cost for the wastewater improvements recommended in scenario AA08 equals $153M/yr in 2019 dollars, which includes the annualized present worth of $2.6B of capital investment as well as annual operation and maintenance. As shown in Table 4-4 below, for scenario AA08 neither indicator shows a change to the burden category compared to the Baseline. While significant costs are associated with scenario AA08, and these costs are assumed to be distributed among ratepayers, the associated increase to ratepayers is not enough to increase the baseline burden category, as defined by either guidance document, to a higher category. By comparison, scenarios AA05 and AA06 do show a change to the burden category for PWD (AA05) and Morrisville and Willingboro (AA06) beyond the Baseline burden category (AA01).

Table 4-4: Affordability metric categories for AA scenarios

Utility Name	Metric	AA01	AA02	AA03	AA04	AA05	AA06	AA07	AA08
CCMUA	HA	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
	RI	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE
City of Trenton	HA	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden
	RI	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE
DELCORA	HA	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
	RI	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE
GCUA	HA	Low Burden	Low Burden	Low Burden	Low Burden	Low-Burden	Low Burden	Low Burden	Low Burden
	RI	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Hamilton Twp WPCF	HA	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
	RI	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE
LBCJMA	HA	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
	RI	LOW	LOW	LOW	LOW	LOW	LOW	LOW	LOW
Morrisville	HA	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden	Low Burden
	RI	LOW	LOW	LOW	LOW	LOW	MID-RANGE	LOW	LOW
PWD	HA	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden	High Burden	Moderate-High Burden	Moderate-High Burden	Moderate-High Burden
	RI	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	HIGH	MID-RANGE	MID-RANGE	MID-RANGE
Willingboro WPCF	HA	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
	RI	LOW	LOW	LOW	LOW	LOW	MID-RANGE	LOW	LOW
Wilmington	HA	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden	Moderate-Low Burden
	RI	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE	MID-RANGE

5. HIGHEST ATTAINABLE DISSOLVED OXYGEN (HADO)

Future condition scenario AA08 is recommended to support the HADO; this scenario provides the highest technically attainable improvement in DO within the FMA from point source wastewater discharges. Scenario AA08 assigns a constant summer ammonia concentration for seven Class A’ discharges at 1.5 mg/L and for two Class A discharges at 5 mg/L; nitrate and CBOD were adjusted accordingly (Section 2.5). In addition, the summer effluent DO for nine Class A’ and A discharges was assigned the higher of 2 mg/L or the current effluent DO limit (DELCORA and GCUA have current DO limits of 4.0 mg/L). However, additional factors, beyond wastewater reductions, must be considered to determine the HADO itself.

5.1 ADDITIONAL HADO FACTORS

Four additional factors were considered to establish the HADO under design conditions: 1) planned CSO reductions; 2) improved effluent DO; 3) seasonally variable wastewater ammonia concentrations; and 4) reserve capacity for future growth. Each is explained below and incorporated into scenario AA15, presented in Section 5.2.

5.1.1 CSO Reductions

There are four combined sewer systems in the Delaware River Estuary: PWD, Camden County MUA, DELCORA, and City of Wilmington. Each system is at various stages of implementation of their long-term control plans (LTCPs) for CSOs. Based on evaluation of each LTCP, the progress “to date”, CSO control results already incorporated into the Baseline condition (for example, the City of Wilmington LTCP is effectively complete and as such the assumed reduction for the HADO scenario is 0%), and conversations with each utility, pollutant loads from CSOs were reduced by the percentages shown in Table 5-1.

Table 5-1: CSO reductions assumed for HADO scenario

Combined Sewer System	Post-LTCP % reduction
Philadelphia Water Department	55%
Camden County MUA	59%
DELCORA	51%
City of Wilmington	0%

This CSO adjustment is intended to capture load reductions that can reasonably be expected based on the full implementation of LTCPs, which will be implemented regardless of the outcome of this AA. These reductions are not intended to reflect any additional load reduction requirements, but rather to capture load reductions expected to occur with management programs already in place. The impact of the implementation of CSO LTCPs on scenario AA08 is shown in Figure 5-1.

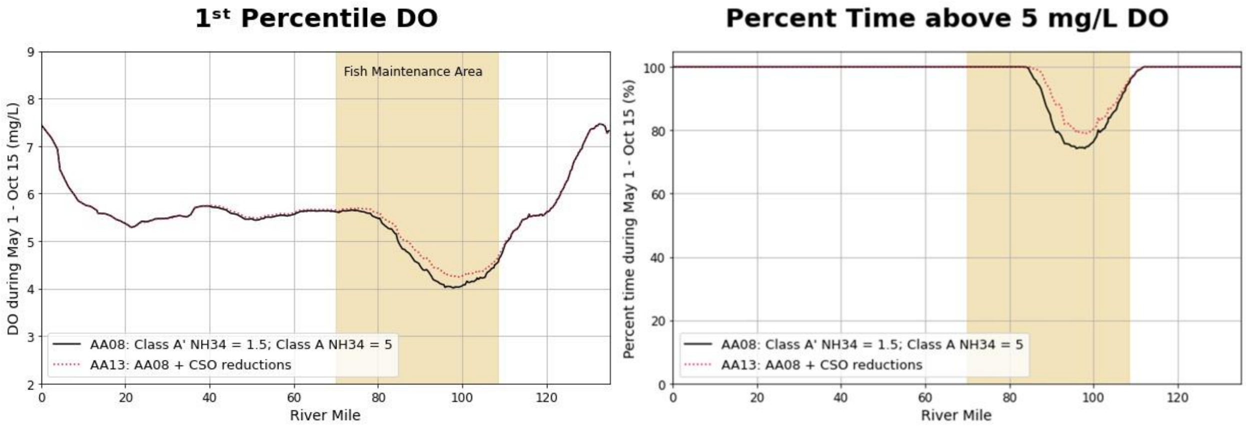


Figure 5-1: Impact of CSO reductions on HADO

5.1.2 Effluent DO Concentration

Removing ammonia via nitrification uses oxygen and, apart from any other design constraints, 2 mg/L would be the expected minimum residual DO after nitrification. Thus, the AA scenarios assigned each effluent DO from each discharge with reduced ammonia to 2 mg/L or the current effluent DO limit if higher. However, effluent DO concentration is important during low-DO periods in the FMA, and therefore must be considered in determining the HADO. Figure 5-2 shows the impact of setting effluent DO concentrations from the largest six discharges to a level of 5.0 mg/L. DRBC is currently testing which discharges can impact the HADO and at what effluent DO levels. In addition, DRBC is amending the cost and feasibility study to further evaluate scenarios that include minimum effluent DO levels. For the purpose of developing this estimated HADO condition, summer effluent DO was set to a level of 4 mg/L for all nine Class A' and Class A discharges. It is possible that the results of the testing and feasibility work currently underway will result in slight modifications to the estimation of the HADO condition.

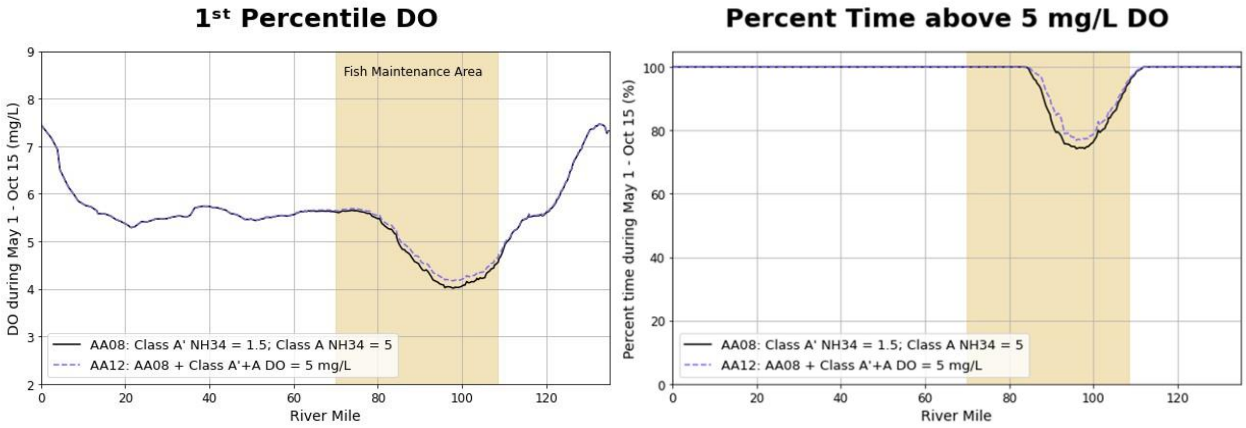


Figure 5-2: Impact of effluent DO on HADO

5.1.3 Seasonally Variable Wastewater Concentrations

Recall that wastewater load reduction scenarios were developed by assigning constant summer effluent concentrations that correspond to particular reduction profiles. For instance, a scenario to simulate reducing ammonia to a level of 1.5 mg/L for a particular discharge would involve assigning a constant ammonia concentration to that discharge during the "summer" (May 1–October 31). This is an extremely conservative methodology. First of all, a treatment plant required to meet a level of 1.5 mg/L during the entire summer, regardless of exactly how that level were implemented in a wastewater permit (e.g., as a daily, weekly, or monthly average), would be designed to always be below 1.5 mg/L. Simulating the concentration as a constant value equivalent to the target level is therefore very conservative. Second, the treatment design for the plant would be based on the months of May and October, when temperatures are lowest. Nitrification is a highly temperature-dependent process; therefore a plant meeting a level of 1.5 mg/L in May and October will perform better during warmer months. Finally, even if the nitrification process were not operating year-round, any plant designed to hit an effluent limit in May would begin the process no later than April to ensure performance by May 1. To better capture the HADO condition, a slightly more realistic assignment of wastewater concentrations was utilized based on Table 5-2. This methodology has been compared to actual data from plants in NJ and remains very conservative compared to actual effluent concentrations. Applying this methodology is not intended to suggest any changes to wasteload allocations or intra-seasonal effluent limitations; instead it is intended to better capture implementation of summer ammonia limits.

Table 5-2: Wastewater adjustments assumed for HADO scenario

Months	**Adjustment**	**Simulated ammonia (mg/L)**	
		SV = 1.5	**SV = 5**
April	1.5 × SV	2.25	7.5
May, October	1 × SV	1.5	5
June, September	5/6 × SV	1.25	4.17
July, August	2/3 × SV	1	3.33

Note: SV = scenario value

5.1.4 Reserve Capacity

Reserve capacity is based upon an assumption that additional ammonia load that could be held in reserve by DRBC for the consideration of future growth. This load may be allocated to new or expanding discharges by Zone or at the discretion of the Commission. For the purpose of preparing an estimated HADO condition that reflects a reasonable level of assumed reserve capacity, the ammonia concentration assigned to all modeled dischargers was increased by 10%.

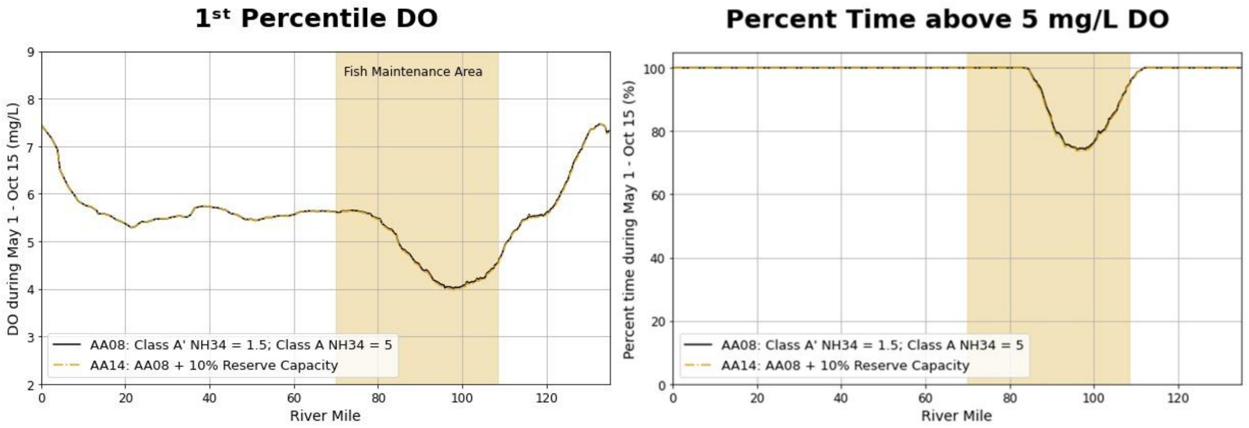


Figure 5-3: Impact of 10% reserve capacity on HADO

A total of 67 wastewater discharges were considered in the eutrophication model and AA evaluation. To accommodate future growth, an additional 10 percent of ammonia load from all discharges was calculated based on the recommended AA08 scenario. Using this approach, a total of 709 kg/day ammonia load (equivalent to 125 MGD at 1.5 mg/L) was incorporated. As shown in Figure 5-3, a 10% reserve capacity using this methodology does not substantially change DO conditions.

5.2 ESTIMATED HADO RESULT

Scenario AA15 incorporates all the modifications to scenario AA08 described in Section 5.1, and was developed to estimate a HADO condition that can be expected if the recommended wastewater treatment and nutrient reduction scenario (AA08) is implemented. As shown in the comparison among Baseline (AA01), AA08, and AA15 scenarios (Figure 5-4), the HADO condition will increase the trough of the DO sag (under design conditions) by 2.3 mg/L and shift the trough upstream by 10 miles, from RM 90 to RM 100.

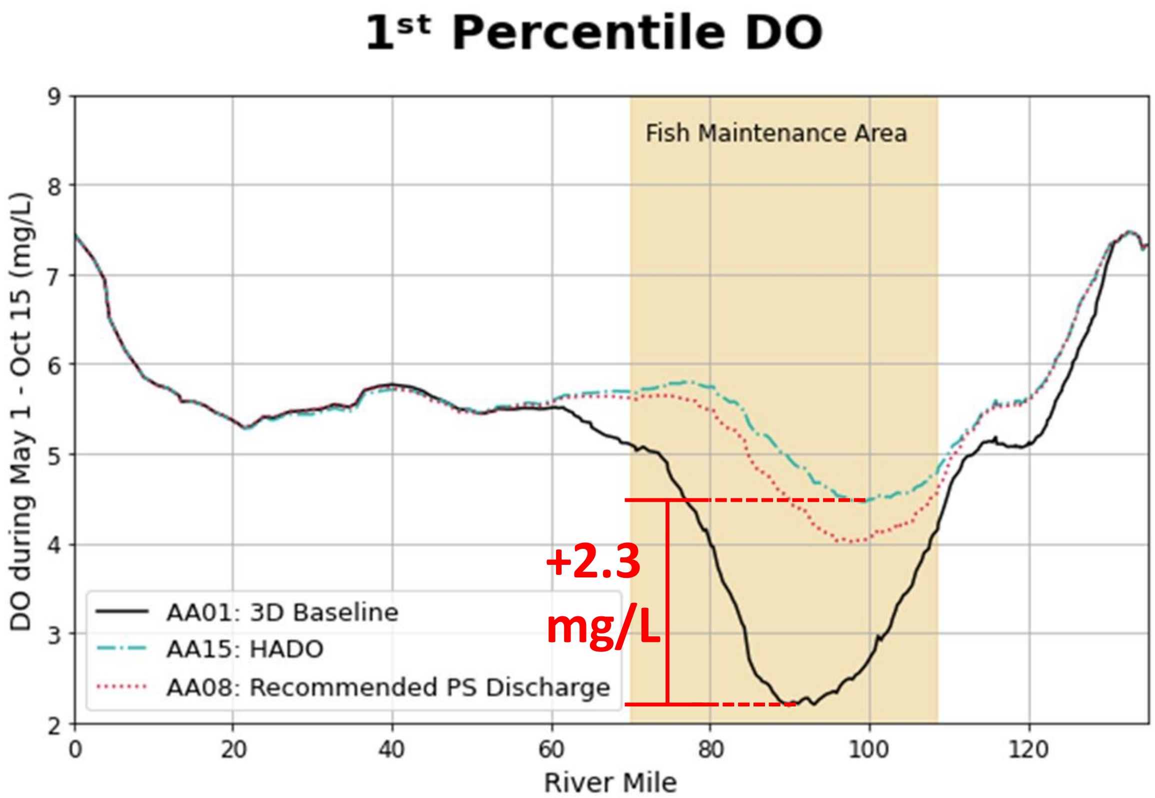
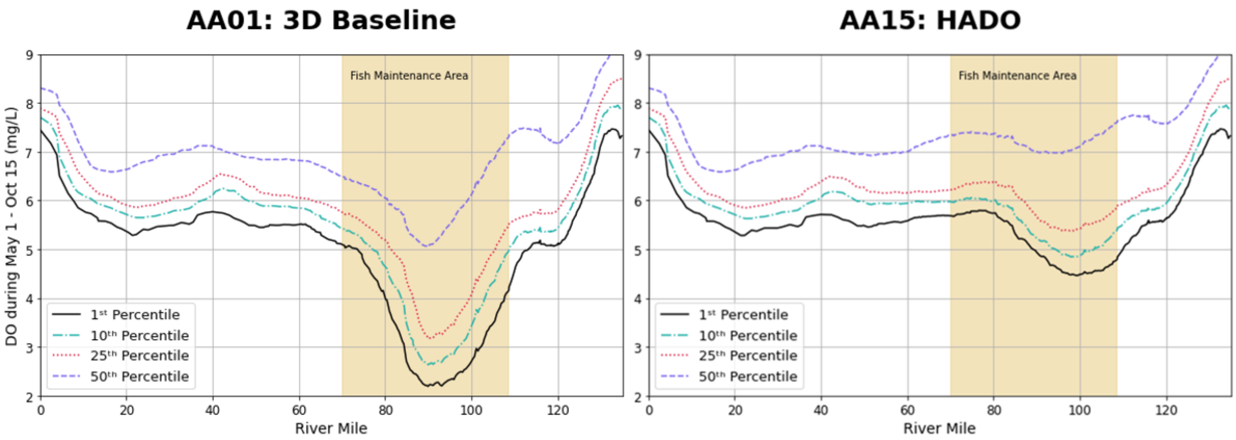


Figure 5-4: Comparison of 3D Baseline, scenario AA08, and HADO (AA15)



Percentile	Min value in FMA	
	AA01	AA15
1	2.2 mg/L	4.5 mg/L
10	2.6 mg/L	4.8 mg/L
25	3.2 mg/L	5.4 mg/L
50	5.0 mg/L	7.0 mg/L

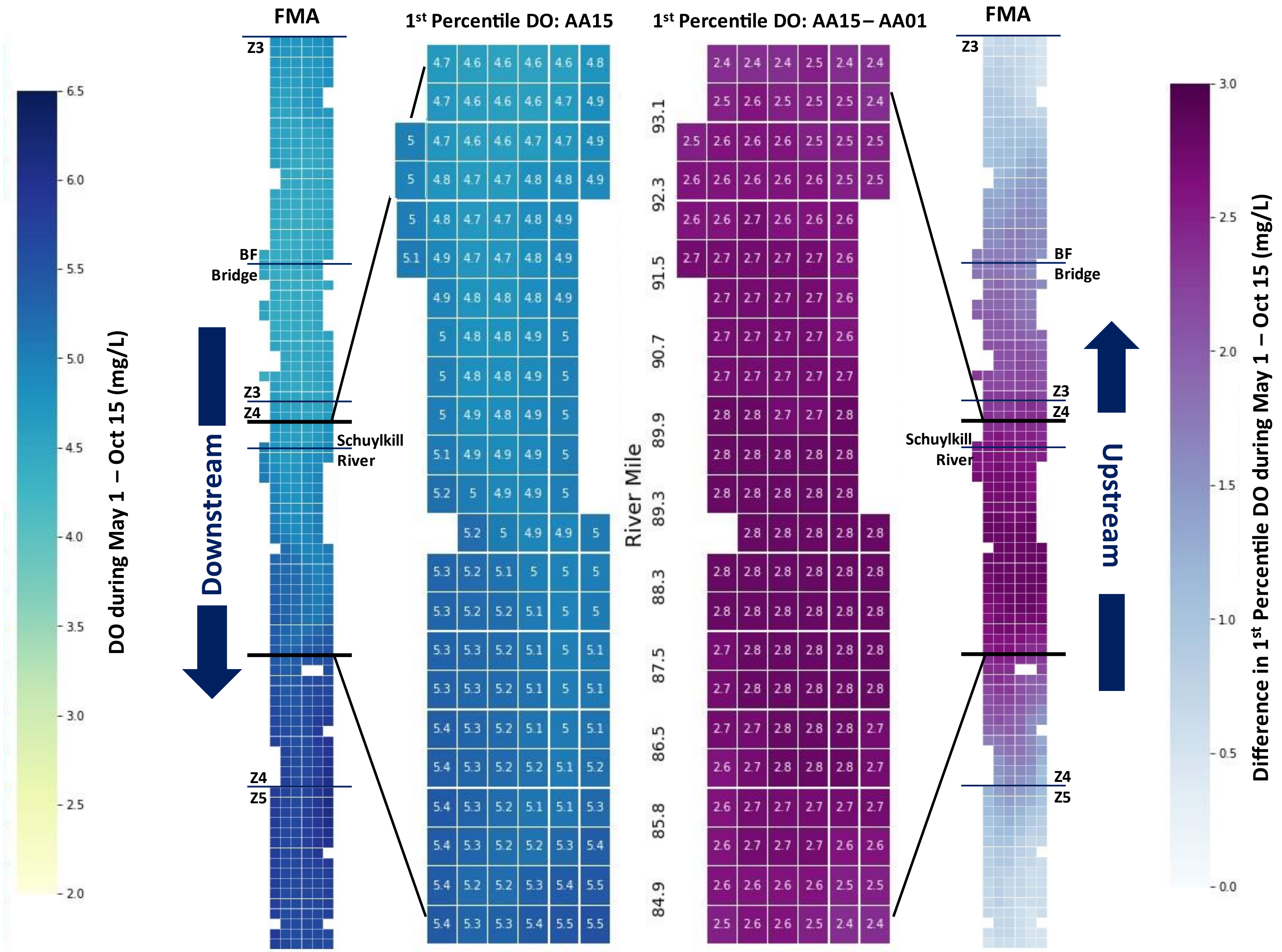
Figure 5-5: Predicted DO percentiles for 3D Baseline and HADO conditions

Figure 5-5 shows the longitudinal 1st, 10th, 25th, and 50th (median) percentile predictions for the Baseline (AA01) and HADO (AA15) scenarios, as well as the differences in minimum percentile values within the FMA. This provides a more complete picture across the lower end of the frequency distribution and illustrates the significant improvement in DO conditions that would be expected from implementation of the recommended AA scenario.

Figure 5-6 visually displays improvement to 1st percentile DO throughout the FMA portion of the Estuary. The left maps show 1st percentile DO expected under the HADO condition and the right maps show increases in 1st percentile DO relative to the Baseline scenario (AA01), zooming in on RM 85–94, where the current DO sag is centered. Increases to the lowest-DO values are consistent throughout the current DO sag, representing 2.4–2.8 mg/L of DO improvement at every modelled location within RM 85–94. Similarly, Figure 5-7 shows the profound difference and significant improvement in DO Relative Stress Index, a metric that captures the relative differences in potential DO stress to fish, within the FMA for the Baseline and HADO scenarios. The tabular results in Figure 5-6 also demonstrate the consistency of the results within each transect (i.e., from bank to bank); this demonstrates that the longitudinal spatial plots used throughout this report are representative.

Finally, Figure 5-8 shows the 1st percentile DO predicted for the estimated HADO condition under actual wastewater flow (as opposed to permitted) and hydrology conditions in 2012, 2018 and 2019, compared with the HADO under design conditions. As described in Section 2.4.1, the years 2012, 2018, and 2019 incorporate a range of temperatures and flows that can be generally characterized as more critical, less critical, and more typical, respectively. Additional comparisons between Baseline and HADO conditions (including longitudinal plots for 1st, 10th, 25th and 50th percentiles, longitudinal plots for percent time over 4, 5, 6 and 7 mg/L, and tabular maps for 1st percentile DO), as well as comparisons of the estimated HADO scenario under different flow conditions, are provided in Appendix B.

The estimated HADO condition, which was developed as described above based on Scenario AA08, represents an estimate of the best DO condition that can be expected under critical conditions based on the physics, chemistry and biology of the system. As stated earlier, socio-economic factors including cost and affordability were both considered, but did not impact the recommended scenario. Technological feasibility, represented by the lowest level of wastewater ammonia concentration (1.5 mg/L), drove the methodology but not the outcome to any significant degree. Based on the estimated HADO condition (AA15), implementation of the recommended AA scenario (AA08) will improve dissolved oxygen in the FMA such that both maintenance and propagation of resident fish will be supported throughout the Delaware River Estuary.



1st Percentile DO: AA15

	4.7	4.6	4.6	4.6	4.6	4.8
	4.7	4.6	4.6	4.6	4.7	4.9
5	4.7	4.6	4.6	4.7	4.7	4.9
5	4.8	4.7	4.7	4.8	4.8	4.9
5	4.8	4.7	4.7	4.8	4.9	
5.1	4.9	4.7	4.7	4.8	4.9	
	4.9	4.8	4.8	4.8	4.9	
	5	4.8	4.8	4.9	5	
	5	4.8	4.8	4.9	5	
	5	4.9	4.8	4.9	5	
	5.1	4.9	4.9	4.9	5	
	5.2	5	4.9	4.9	5	
		5.2	5	4.9	4.9	5
	5.3	5.2	5.1	5	5	5
	5.3	5.2	5.2	5.1	5	5
	5.3	5.3	5.2	5.1	5	5.1
	5.3	5.3	5.2	5.1	5	5.1
	5.4	5.3	5.2	5.1	5	5.1
	5.4	5.3	5.2	5.2	5.1	5.2
	5.4	5.3	5.2	5.1	5.1	5.3
	5.4	5.3	5.2	5.2	5.3	5.4
	5.4	5.2	5.2	5.3	5.4	5.5
	5.4	5.3	5.3	5.4	5.5	5.5

1st Percentile DO: AA15 – AA01

	2.4	2.4	2.4	2.5	2.4	2.4
	2.5	2.6	2.5	2.5	2.5	2.4
2.5	2.6	2.6	2.6	2.5	2.5	2.5
2.6	2.6	2.6	2.6	2.6	2.5	2.5
2.6	2.6	2.7	2.6	2.6	2.6	
2.7	2.7	2.7	2.7	2.7	2.6	
	2.7	2.7	2.7	2.7	2.6	
	2.7	2.7	2.7	2.7	2.6	
	2.7	2.7	2.7	2.7	2.7	
	2.8	2.8	2.7	2.7	2.8	
	2.8	2.8	2.8	2.8	2.8	
	2.8	2.8	2.8	2.8	2.8	
		2.8	2.8	2.8	2.8	2.8
	2.8	2.8	2.8	2.8	2.8	2.8
	2.8	2.8	2.8	2.8	2.8	2.8
	2.7	2.8	2.8	2.8	2.8	2.8
	2.7	2.8	2.8	2.8	2.8	2.8
	2.7	2.7	2.8	2.8	2.8	2.7
	2.6	2.7	2.8	2.8	2.8	2.7
	2.6	2.7	2.7	2.7	2.7	2.7
	2.6	2.7	2.7	2.7	2.6	2.6
	2.6	2.6	2.6	2.6	2.5	2.5
	2.5	2.6	2.6	2.5	2.4	2.4

Figure 5-6: Tabular maps of DO improvement in FMA under HADO condition

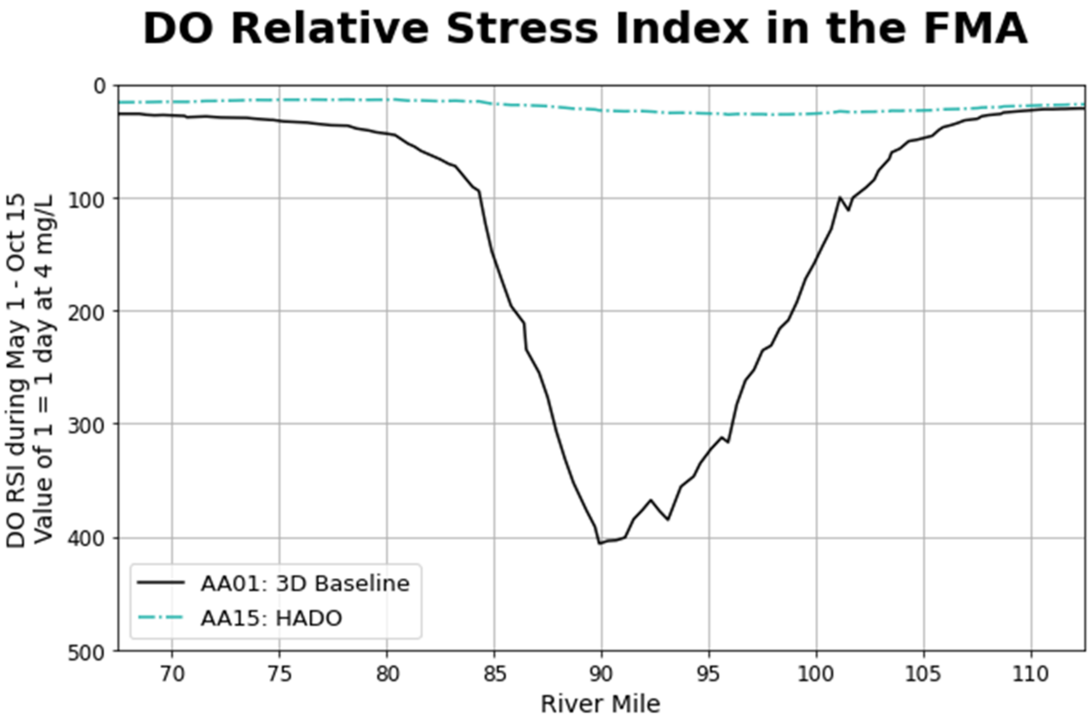


Figure 5-7: Expected improvement in DO RSI under HADO condition

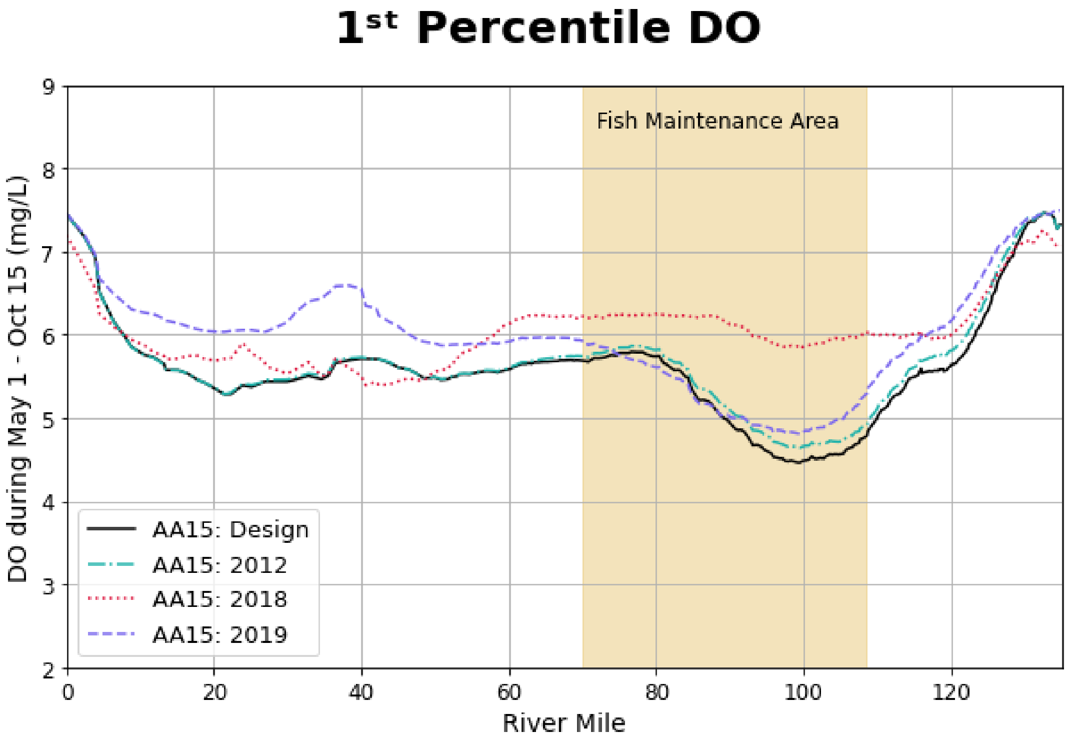


Figure 5-8: HADO under different flow conditions

As demonstrated above, the minimum DO under critical design conditions will increase from 2.2 to 4.5 mg/L in the FMA, and this will be accompanied by a significant increase in the duration at any location during which the DO will be over 4, 5, 6 and 7 mg/L. The HADO will eliminate the occurrence of DO levels below 4.3 mg/L, a level below which will not support propagation of one or more DO-sensitive species in the Delaware River Estuary (DRBC, 2022c). Within the range of suitability from 4.3 mg/L and 7.0 mg/L (DRBC, 2022c), the degree of propagation attained will depend on the timing, frequency, and duration of exposure to particular DO levels. The HADO condition exceeds a level of 5 mg/L 100% of the time during nine months of the year, and will increase the exceedance of 5 mg/L during the months of July through September from 17% to 72% compared to the Baseline, as shown in Figure 5-9. Furthermore, the number of river miles over which the water column under critical conditions can be expected to ever drop below 5 mg/L will decrease from 51 to 12 miles. This represents an excellent DO condition for any estuary and will support both maintenance and propagation of resident fish. In addition, the HADO condition will exceed (i.e., be better than and result in more DO than required by) the criteria established by EPA to protect DO-sensitive fish in the Chesapeake Bay including Atlantic sturgeon, one of the more sensitive species in the Estuary.

The HADO condition will form the basis for the development of water quality criteria, which will be performed in collaboration with co-regulators and with input from the Commission's WQAC. More than one criteria will likely be adopted to account for seasonal and temporal variations in DO. A final proposal will be the subject of rulemaking, in which DRBC will propose a revised designated use and draft water quality criteria to protect that use.

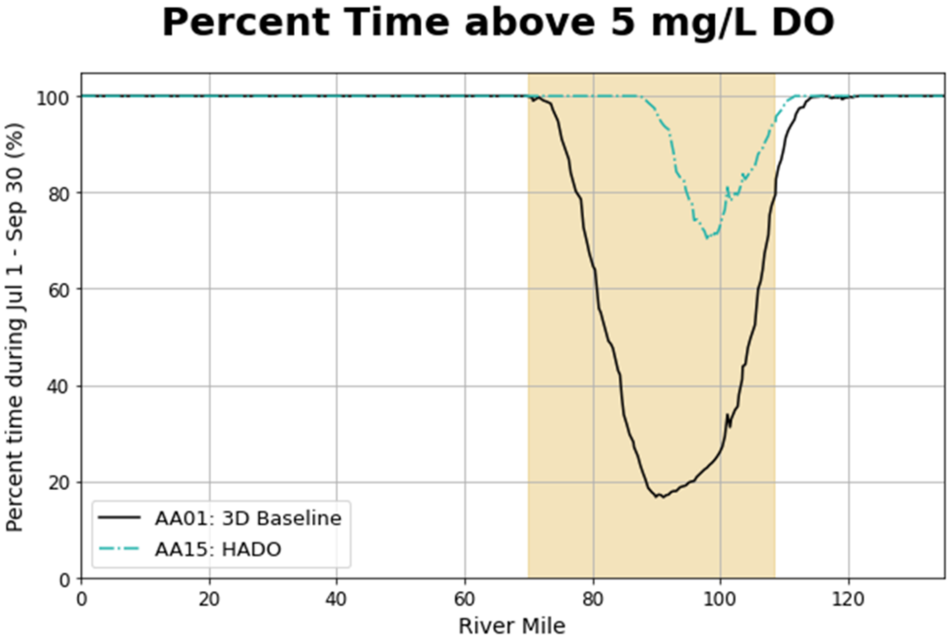


Figure 5-9: Percent of time above 5 mg/L (July–September) for 3D Baseline and HADO

6. TECHNICAL SUMMARY

By Resolution No. 2017-4, the Commission directed the DRBC staff to initiate a rulemaking process to revise the aquatic life uses of the Delaware River Estuary and the water quality criteria necessary to protect these uses, with the understanding that before new standards could be proposed or finalized, additional studies were needed to support rulemaking. The studies outlined by Resolution No. 2017-4 have been completed. A linked, three-dimensional hydrodynamic and eutrophication model for the Delaware River Estuary was developed, calibrated, and utilized to evaluate potential DO improvement by source control scenarios. Multiple sensitivity and future condition test scenario simulations were performed to identify key variables and sources to improve the DO sag around Philadelphia and Camden and to enhance overall DO conditions in the FMA.

The Commission’s directive emphasized the importance of a collaborative process informed by technical studies and specialized scientific and engineering expertise. From the outset of this project, DRBC staff have drawn on the expertise of the Commission’s member agencies and the basin community through the WQAC, meetings with co-regulators, and consultation with its Model Expert Panel. The Commission’s WQAC is comprised of representatives from DRBC’s state and federal partner agencies, the industrial and municipal regulated community, environmental groups, local watershed organizations, and academia. Its meetings are announced in advance and open to the public. Since the adoption of Resolution No. 2017-4, the WQAC has met twenty-one times, including monthly from April through September 2022 to share and discuss the Baseline design conditions, assumptions, scenario development, evaluation metrics, findings, and overall progress of the AA studies. Staff engaged in a similar level of interaction with co-regulators and the Model Expert Panel. As necessary, staff met with dischargers individually to gather more reliable information and to improve assumptions used in the AA studies. The results presented in this report are summarized below.

Summary of Analysis of Attainability

An analysis of attainability was performed under 2012 hydrologic conditions, which exhibited the worst ambient DO conditions observed in the Estuary in more than 12 years. The Baseline design condition was developed utilizing the permitted effluent flows for sixty-seven (67) wastewater discharges. Effluent concentrations were assigned using the median values from 2018–2019 effluent monitoring data to reflect current effluent characteristics. The work comprising this analysis of attainability, together with supporting studies, including those performed by the DRBC and those it commissioned, shows:

- The addition of technically feasible advanced treatment by nine (9) out of 67 wastewater point-source discharges to reduce effluent ammonia nitrogen during the summer permitting season (May to October) will significantly improve the level of dissolved oxygen that can be achieved in the FMA (Zones 3 and 4 and upper portion of Zone 5). These nine discharges contribute 96 percent of total ammonia nitrogen load from wastewater treatment point-source discharges to the

Delaware Estuary. The range of required effluent ammonia nitrogen reduction from these nine point-source dischargers (for AA08) is 61–94% from assigned effluent loading conditions, with an overall reduction of 87%. The reduction percentages show a wide range due to varying initial ammonia nitrogen concentrations.

Under recommended scenario AA08:

  - Seven (7) wastewater treatment plants located in the FMA—Northeast Water Pollution Control Plant (PWD NE), Southeast Water Pollution Control Plant (PWD SE), Southwest Water Pollution Control Plant (PWD SW), Camden County Municipal Utilities Authority (CCMUA), Gloucester Utility Authority (GCUA), Delaware County Regional Water Quality Control Authority (DELCORA), and City of Wilmington Wastewater Treatment Plant—reduce effluent ammonia nitrogen concentration to a level of 1.5 mg/L in order to improve DO conditions in the FMA.
  - Two (2) wastewater treatment plants located in Zone 2—Hamilton Township Water Pollution Control Facility and Lower Bucks County Joint Municipal Authority (Lower Bucks JMA)— reduce effluent ammonia nitrogen concentration to a level of 5 mg/L to improve DO conditions in the upper portion of the FMA.

- Feasibility and costs to achieve various effluent pollutant concentration levels were characterized based on proven treatment technologies with long-term performance records to ensure a reasonable degree of confidence in plant upgrade performance for each of the existing treatment types (Kleinfelder, 2021).
  - Estimated annualized present cost for recommended wastewater improvements for AA08 is approximately $153M per year in 2019 dollars, which includes annualized present worth cost and annual operation and maintenance cost. The complexity degree of cost estimate is American Association of Cost Estimating (AACE) Level 4 estimate.
  - Total Present Worth Cost is $2.6B in 2019 dollars.
  - The capital, operations, and maintenance costs of advanced treatment associated with scenario AA08 are significant; however, based upon analyses performed using EPA and utility industry (AWWA) methods, the cost burden of the additional treatment will not increase the affordability burden category on households within the service areas of the affected treatment plants.
- An estimated highest attainable dissolved oxygen (HADO) condition (AA15) was developed based on scenario AA08. Four additional measures were considered which would impact the ambient DO conditions:
  - Full implementation of CSO long-term control plans (LTCPs)
  - Effluent DO of 4 mg/L for all nine dischargers

    - Lower than 1.5 mg/L summertime effluent ammonia nitrogen conditions for the nine point-source dischargers, due to expected higher treatment efficiency during warmer temperatures
    - Addition of a ten (10) percent ammonia load to sixty-seven point-source dischargers as a reserve capacity
- The HADO scenario (AA15) simulation predicts profound improvements in the DO condition within the FMA.
    - At 1st percentile "critical" conditions, the minimum DO at the lowest point of the sag would increase by approximately 2.3 mg/L to approximately 4.5 mg/L.
    - The lowest point of the DO sag would move upstream approximately 10 miles to around RM 100.
    - DO would exceed 4.5 mg/L 100% of the time throughout the FMA. DO of 4.5 mg/L is currently exceeded only about 50% of the time within the DO sag.
    - DO would exceed 5.0 mg/L throughout the FMA at least 83% of the time.
    - DO would exceed 6.0 mg/L throughout the FMA at least 62% of the time.
    - DO would exceed 7 mg/L throughout the FMA at least 50% of the time.
- Given the significantly improved level of dissolved oxygen associated with the HADO condition, the aquatic life use of "fish propagation" is attainable throughout the Estuary including in the FMA.

Rulemaking and Development of Implementation Plan

The results of this analysis of attainability along with the supporting studies will provide a basis for the development of revised water quality standards (designated uses and water quality criteria). The DRBC water quality regulations will be updated, and the revised water quality standards will generally be consistent with guidance provided by the EPA for implementation of the Clean Water Act. The water quality criteria will consist of numeric values for dissolved oxygen together with the appropriate temporal unit(s) (e.g., minimum, daily mean, 7-day mean) and spatial extents. The development of water quality criteria will be based upon a sound scientific rationale, including the detailed work comprising this AA, EPA guidance, EPA national criteria, and criteria developed or approved by EPA to protect similar uses.

Major federal actions, which may include the approval of water quality standards established by states when the standards could impact endangered species, may require formal consultation with the National Marine Fisheries Service (NMFS) pursuant to Section 7 of the Endangered Species Act (ESA), with regard to both Atlantic and shortnose sturgeon. DRBC will provide technical support to the EPA as needed during a formal ESA consultation process.

To achieve the improved DO conditions in the Estuary, a plan must be developed to implement the effluent limits identified in this study. The Commission will undertake this task in consultation with co-regulators and stakeholders.

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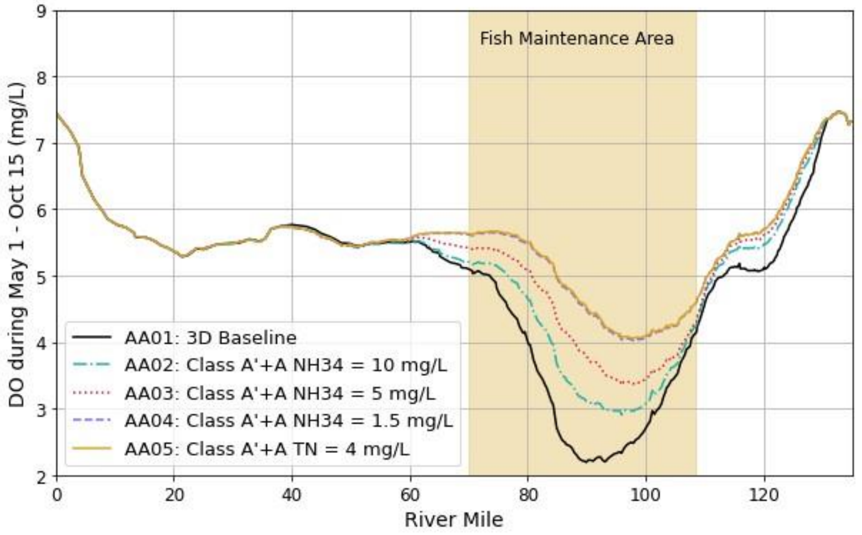
Appendix A: AA Scenario Comparisons

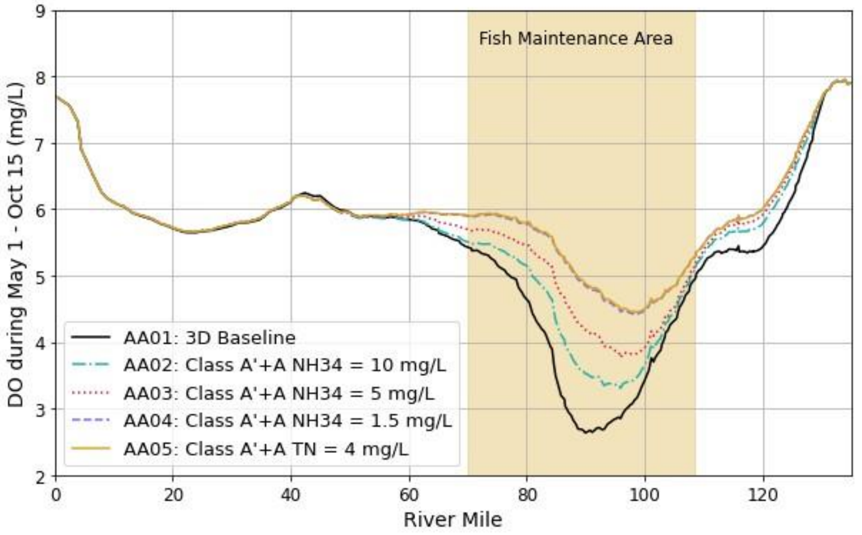
- Comparisons among scenarios AA01–AA05
- Comparisons among scenarios AA04, AA06 & AA07
- Comparisons among scenarios AA04, AA07, AA08 & AA10

See Section 4.1 and Table 4-1 for detailed scenario descriptions.

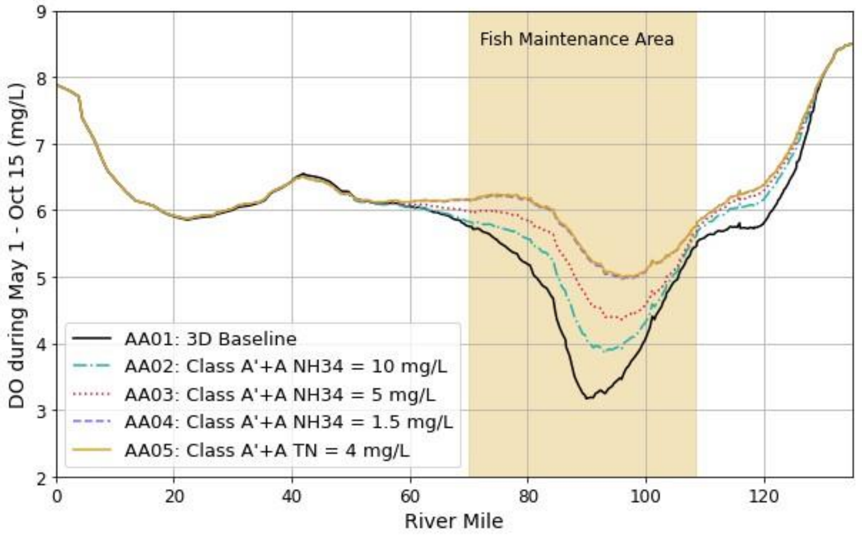
1st Percentile DO



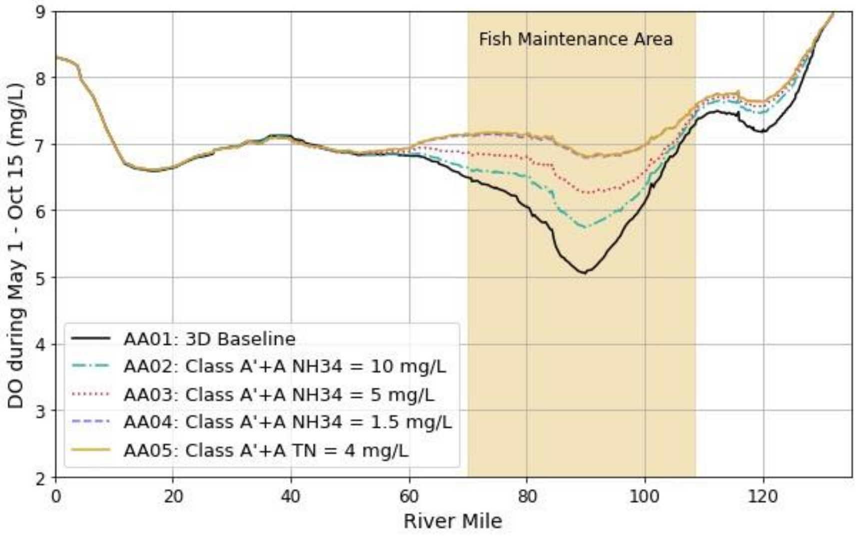
10th Percentile DO

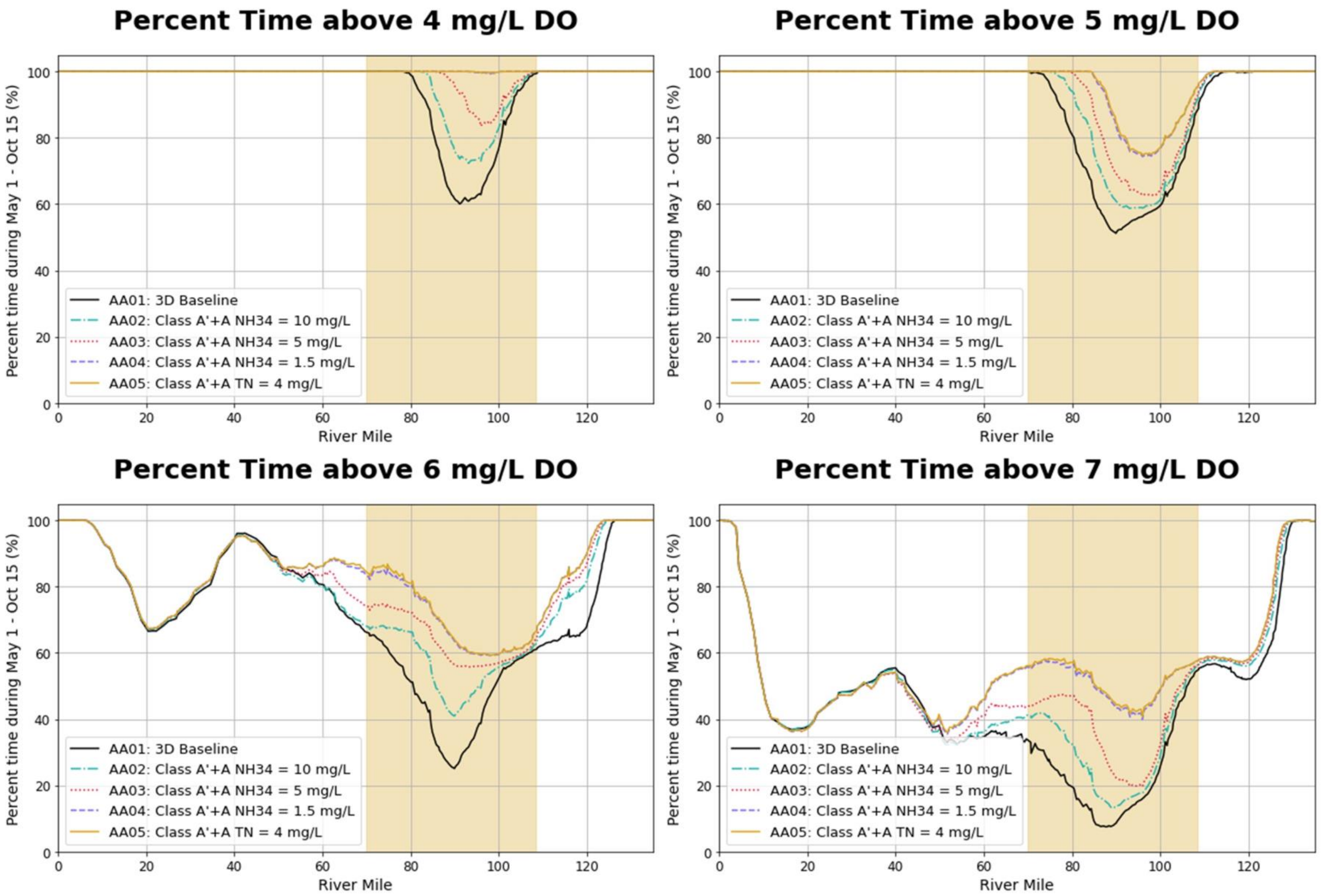


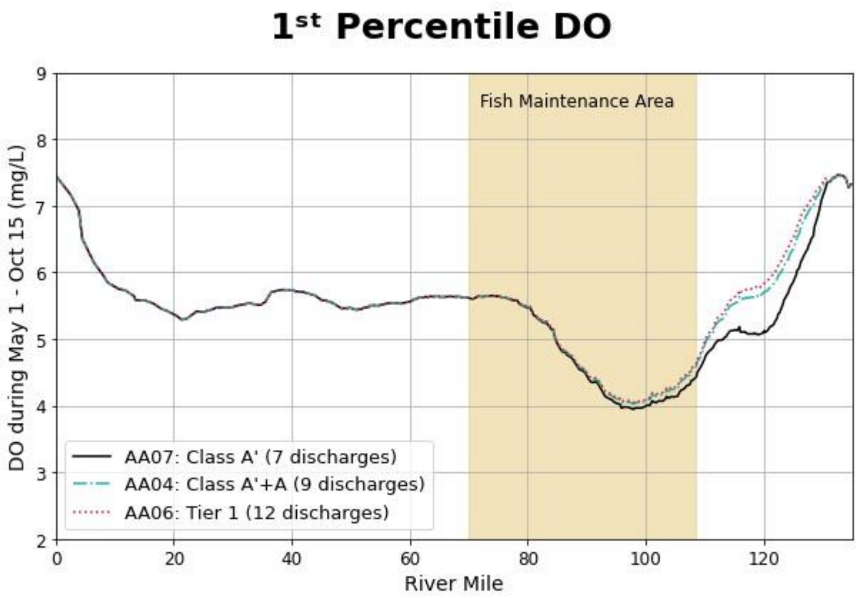
25th Percentile DO

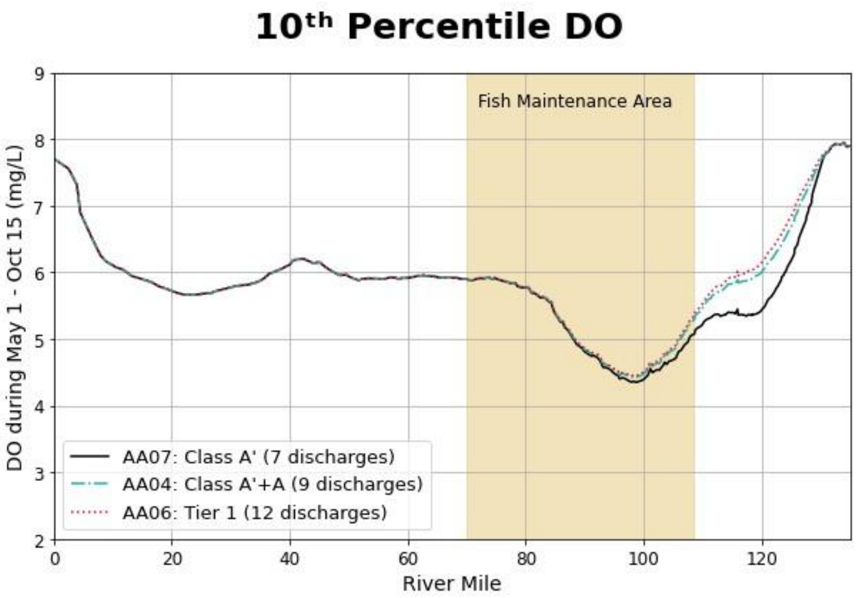


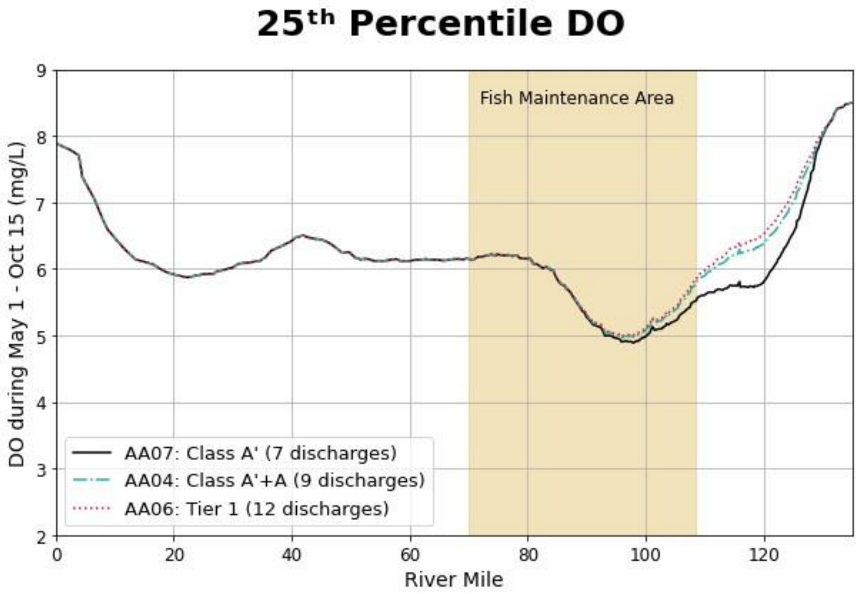
50th Percentile DO

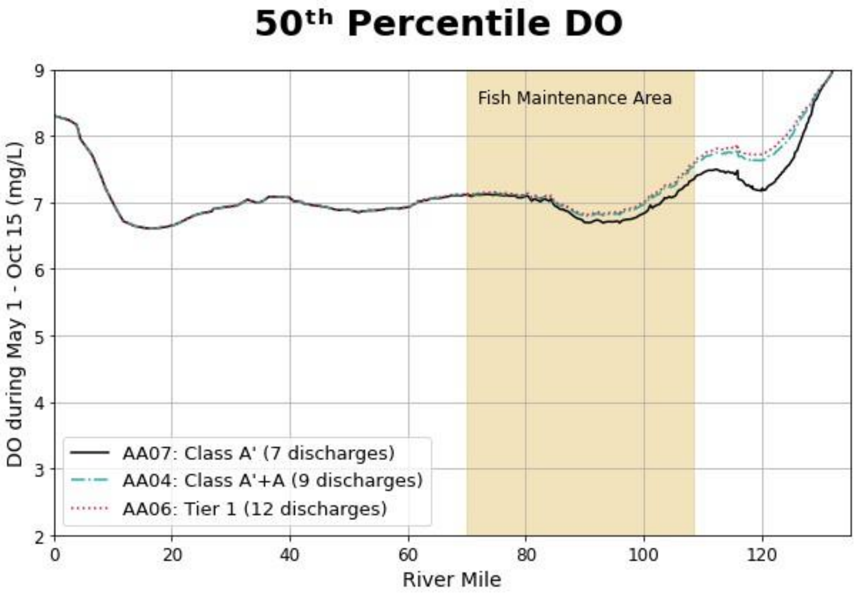


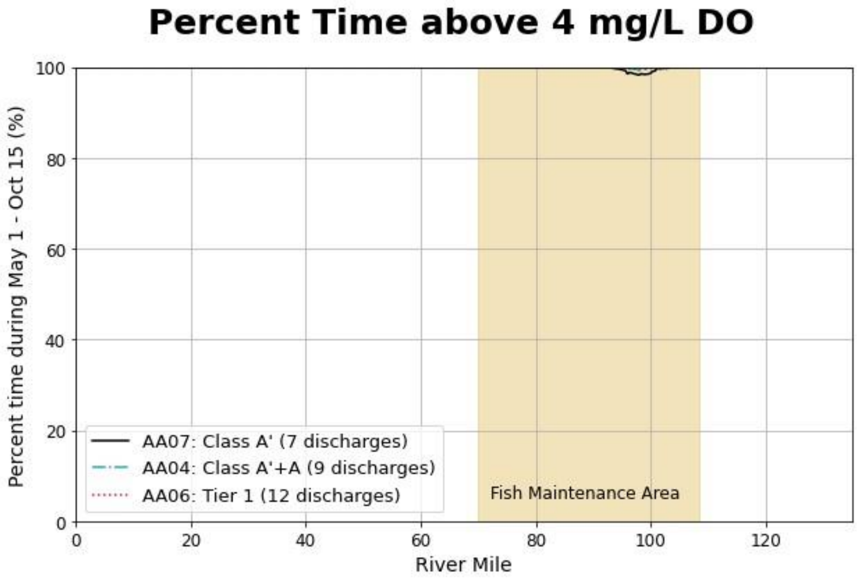

Percent Time above 4 mg/L DO
Percent Time above 5 mg/L DO
Percent Time above 6 mg/L DO
Percent Time above 7 mg/L DO
Percent time during May 1 - Oct 15 (%)
River Mile
0
20
40
60
80
100
120
AA01: 3D Baseline
AA02: Class A'+A NH34 = 10 mg/L
AA03: Class A'+A NH34 = 5 mg/L
AA04: Class A'+A NH34 = 1.5 mg/L
AA05: Class A'+A TN = 4 mg/L

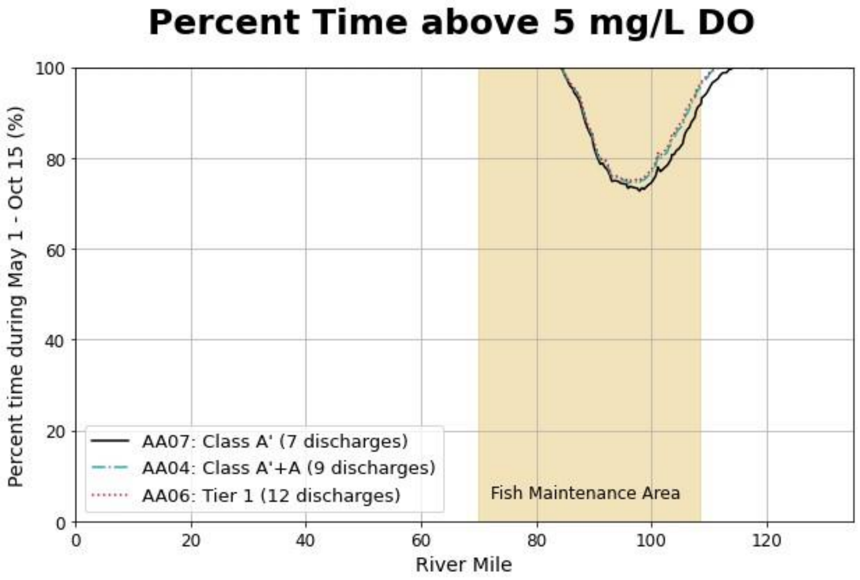

1st Percentile DO

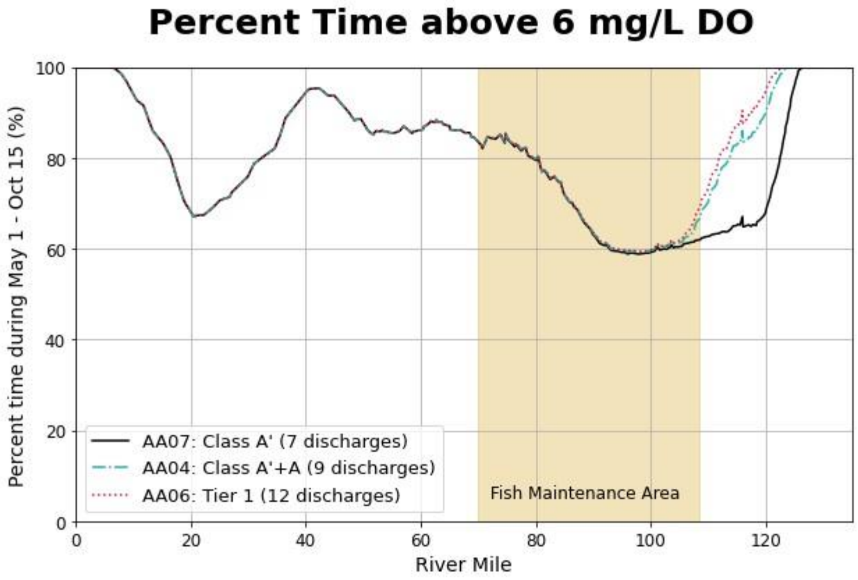

10th Percentile DO

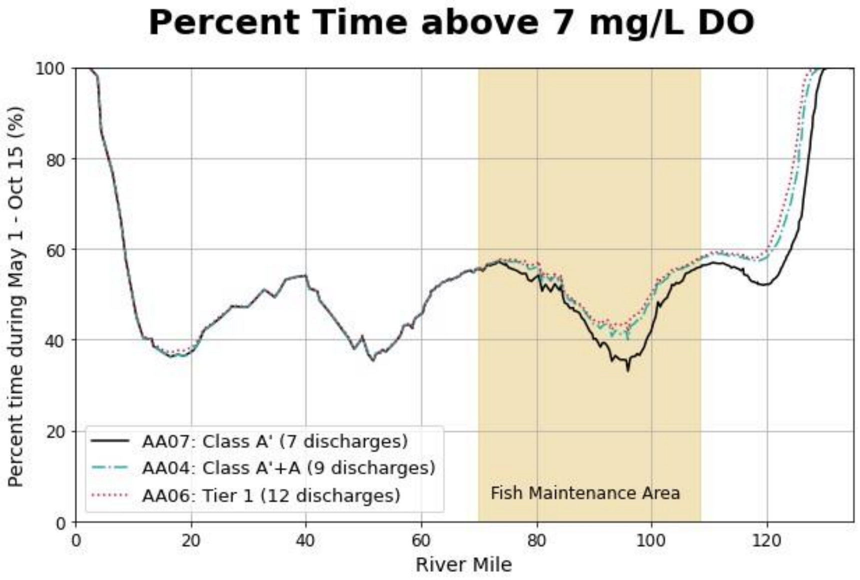

25th Percentile DO

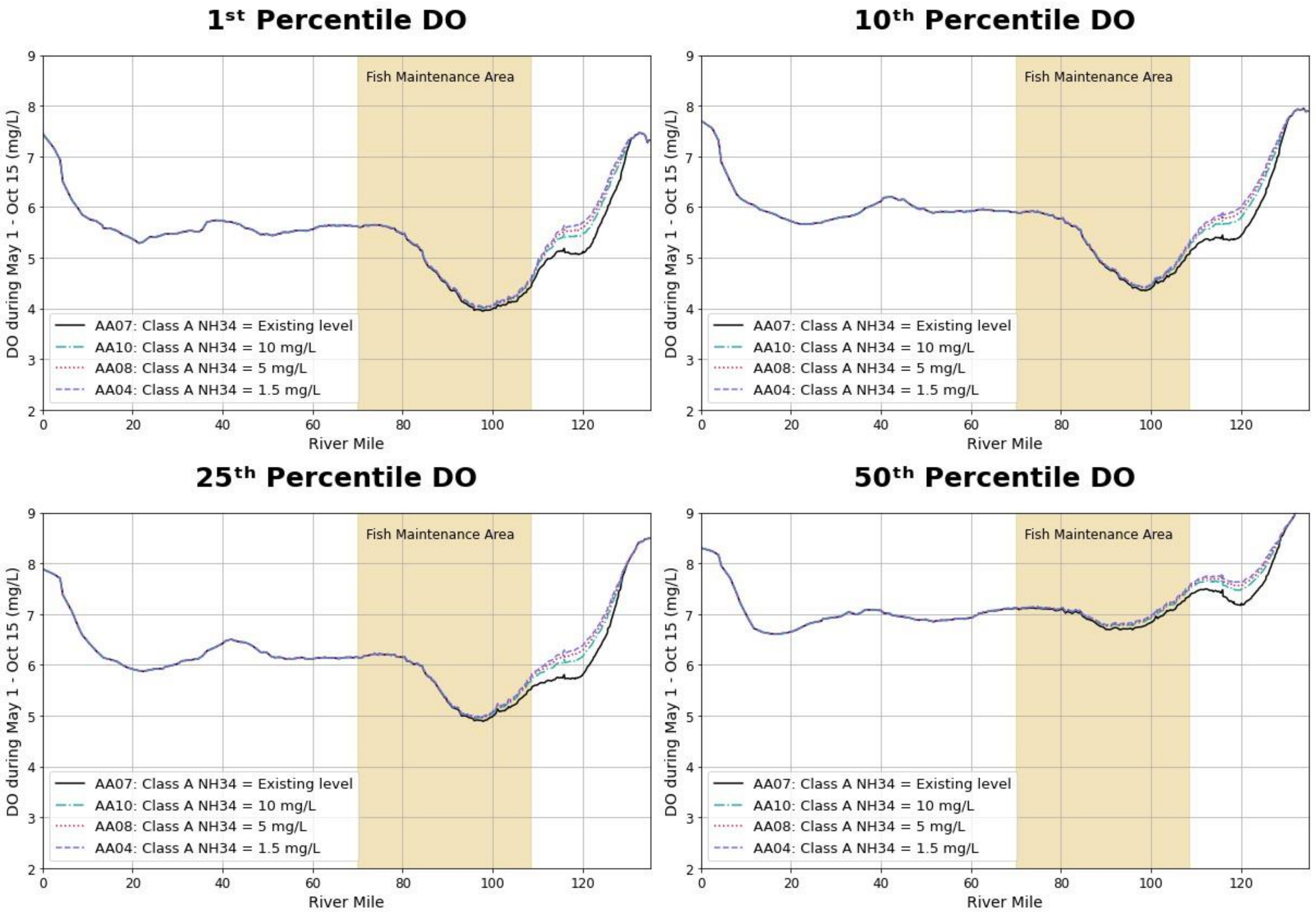

50th Percentile DO

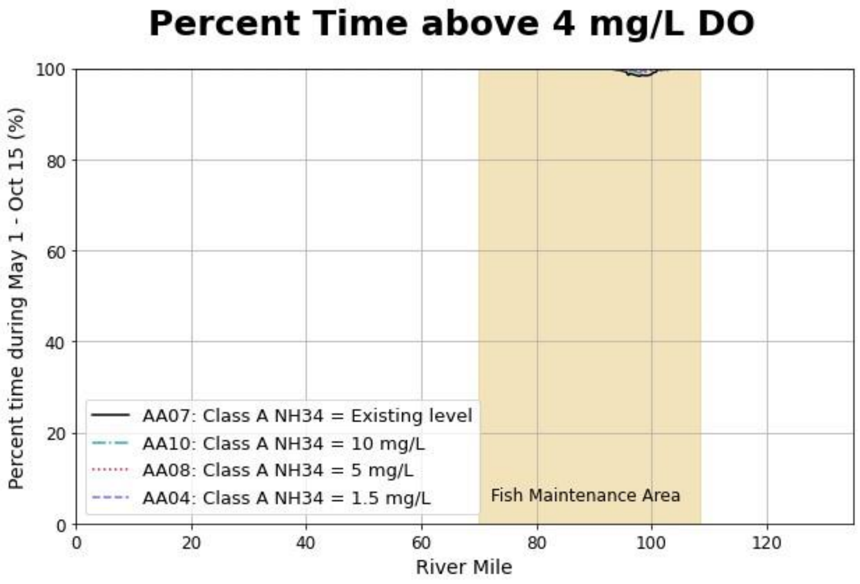

Percent Time above 4 mg/L DO
Percent time during May 1 - Oct 15 (%)
0
20
40
60
80
100
River Mile
0
20
40
60
80
100
120
AA07: Class A' (7 discharges)
AA04: Class A'+A (9 discharges)
AA06: Tier 1 (12 discharges)
Fish Maintenance Area

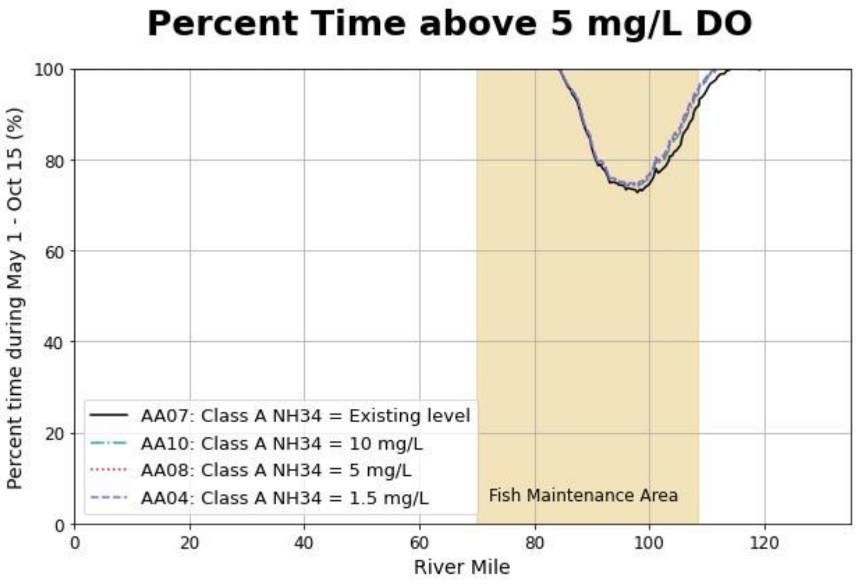

Percent Time above 5 mg/L DO
Percent time during May 1 - Oct 15 (%)
0
20
40
60
80
100
River Mile
0
20
40
60
80
100
120
AA07: Class A' (7 discharges)
AA04: Class A'+A (9 discharges)
AA06: Tier 1 (12 discharges)
Fish Maintenance Area

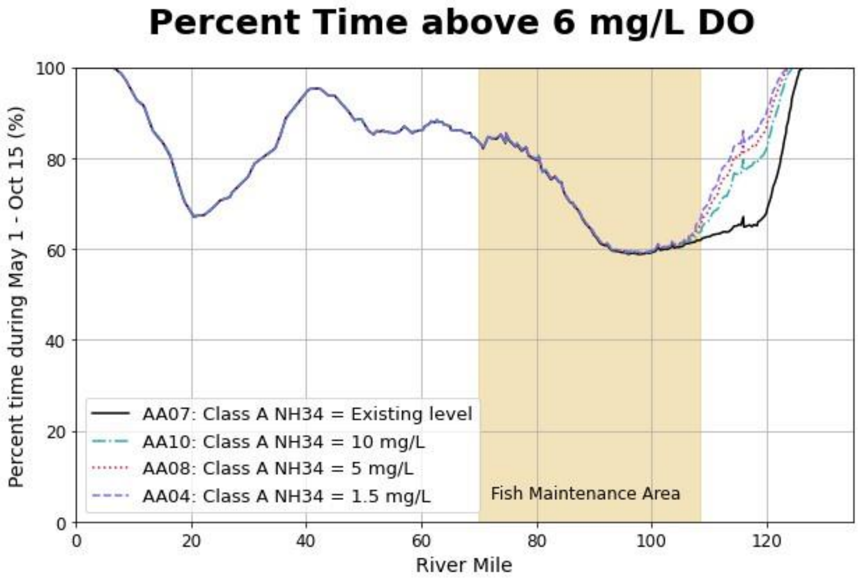

Percent Time above 6 mg/L DO
Percent time during May 1 - Oct 15 (%)
0
20
40
60
80
100
River Mile
0
20
40
60
80
100
120
AA07: Class A' (7 discharges)
AA04: Class A'+A (9 discharges)
AA06: Tier 1 (12 discharges)
Fish Maintenance Area

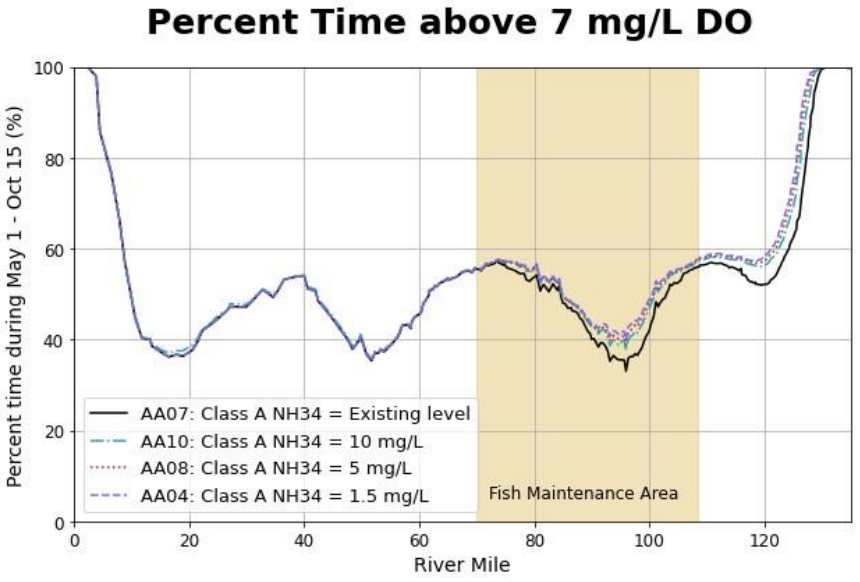

Percent Time above 7 mg/L DO
Percent time during May 1 - Oct 15 (%)
0
20
40
60
80
100
River Mile
0
20
40
60
80
100
120
AA07: Class A' (7 discharges)
AA04: Class A'+A (9 discharges)
AA06: Tier 1 (12 discharges)
Fish Maintenance Area


1st Percentile DO
10th Percentile DO
25th Percentile DO
50th Percentile DO
Fish Maintenance Area
DO during May 1 - Oct 15 (mg/L)
River Mile
0
20
40
60
80
100
120
2
3
4
5
6
7
8
9
AA07: Class A NH34 = Existing level
AA10: Class A NH34 = 10 mg/L
AA08: Class A NH34 = 5 mg/L
AA04: Class A NH34 = 1.5 mg/L


Percent Time above 4 mg/L DO

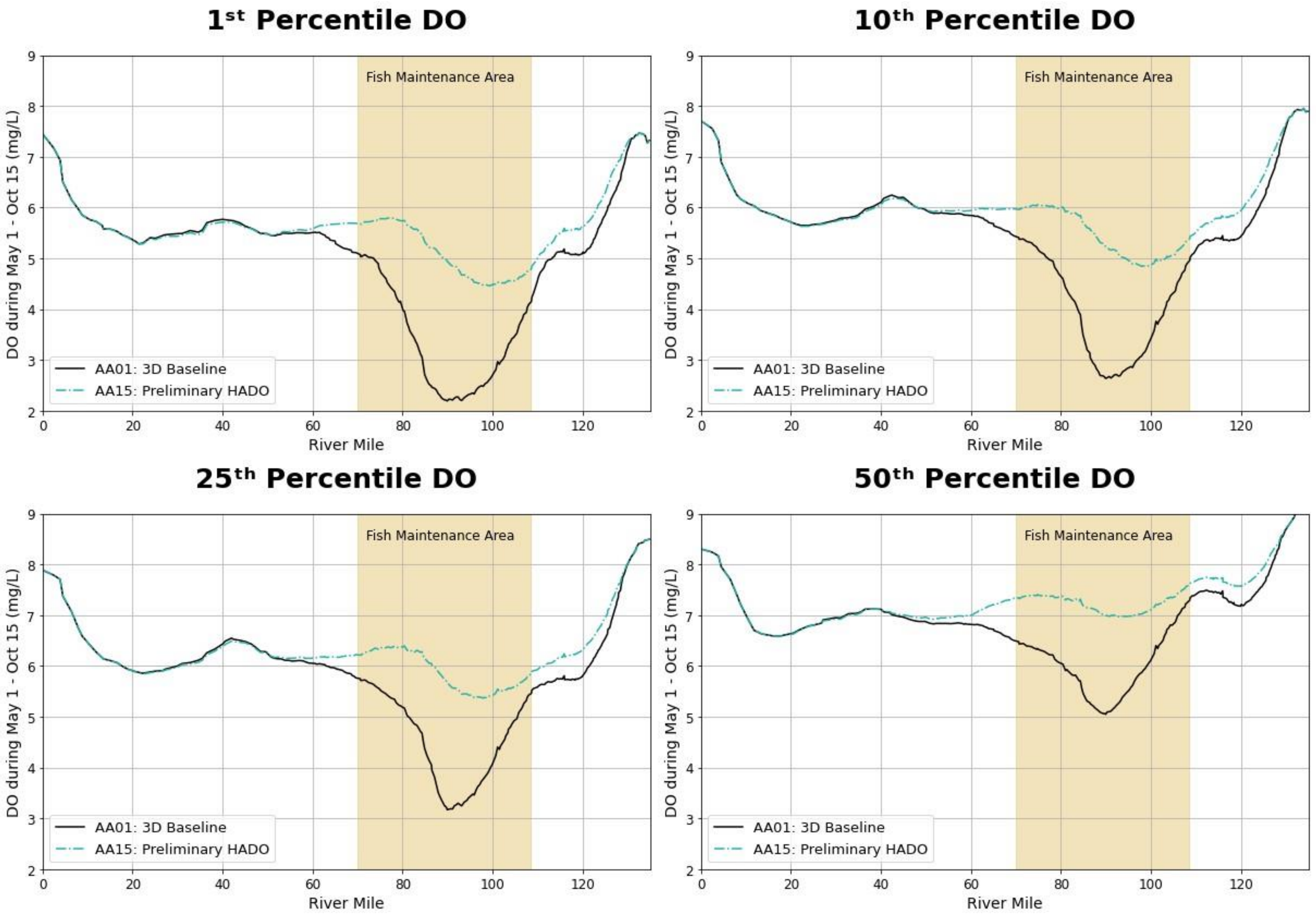

Percent Time above 5 mg/L DO

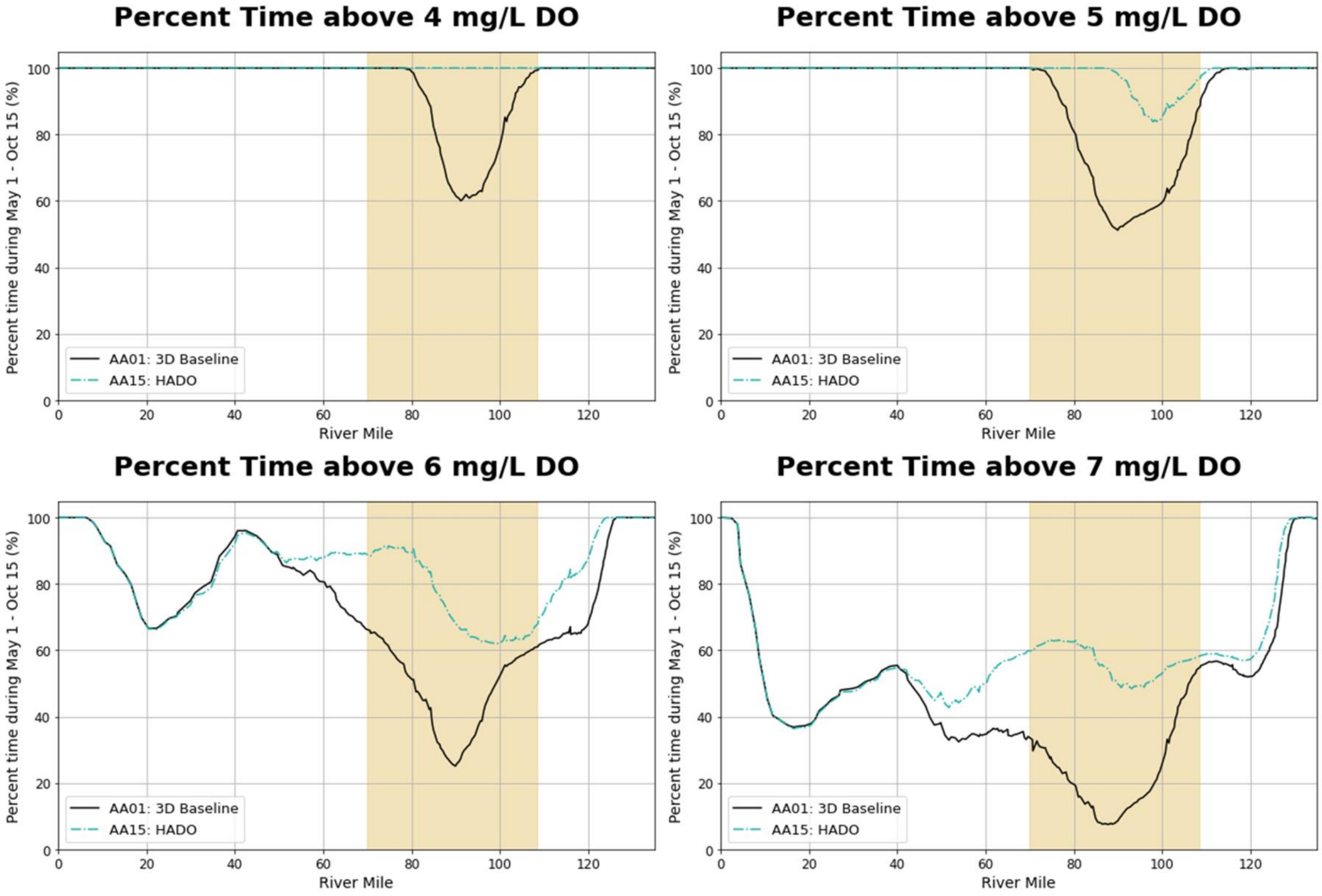

Percent Time above 6 mg/L DO

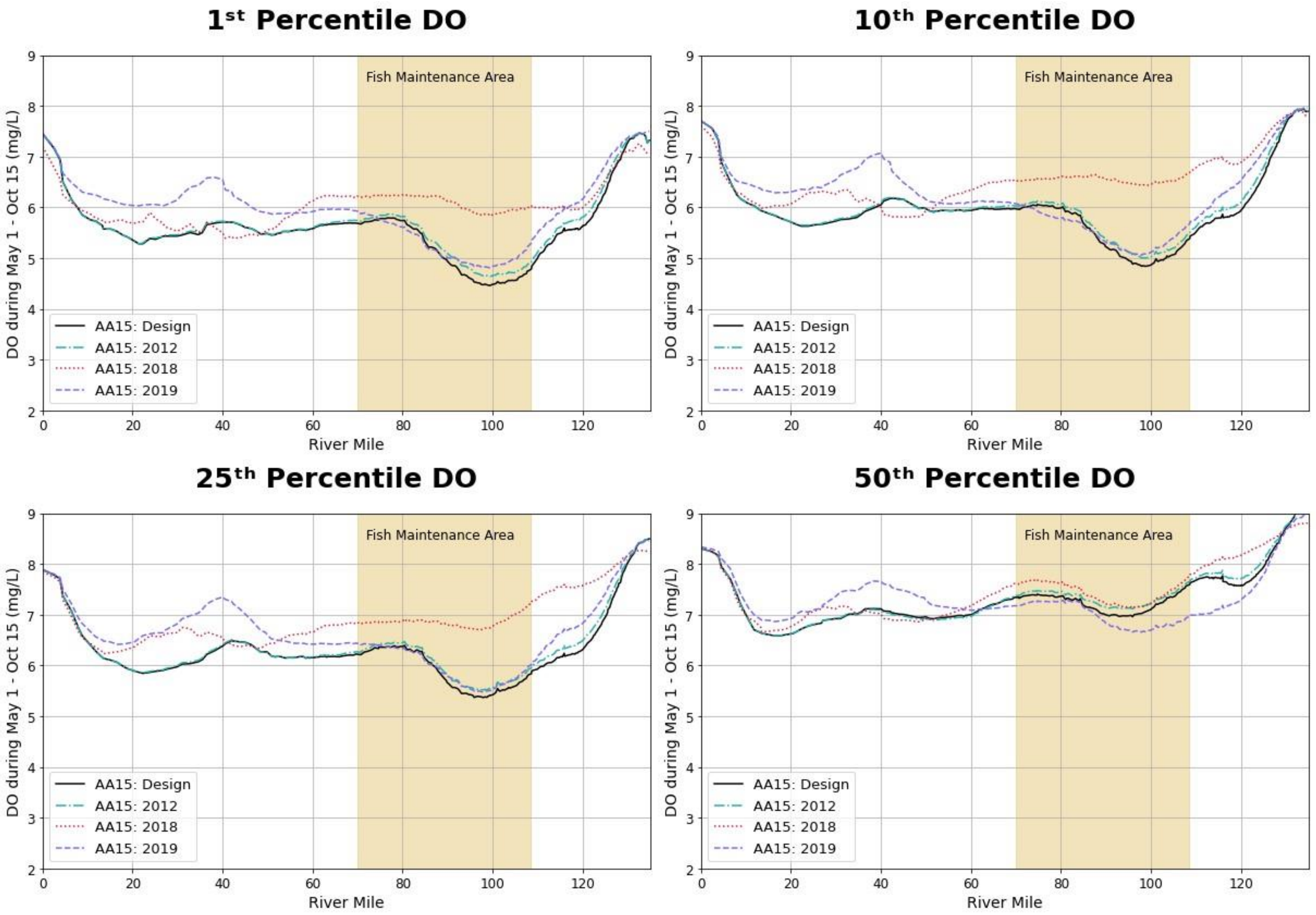

Percent Time above 7 mg/L DO

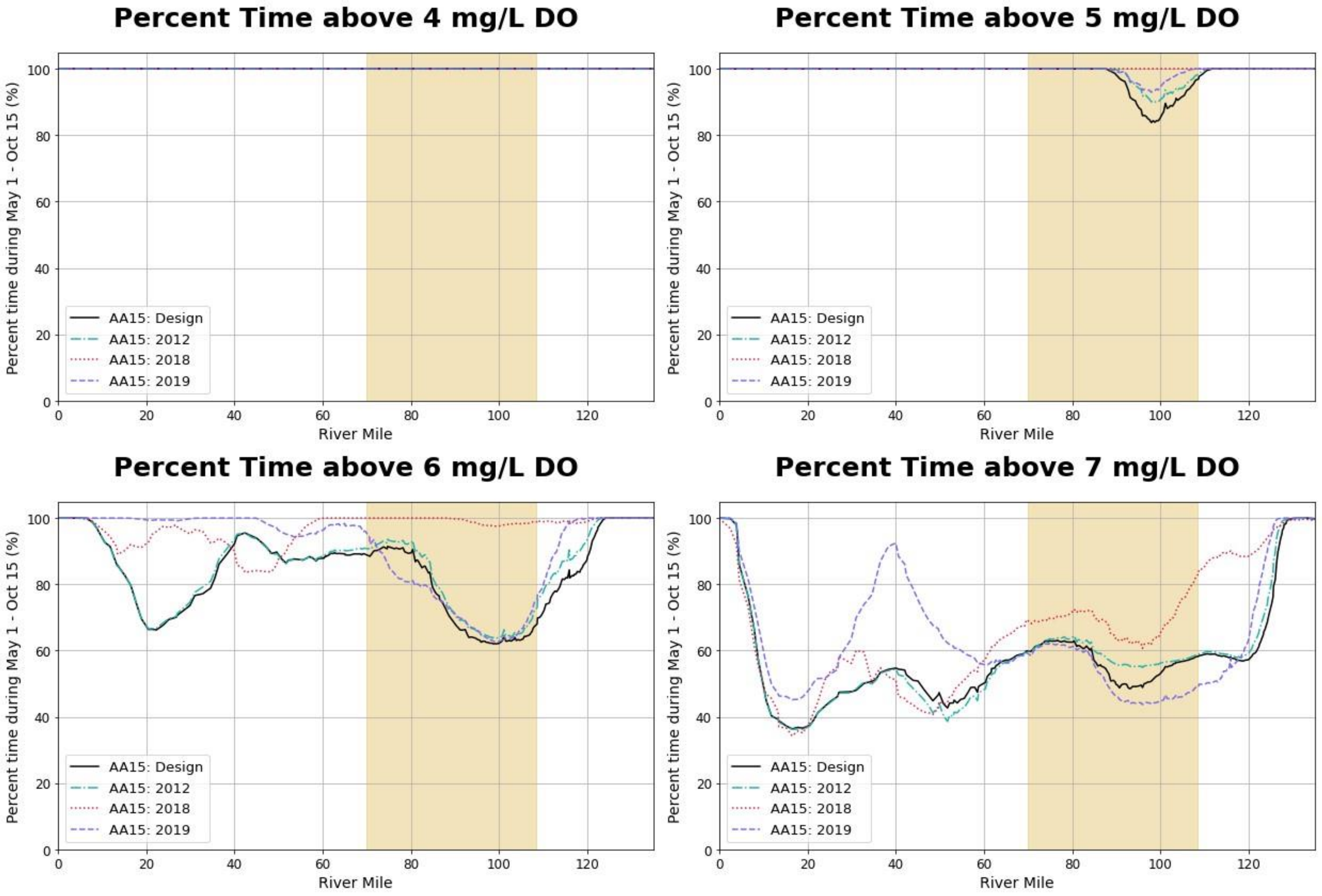
Appendix B: HADO Comparisons

- Comparisons between AA15 and Baseline
- Comparisons of AA15 scenario under different flow conditions

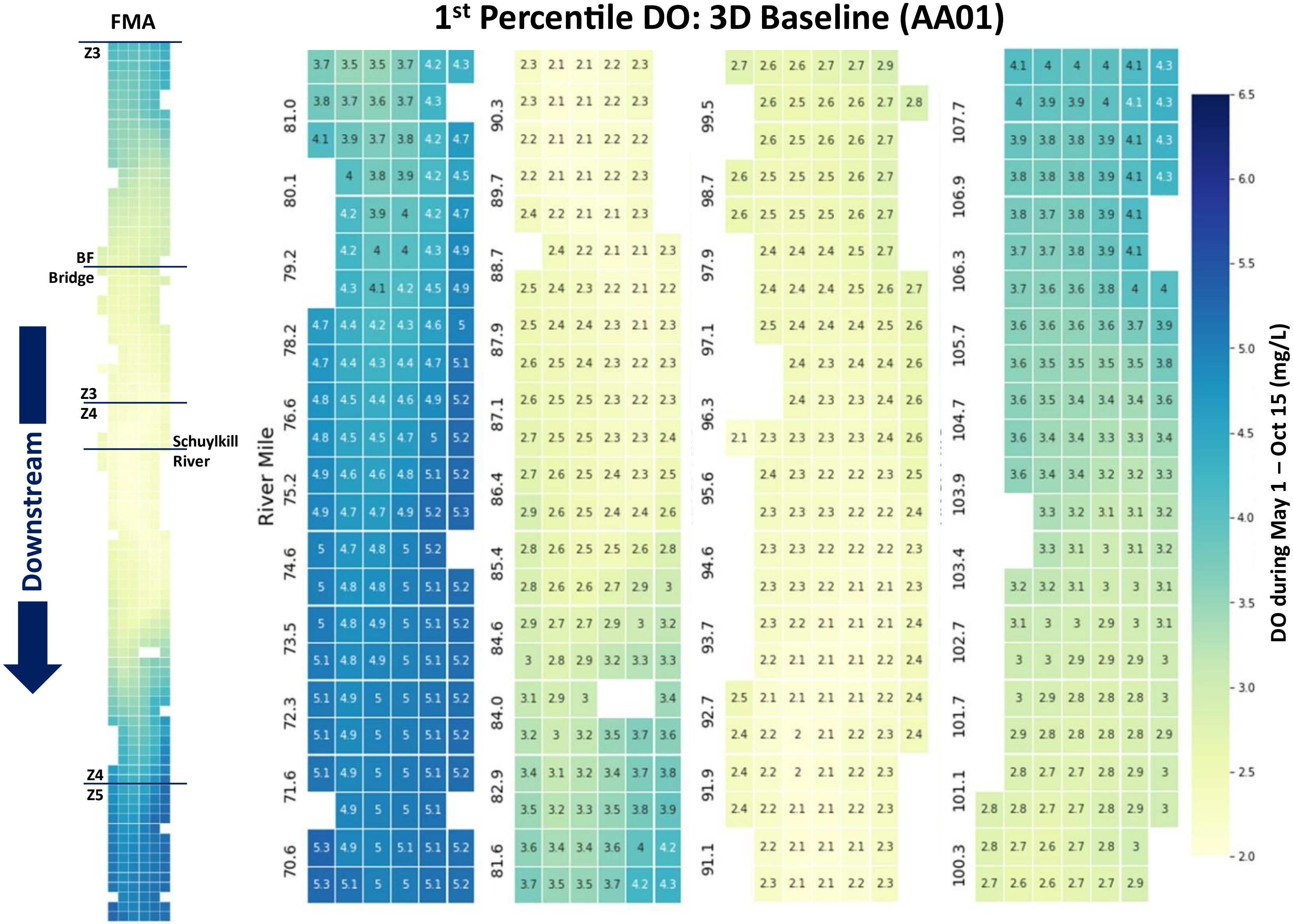

1st Percentile DO
10th Percentile DO
25th Percentile DO
50th Percentile DO
Fish Maintenance Area
DO during May 1 - Oct 15 (mg/L)
River Mile
0
20
40
60
80
100
120
2
3
4
5
6
7
8
9
AA01: 3D Baseline
AA15: Preliminary HADO


Percent Time above 4 mg/L DO
Percent Time above 5 mg/L DO
Percent Time above 6 mg/L DO
Percent Time above 7 mg/L DO
Percent time during May 1 - Oct 15 (%)
River Mile
0
20
40
60
80
100
120
AA01: 3D Baseline
AA15: HADO

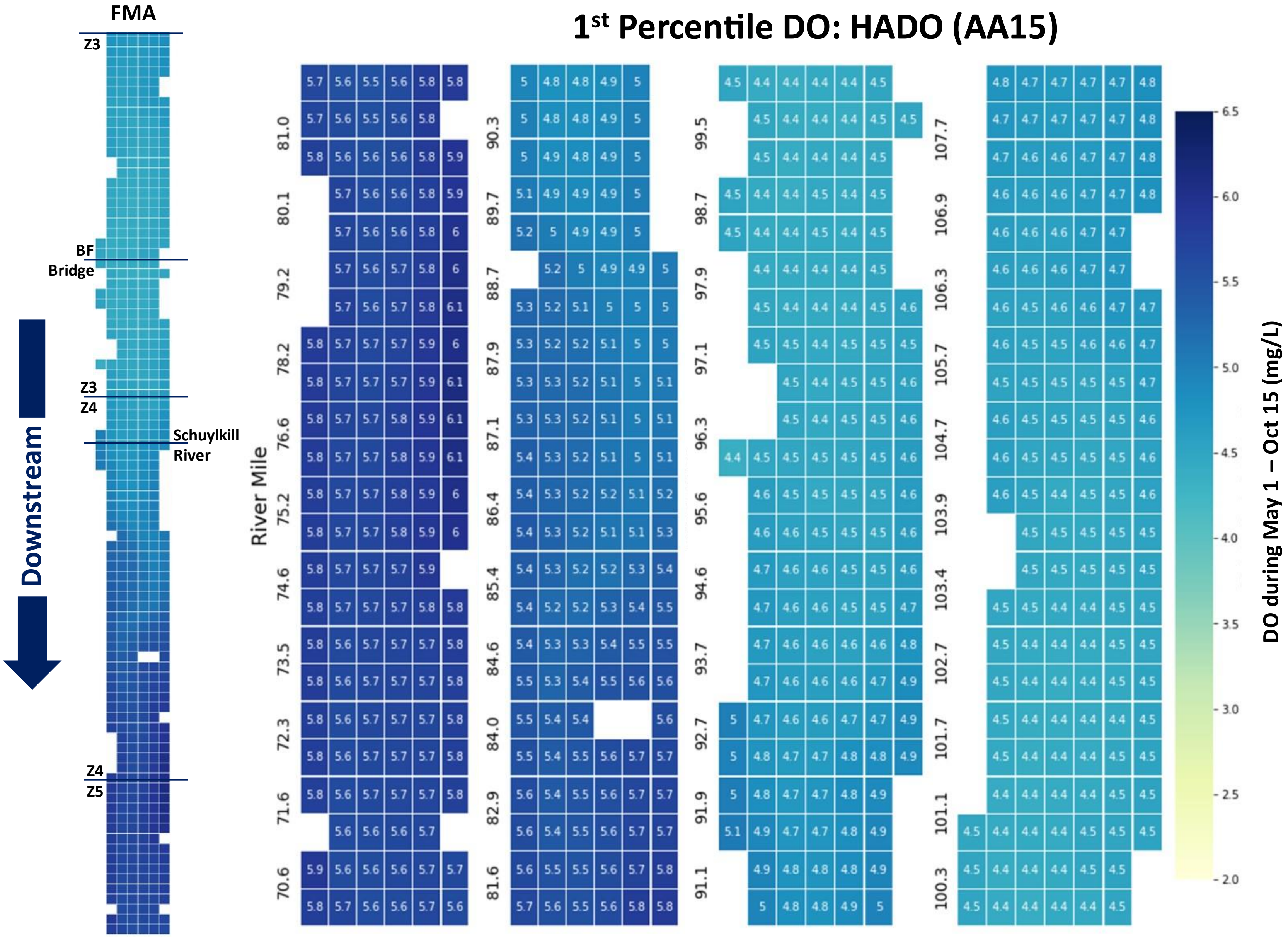

1st Percentile DO
10th Percentile DO
25th Percentile DO
50th Percentile DO
Fish Maintenance Area
DO during May 1 - Oct 15 (mg/L)
River Mile
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
AA15: Design
AA15: 2012
AA15: 2018
AA15: 2019


Percent Time above 4 mg/L DO
Percent Time above 5 mg/L DO
Percent Time above 6 mg/L DO
Percent Time above 7 mg/L DO
Percent time during May 1 - Oct 15 (%)
River Mile
0
20
40
60
80
100
120
AA15: Design
AA15: 2012
AA15: 2018
AA15: 2019

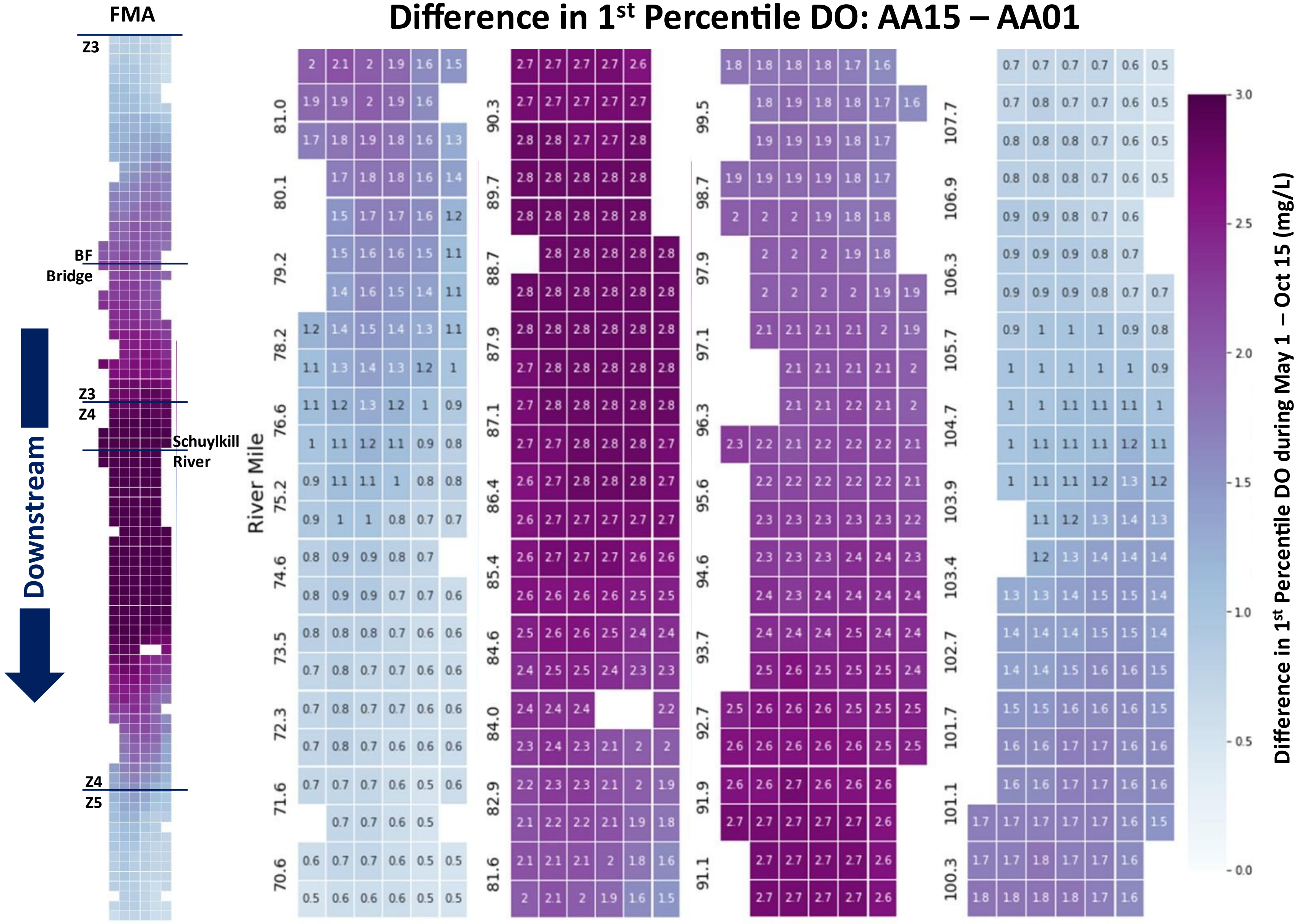
1st Percentile DO: 3D Baseline (AA01)



1st Percentile DO: HADO (AA15)



Difference in 1st Percentile DO: AA15 – AA01



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