DELAWARE RIVER WATERSHED INITIATIVE POLLUTION ASSESSMENT

Stage 2 Project Report

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

Goals and Objectives for Pollution Assessment

The overall goals of the Delaware River Watershed Initiative (DRWI) Pollution Assessment were to:

A. Identify hotspots of excess nonpoint source pollution (nitrogen, phosphorus, sediment) in stream reaches and catchments of the Delaware River Basin.
B. Quantify progress toward improving water quality by DRWI-style restoration and land protection activities, answering questions such as:
    - What fraction of excess nonpoint source pollution has been reduced by DRWI and other projects?
    - What level of investment is still required to achieve acceptable water quality?
C. Report cumulative findings for each geography of interest, including DRWI-established Clusters and the Focus Areas within.

The DRWI Pollution Assessment was conducted in two stages.

The **Stage 1 Pollution Assessment: Rapid Assessment** (report submitted to WPF in Feb. 2022) provided contextual framing of DRWI achievements to date for a strategy review by the Foundation. The Assessment was developed from existing tools such as, Model My Watershed (ModelMW) and the Focus Area Evaluation Tool (FAET) that had datasets in need of updates (land cover from 2011 and weather from 1960-1990) and not all implemented DRWI project data available. The Stage 1 timeline was too short to update these datasets.

The **Stage 2 Pollution Assessment: Refined Assessment**, reported herein, was designed to:

- Provide a more robust and dynamic assessment system for more accurate future program assessments and conservation planning.
- Update key datasets:
    - Land cover from 2011 to 2019 product (2001-2019);
    - Weather data from 1960-90 to 2000-19;
    - Higher-resolution stream networks; and
    - Conservation projects from more sources and further back in time.
- Develop assessment system based on previously-developed tools to:
    - Rapidly reanalyze progress toward achieving acceptable water quality;
    - Explore hotspot maps and summary data to inform focus area targets and opportunities, and to estimate future costs to achieve a beneficial water quality goal; and
    - Iteratively re-do assessments based on changing input and targets/objectives.

Summary of Findings and Implications

Overall, DRWI accomplishments directly related to DRWI work and William Penn Foundation funding include 26,414 acres of protected forests and more than 1,446 restoration best management practices covering more than 296,841 acres, including implementation of agricultural restoration and urban stormwater management projects.

Excess nutrients and sediment often result in poor water quality, poor recreational and aesthetic conditions, and biological impairment in streams and their downstream rivers and estuaries (in the DRB and worldwide). After initial Stage 1 synthesis, a decision was made to focus primarily on phosphorus due to it frequently limiting biological productivity and being tightly linked to sediment through transport dynamics. Efforts described in a previous report quantified pollution reduction outcomes and forest protection success from these projects and represented a first step (Stage 1) in our overall assessment. This earlier assessment was subsequently refined (Stage 2 results reported herein) and focused on improving the accuracy of pollutant loading and cost estimates with more up-to-date data inputs and better algorithms, improving automation of the modeling and analysis framework for repeating analyses in the future, adding load reductions from non-DRWI restoration projects funded by state and federal programs, and adding alternative analyses for quantifying land protection strategies.

Across the entire study geography, total phosphorus reductions attributable to DRWI restoration efforts were estimated at 45,800 lbs/yr and non-DRWI restoration efforts reduced TP loads by at least 44,012 lbs/yr. DRWI efforts resulted in as much of a benefit to water quality as all government-funded projects combined. In addition, the DRWI strategy of focusing work on headwater areas had clear benefits to water quality far downstream from the Focus Area.

The DRWI and non-DRWI load reductions were about 6.7% and 6.5% of the excess TP nonpoint source load, respectively. The estimated total phosphorus load prior to BMP implementation was ~3.6 million pounds per year, with point sources accounting for ~37.7% of the TP load or 1.36 million lbs/yr. The remaining load of ~ 2.25 million lbs/year was attributed to nonpoint sources. The “healthy water” target threshold for total phosphorus load across the study area was estimated to be ~1.56 million lbs/yr. Therefore, excess TP load attributable to nonpoint sources was estimated to be 681,672 lbs/yr. The remaining excess TP nonpoint source load after accounting for restoration projects throughout the geography was 591,860 lbs/yr, or about 86.8% of the original excess nonpoint source TP load.

Since the remaining load of 591,860 lbs/yr is about 13 times greater than the amount reduced to-date from DWRI-funded activities (i.e., 45,800 lbs/yr), it might be reasonable to expect, as a very rough approximation, that an amount equal to 13 times that already spent would be needed to reach load reduction goals for phosphorus in the DRB and adjacent areas in southern New Jersey. Alternatively, our cost estimation approach detailed herein suggests that the cost to achieve the “healthy water” target for nonpoint source phosphorus loads would be approximately $555.3 million in the DRB or about $579.8 million if study areas outside of the DRB are included (using BMP cost estimates in 2022 US dollars).

Approximately 19.8% (1,669,104 acres) of the greater DRB area is protected natural land (including the Kirkwood-Cohansey area). Land protection efforts via the DRWI’s Delaware River Watershed Protection Fund have secured more than 26,400 acres of natural land, mostly in headwater landscapes with significant forest cover and high water quality. These lands and their natural ecosystems services help to produce high water quality downstream now and for future generations. Our approach to estimate the future pollution prevented from these parcels resulted in estimates of about 9,050 lbs/yr or about 18% of the loads reduced by DRWI restoration efforts. Although this is small relative to the loads reduced by restoration, the benefits provided will endure in perpetuity. This approach represents one dimension of the benefit provided and we encourage readers of this report to explore the multi-faceted approach taken in a companion study led by the Open Space Institute titled “Protecting Forests for Clean Water: Findings from a 10-year initiative inform field-wide best practices” (OSI, 2023; contact Abigail Weinberg).

Last, we estimated the relative percentages of natural land and its protection status for each HUC12 sub-basin across the study geography (DRB and K-C area) in an effort to better understand future opportunities for natural land protection and the feasibility and costs to achieve the goal of 30% natural land protected. Of the 480 HUC12 sub-basins included in this study, 114 had greater than 30% of the natural area protected, 82 don't have enough natural land remaining to exceed a 30% goal, and 284 are less than 30% protected but have enough natural land remaining to achieve the goal. The uneven distribution of remaining natural land across the DRB would thus present a challenge for achieving a 30% goal equally across the HUC12 geographies unless the strategy includes afforestation in some geographies. However, when HUC12s are aggregated into their larger HUC08 sub-basins, the 30% goal for each of the 14 HUC08 sub-basins is achievable. The estimated acreage needed to achieve the goal within the DRB is 859,920 acres and about 3,920 acres are needed across the two HUC08s that are outside of the DRB. Given the past costs to secure natural land protection experienced by DRWI efforts, we estimated ~$7.25 billion and $14.33 million would be needed to achieve the 30% goal (based on Fair Market Value comparables from DRWI protection purchases).

Contributors and Acknowledgments

This project was supported by The William Penn Foundation and the National Fish and Wildlife Foundation.

LimnoTech contributors included Anthony Aufdenkampe, Sarah Jordan, Caitlin Lulay, and Xavier Rojas Nogueira.

Stroud Water Research Center contributors included David Arscott and Sara Damiano.

The Academy of Natural Sciences (ANS) / Drexel University contributors included Barry Evans, Lin Perez, Michael Campagna, and Marie Kurz (now at Oak Ridge National Laboratory).

We thank R. John Dawes and the team at The Commons for their work to manually export project information from FieldDoc multiple times for use in Stage 1 of this project, and for developing a FieldDOC API for automated export of project data for Stage 2. We also thank colleagues at Element84 (formerly Azavea) for providing software support and updating Model My Watershed as foundational components of the work described herein. Thanks to Matt Ehrhart and John Jackson at the Stroud Center for their advice and input during the project.

Research Purpose and Rationale

Background: The Delaware River Watershed Initiative

The Delaware River Watershed Initiative (DRWI; https://4states1source.org/) is a multidisciplinary collaboration of more than 70 organizations working to conserve and restore the streams that supply drinking water to 15 million people in New York, New Jersey, Pennsylvania and Delaware. The DRWI collaboration, enabled by leadership funding provided from the William Penn Foundation (WPF), facilitated environmental work across the basin to reduce water pollution, protect headwaters and promote water-smart practices and policies. Under this initiative, environmental, scientific, educational, and conservation organizations worked from 2014 to 2025 to protect and restore the Delaware River system in eight priority geographies, referred to as Clusters: Poconos-Kittatinny, Upper Lehigh, New Jersey Highlands, Middle Schuylkill, Schuylkill Highlands, Upstream Suburban Philadelphia, Brandywine-Christina, Kirkwood-Cohansey Aquifer (Fig. 1). These priority locations included parts of pristine headwaters and working forests of the upper watershed, farmlands, suburbs, and industrial and urban centers downstream, and the coastal plain where the river and emerging groundwater empties into either the Delaware Bay or the Atlantic Coast. DRWI partner organizations further constrained and targeted the deployment of restoration and protection projects in Focus Areas that were nested within Clusters.

A DRWI coordinating committee helped to align these organizations to concentrate and scale up their impact to accelerate the protection of important landscapes, restoration of degraded areas, and adoption of green infrastructure and responsible farming practices. Strategies to protect and restore landscapes to promote good water quality included forest land protection, implementation of agricultural best management practices (e.g., riparian forest buffers, streambank fencing, barnyard manure management systems, soil conservation and health strategies like cover cropping), and green stormwater management infrastructure (e.g., rain gardens and infiltration basins).

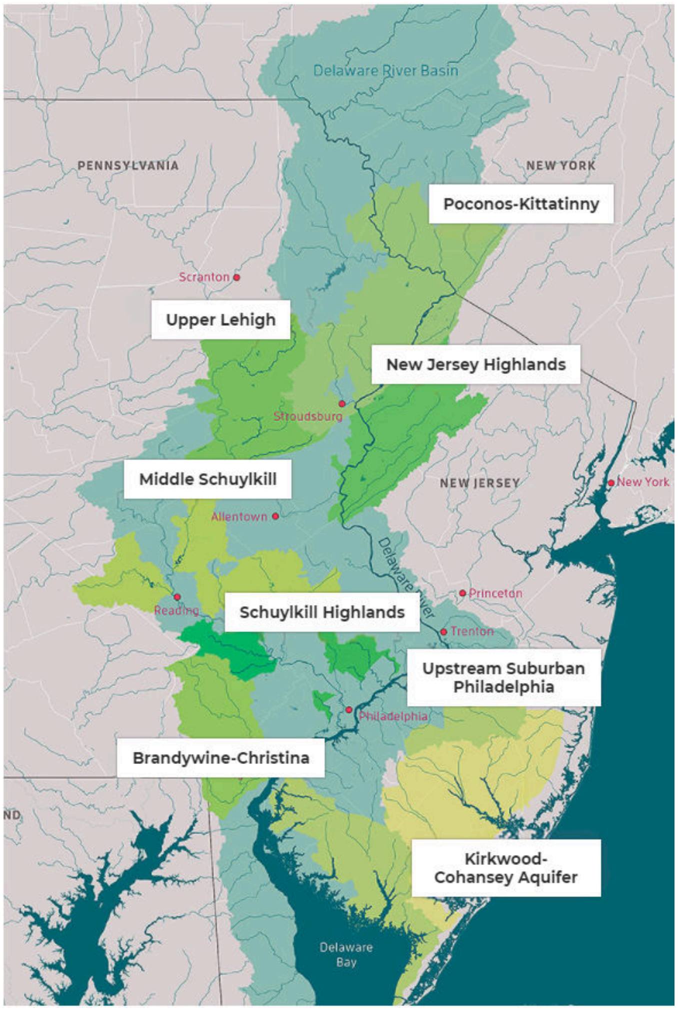

Figure 1: The Delaware River Basin and the eight Clusters of the Delaware River Watershed Initiative.

Project implementation and environmental outcomes were tracked and monitored at more than 300 locations across the basin. All organizations contributed project-relevant data on these efforts to a DRWI database (i.e., FieldDocs) that can provide each organization with project status/tracking information and summary statistics via a data summary and display dashboard (DRWI dashboard).

The DRWI is unique due to its highly collaborative effort that uses best available science and prioritizes ongoing learning informed by feedback from the data collection and analysis process. Overall, DRWI accomplishments directly related to DRWI work and William Penn Foundation funding include 26,414 acres of protected forests and more than 1,446 restoration best management practices covering more than 296,841 acres, including implementation of agricultural restoration and urban stormwater management projects. In addition, collaborating partners and others in the DRB have implemented hundreds more BMPs that have been funded through other programs or with leverage from these efforts. Collectively, these projects prevented and/or reduced pollution in stormwater runoff, reduced flood risk and erosion, provided critical habitat for native flora and fauna, and helped deliver cleaner water to rivers and streams throughout the basin (among other benefits).

The William Penn Foundation initially committed to supporting the DRWI for 10 years. In order to inform the Foundation and other stakeholders about progress, WPF commissioned the work reported herein to estimate progress to protect and restore water quality in targeted geographies in the Delaware River Basin (DRB). In this study, we utilized water quality modeling tools to estimate the impact of water pollution reduction and forest protection strategies from these efforts and then related these outcomes to broader estimates of total water pollution in the DRB. We initially focused on excess nutrients (nitrogen and phosphorus) and sediment that result from human influenced/impacted landscapes due to historic conditions and land management. Excess nutrients and sediment often result in poor water quality, poor recreational and aesthetic conditions, and biological impairment in streams and their downstream rivers and estuaries (in the DRB and worldwide). After initial synthesis, a decision was made to focus primarily on phosphorus due to the nutrient frequently limiting biological productivity and being tightly linked to sediment through transport dynamics. Efforts described in a previous report quantified pollution reduction outcomes and forest protection success from these projects and represented a first step (Stage 1) in our overall assessment. This earlier assessment was subsequently refined (Stage 2 results reported herein) and focused on improving pollutant loading and cost estimates, improving automation of algorithms for repeating analyses in the future, adding load reductions from BMP projects under other programs or initiatives, and adding alternative analyses for quantifying land protection strategies.

Research Questions

The overall goals of the DRWI Pollution Assessment were to:

A. Identify hotspots of excess nonpoint source pollution (nitrogen, phosphorus, sediment) in stream reaches and catchments of the Delaware River Basin.
B. Quantify progress toward improving water quality by DRWI-style restoration and land protection activities, answering questions such as:
    - What fraction of excess nonpoint source pollution has been reduced by DRWI and other projects?
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The DRWI Pollution Assessment was conducted in two stages. The **Stage 1 Pollution Assessment: Rapid Assessment** (report submitted to WPF in Feb. 2022) provided contextual framing of DRWI achievements to date for a strategy review by the Foundation. The Assessment was developed from existing tools such as, Model My Watershed (ModelMW) and the Focus Area Evaluation Tool (FAET) that had datasets in need of updates (land cover from 2011 and weather from 1960-1990) and not all implemented DRWI project data available. The Stage 1 timeline was too short to update these datasets.

The **Stage 2 Pollution Assessment: Refined Assessment**, reported herein, was designed to provide a more robust and dynamic assessment system for more accurate future program assessments and conservation planning. Several key datasets were updated to utilize more current, accurate, and precise geographic and environmental data, including:

- Land cover updated from 2011 to a 2019 product;
- Weather data updated from 1960-90 to 2000-19;
- Stream network hydrography updated to a higher-resolution stream network; and
- Conservation projects from more sources and further back in time.

The assessment system refinement was based on previously-developed tools to:

- Track water pollution by source as it travels, mixes, dilutes, accumulates, and attenuates downstream through the stream reach network.
- More efficiently reanalyze progress toward achieving acceptable water quality;
- Explore hotspot maps and summary data to inform focus area targets and to estimate future opportunities and costs to achieve a beneficial water quality goal; and
- Iteratively re-do assessments based on changing input and targets/objectives.

Modeling efforts were designed to address several specific questions:

- What are the water quality benefits across the DRWI and within Clusters and their Focus Areas and how do the benefits compare with other, non-DRWI efforts across the geography?
- What is the geographic variability of nonpoint source nutrient and sediment loading from the DRB landscape, how does this pollution travel, mix, dilute, accumulate, and attenuate downstream through the stream reach network, and what is the value of restoring or protecting headwaters to downstream water quality?
- Where and how much progress has been made in reducing pollution, and what geographies would be targeted for future efforts to address remaining excess loads?
- How much more non-point source restoration work would need to be completed to achieve healthy water goals and what are the estimated costs of that work if a similar suite of best management practices were to be prioritized?
- How have DRWI land protection efforts helped to prevent future nonpoint source nutrient and sediment loads and how do protection efforts compare to the loads reduced via restoration?
- How much of the DRB has been protected through land preservation, how much more protection is needed to ensure that 30% of the DRB landscape is protected, and what are the cost estimates to achieve this goal?

Target Audience

There were three primary audiences targeted for this work: (1) staff and leadership at the William Penn Foundation, (2) DRWI partner organizations and individuals, and (3) other organizations and individuals pursuing water resources management in the DRB and elsewhere.

RESEARCH APPROACH

This section provides a brief overview of the Modeling and Analysis Framework and the Data Sources used for the DRWI Pollution Assessment. We also describe the Strengths and Limitations of our approach, and how we leveraged Research Advisory Committee Input.

Modeling and Analysis Framework

Overview of Pollution Assessment Framework

A suite of modeling tools previously funded via DRWI (including Model My Watershed and derivatives thereof) were used to estimate current nitrogen, phosphorus and sediment loads from all sources throughout the DRB. Figure 2 illustrates the modeling schema utilized in this effort. To summarize, ModelMW was utilized to model nutrient and sediment loading across the DRB. Project-specific data were harvested from FieldDOC (data submitted by participating organizations), and a series of scripts and algorithms were developed to remove point source loads, track nonpoint source loads through the hydrologic network, and calculate load reductions or future prevented loads (among other details). All source code have been released under open-source licenses in a series of connected repositories at https://github.com/WikiWatershed and https://github.com/TheAcademyofNaturalSciences. Details are provided in our Appendix 2: Methodology.

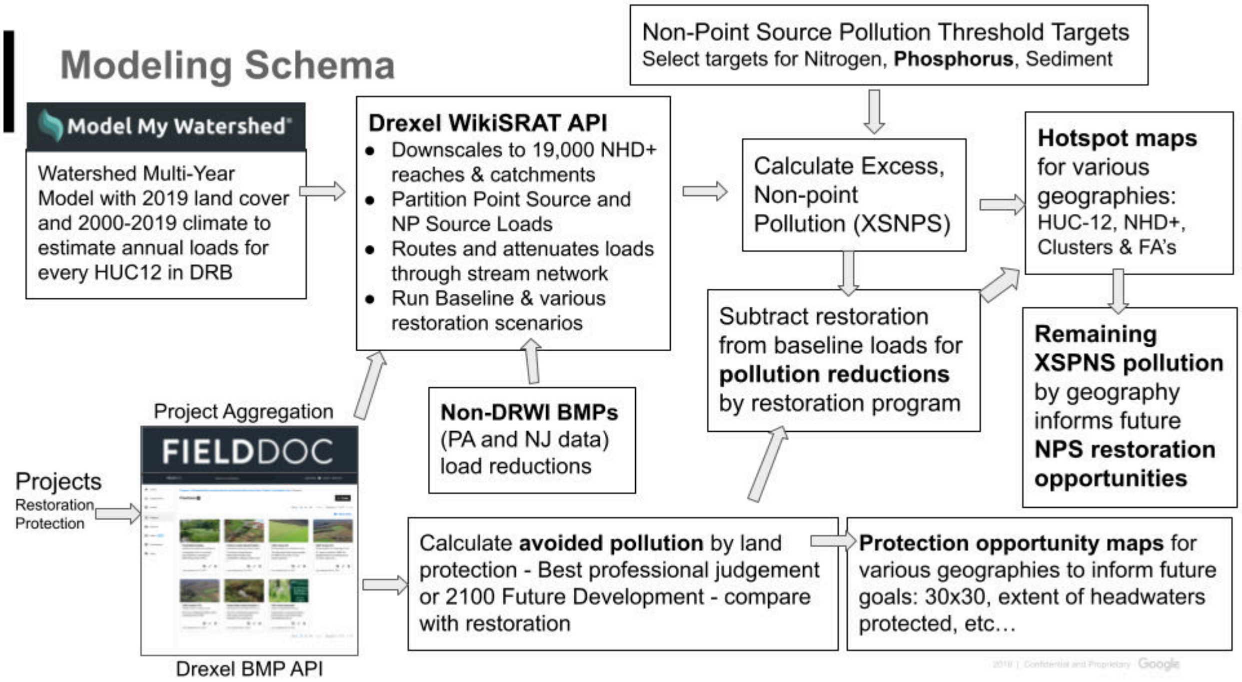

Figure 2. Framework for modeling and analysis used by the DRWI Pollution Assessment project. The editable version of Fig. 2 can be found in DRWI-PollutionAssessment-ProjectUpdate-GISWorkGroup, and a detailed Data Flow Diagram is available at https://miro.com/app/board/uXjVOapsR_E=/

Modeling Baseline Pollution

Pollution concentrations and loading rates were estimated using Model My Watershed (ModelMW, https://modelmywatershed.org) and its Watershed Multi-Year Model (a.k.a., Mapshed or GWLF-E), which has become one of the watershed modeling systems recommended by Pennsylvania Department of Environmental Protection (PA DEP). For our baseline assessment, we ran ModelMW for each of the 480 USGS Hydrologic Units at Code-level 12 (HUC12) in the greater DRB region, without any restoration or protection activities. These ModelMW results provided pollution load estimates by source type (i.e., loading from land uses and natural cover types, ag animals, septic (rural) and wastewater treatment plants (point sources), stream bank erosion, and sub-surface flow).

To further pinpoint hotspots of pollution to the finest resolution available in the USGS National Hydrography Dataset Plus (NHDPlus), we processed each of the 480 HUC12 model results through Drexel's WikiSRAT API, which uses algorithms developed for the Stream Reach Assessment Tool (SRAT) and utilized for the Focus Area Evaluation Tool (FAET) to:

- Downscale pollution loading rates by source types from the HUC12 scale to the much finer NHDplus catchment scale, and
- Route in-stream pollution downstream through the NHDplus stream network, mixing, diluting, accumulating and attenuating pollution loads.

For Stage 2, all models were automated through a series of Python scripts and accessed modeling capabilities through the ModelMW API, the WikiSRAT API, and the FieldDOC API, which were all developed or enhanced under this project. This automation capability provides a substantial contribution to the water conservation community, by enabling rapid future updates to all our estimates.

The outputs from these combined models are catchment loading rates and stream reach concentrations for each of the three pollutants from each of the 19,496 NHDplus catchments and their stream reaches for the greater DRB region within which the DRWI is nested. Note, to incorporate all DRWI geographies, we define the "greater DRB region" to include the DRB and two adjacent HUC08 sub-basins in southern New Jersey that the DRWI names the Kirkwood-Cohansey region (see Fig. 1).

Modeling Reduced Pollution by Restoration

WikiSRAT provides the capability to reduce pollution loads from NHDplus catchments using detailed data on implemented restoration practices, their locations, and their modeled levels of pollution reduction. These reductions were applied before pollutants were routed into and through the stream network, offering a powerful opportunity to evaluate how upstream restoration practices benefit downstream water quality.

We ran a second set of WikiSRAT simulations on the baseline ModelMW outputs. These WikiSRAT simulations incorporated the pollution reductions from each of 1,446 DRWI restoration practices implemented in Phase 1 and Phase 2 of DRWI activities along with all available information on non-DRWI restoration practices in PA and NJ, as described in Reduced Pollution by Restoration below.

Pollution reduced by restoration is therefore the difference between baseline model results and restoration-scenario modeling results.

reduced pollution = baseline modeled pollution – restoration-scenario modeled pollution

Modeling Prevented Pollution by Land Protection

ModelMW and WikiSRAT both have the capability to simulate scenarios of modified land cover. We used this capability to run a second set of ModelMW simulations on each of the 480 HUC12s, using "what-if" scenarios of future land development on the protected parcels. Our approach to developing these future land development scenarios were informed by a "Land Protection Impact Assessment (LPIA)" led by the Open Space Institute (OSI) as described in Future Prevented Loads, below.

We then used these baseline, restoration-reduced, and future prevented modeling outputs to perform all subsequent Pollution Assessment calculations outside the modeling systems.

Analysis of Excess Nonpoint Source Pollution

Excess pollution is the amount of pollution above the healthy waters threshold target established in Stage 1, and described in Pollution Threshold Targets for Healthy Water, below.

excess pollution = baseline modeled pollution – threshold value

Nitrogen and phosphorus pollution have point sources – such as waste water treatment plants (WWTP) – that are actively being addressed by municipalities, states, and the US Environmental Protection Agency under the Clean Water Act. Model My Watershed includes point sources in both baseline and restoration simulations. Combined Sewer Overflows (CSOs) are not directly considered in point source or excess pollution categories and do not affect this assessment.

Nonpoint sources – such as runoff from croplands, lawns, and pavement – have historically been much more challenging to mitigate because of diffuse ownership, lack of incentives, and minimal investments. DRWI efforts thus focused exclusively on reducing and preventing nonpoint sources of pollution. To estimate the amount of pollution that was addressable by DRWI-style restoration and land protection activities, we subtracted out the point source pollution from the excess pollution.

Excess nonpoint source (XSNPS) pollution is thus excess pollution minus point source pollution.

excess nonpoint source pollution = excess pollution – point source pollution

ModelMW and WikiSRAT were not designed to directly make these calculations or even provide all the necessary outputs for the most precise calculations, so for Stage 2 we enhanced ModelMW and WikiSRAT to calculate the source of pollution from any stream reach in the basin and therefore more accurately estimate the nonpoint source contribution to pollution concentrations within reaches and small catchments.

Even with enhanced model outputs, we performed all further calculations within a Python environmental data science framework, using geospatial Python libraries and tools such as GeoPandas, GeoViews, and Jupyter Notebooks. This analysis framework enabled our team to perform reproducible calculations over the 19,496 NHDplus catchments and reaches, map outputs, and aggregate or sum over specific areas of interest, such as USGS Hydrologic Units at all levels (HUC12, HUC10, HUC08) and DRWI Clusters and their Focus Areas.

Analysis of Remaining Nonpoint Source Pollution

A key goal of the Pollution Assessment was to quantify the amount of nonpoint source pollution remaining in streams to achieve the healthy streams goal after all restoration benefits were accounted for. We calculated this by subtracting reduced pollution from restoration from excess nonpoint source pollution.

remaining nonpoint source pollution = excess nonpoint source pollution – reduced pollution

Aggregating by Geography

DRWI organized conservation efforts under eight Clusters (Fig. 1) and their Focus Areas (Fig. 3A). These geographies were valuable to the DRWI for many reasons, yet they posed challenges to quantifying pollution loads in stream networks because they often crossed watershed divides and were therefore composed of diverse hydrologic units. The US Geological Survey's National Hydrography Dataset Plus (NHDPlus) divides the USA along watershed divides into Hydrologic Units that follow an upstream to downstream topology (Fig. 3B).

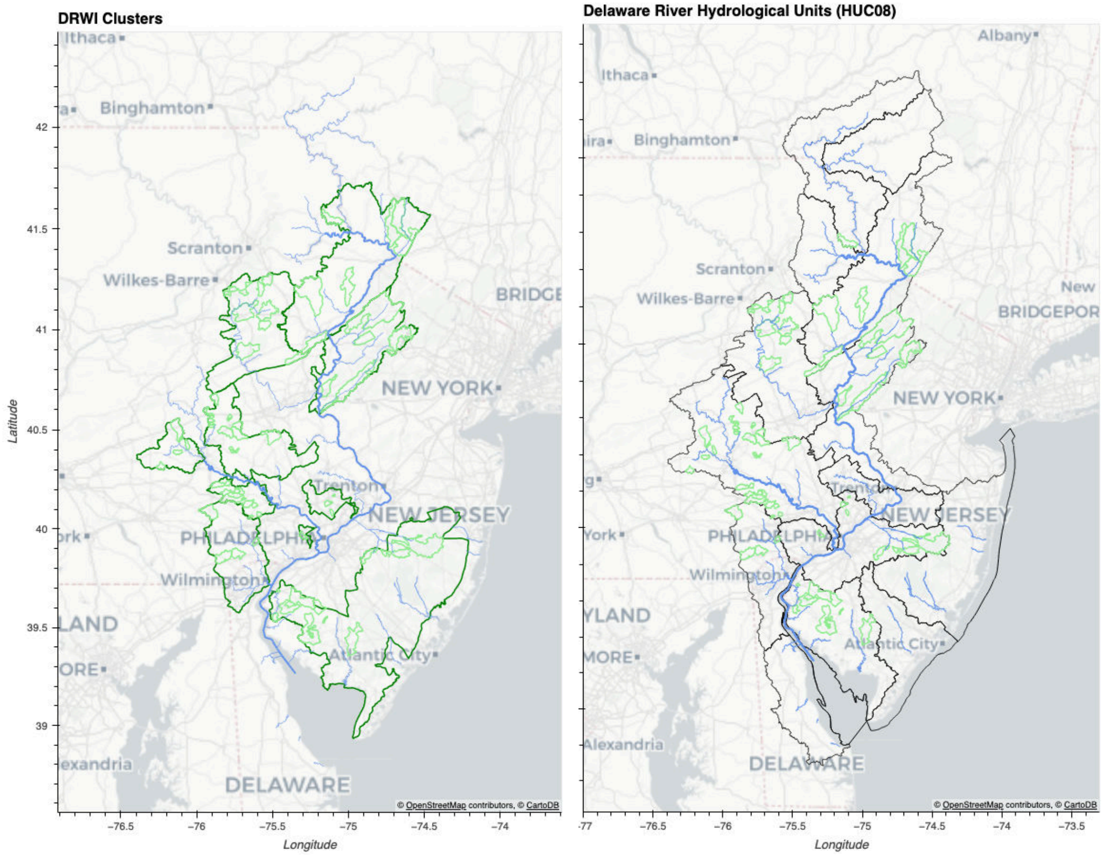

Figure 3: The eight DRWI Clusters (left, dark green boundaries) organized conservation efforts in DRWI Focus Areas (left and right, light green boundaries). These DRWI geographies overlap with 14 US Geological Survey Level-8 Hydrologic Units (HUC08) (right, black boundaries), each of which is composed of smaller HUC10 geographies and further divided into yet smaller HUC12 geographies that all delineate watershed divides.

The Stage 2 Pollution Assessment advanced modeling capabilities to track pollution reductions through a stream network to demonstrate downstream benefits to upstream restoration and protection projects. To track these downstream benefits, we reoriented our Stage 2 analysis around USGS HUC12, HUC10, and HUC08 geographies. Fortunately, DRWI Clusters are almost entirely contained within HUC08s of similar names. Minor discrepancies in these boundaries, however, do result in minor differences in any reporting by Cluster. We therefore recommend all future analyses be performed around USGS HUCs.

Data Sources

Datasets Supporting Models

The base geospatial data informing modeling efforts herein are included and documented in ModelMW. Specifically, documentation for all layers that are visually available in ModelMW can be found at https://wikiwatershed.org/knowledge-base/layers-viewable-mapped-data/ and layers utilized by the Watershed Multi-Year Model (not visualized, but included in model runs) can be found at https://wikiwatershed.org/knowledge-base/water-quantity-and-quality-models/. These include:

- NOAA North American Land Data Assimilation System (NLDAS) daily weather data (temperature, precipitation, etc.) from 2000-2019
- USGS/EPA National Hydrography Dataset Plus (NHDplus) v2 High Resolution stream network (released in 2019) and Hydrologic Unit boundaries.
- USGS Digital Elevation Model (DEM), at 30 m resolution, hydrographically corrected to the NHDplus v2 stream network.
- USGS National Land Cover Dataset (NLCD), 2019 data (released in 2022)
- USDA Gridded Soil Survey Geographic (gSSURGO) Database, for Hydrologic Soil Groups
- A DRB-enhanced version of EPA's Discharge Monitoring Report (DMR) Data quantifying point sources pollutant loads
- USDA County-Level Farm Animal Populations
- USGS Stream Baseflow Index
- USGS Shallow Groundwater Nitrogen dataset
- USGS Soil Phosphorus and Nitrogen datasets

These data are inputs to the model algorithms used by Model My Watershed's Watershed Multi-Year Model (i.e. Mapshed/GWLF-E), as described at https://wikiwatershed.org/kbcategories/mmw-tech/.

Our modeling approach utilized a sub-basin modeling routine for ModelMW called WikiSRAT that connects to the ModelMW framework and utilizes the same datalayers. Documentation for WikiSRAT is archived on GitHub at https://github.com/TheAcademyofNaturalSciences/WikiSRATMicroService. WikiSRAT is a service built and maintained by colleagues at the Academy of Natural Science of Drexel University.

Restoration and protection projects completed by organizations contributing to the DRWI were entered by participants in the FieldDoc platform. FieldDoc helps practitioners set conservation goals, model impact, track progress, and map grant-funded restoration projects. FieldDOC was created and is maintained by The Commons (for more information, https://www.chesapeakecommons.org/fielddoc).

Pollution Threshold Targets for Healthy Water

Pollution threshold targets were established in Stage 1 for nitrogen, phosphorus, sediment, as a basis for evaluating "excess pollution". These pollutants all occur naturally at certain levels in healthy streams, but impaired streams typically have substantially elevated concentrations of these pollutants.

We reviewed the literature on threshold values that represent transition points between "impaired" and "non-impaired" streams. This included a review of various studies and reports written about areas in and around the DRB. These included work by the USEPA on threshold values for different ecoregions within the U.S., reports of TMDL studies by state agencies in Pennsylvania and New Jersey, and a study done by Sheeder and Evans (2004)[1] on nutrient and sediment criteria for PADEP.

For each pollutant, we selected target values (Table 1) for:

- **Mean annual concentration** (pollutant mass per volume of water) for a stream reach, which is most related to how aquatic organisms respond to the pollution; and
- **Mean annual area-normalized loading rates** (pollutant mass per land area per year) for a land catchment draining into a stream reach, which is most related to where pollution enters the stream network.

These values were set at the lower 95% confidence limit for impaired streams and catchments, based on reanalysis of the study by Sheeder and Evans (2004). Streams and catchments below these threshold values are only 5% likely to be impaired. Detailed background and rationale are provided in the Task 1 section of our Stage 1 report: DRWI-PollutionAssessment-Stage1-Report-Final-Revised .

Table 1. Pollution Threshold Values for Impaired Streams.

Pollutant	Target Concentration (mg/L)	Target Loading Rate (lbs/ac/y)
Total Nitrogen (TN)	4.725	15.23
Total Phosphorus (TP)	0.09	0.28
Total Suspended Sediment (TSS)	237.3	824.2

Conservation Practices

Restoration and Protection Practices from FieldDoc

The Delaware River Restoration Fund (DRRF), Delaware River Operational Fund, and Delaware Watershed Conservation Fund together resulted in the implementation of 1,446 restoration practices (i.e., best management practices, BMPs) over the course of DRWI Phase 1 and 2 between 2014 to present day (September 18, 2023). The Delaware River Watershed Protection Fund (Forestland Capital Grants) directly led to 75 land protection projects. We collectively refer to all these projects and practice implementations across the DRWI restoration, hybrid, and protection Clusters and their respective Focus Areas as DRWI conservation practices.

Details on each of these practices were recorded by the implementer of each BMP in the FieldDoc Platform. We fetched information and model-relevant data for each practice using the new FieldDoc API (Application Programming Interface), which developers at The Commons created with project funds during the Stage 2 Pollution Assessment. Our last data pull from FieldDoc for this work was on September 18, 2023.

We modeled pollution reductions from each restoration practice using an automated modeling service developed by Drexel University (Academy of Natural Sciences of Drexel University and The Drexel University College of Computing and Informatics) in support of NFWF's Restoration Project Impact Analysis. The 1,446 BMPs fall within 55 BMP practice types. Details on DRWI practices are provided in Appendix 1: Conservation Practices in DRB, Table A1-1, and Table A1-2.

Restoration Practices from PA and NJ Databases/Sources

Information on non-DRWI BMPs was obtained in Stage 2 for Pennsylvania and New Jersey. Project-specific BMP data was obtained from PADEP (Table A1-3) and county-level BMP information was

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[1] Sheeder, S.A., Evans, B.M. 2007. Estimating Nutrient and Sediment Threshold Criteria for Biological Impairment in Pennsylvania Watersheds. JAWRA. Vol.40(4): 881-888. https://doi.org/10.1111/j.1752-1688.2004.tb01052.x

obtained for PA and NJ (Table A1-4). These BMP datasets substantially expand our accounting of total restoration activities in the DRW, yet they do not represent a full accounting, as we know these datasets to be incomplete and were not able to get similar data for NY or DE. Pollution reductions from all non-DRWI BMPs were modeled using similar approaches to DRWI practices, described above. Details on non-DRWI practices are provided in Appendix 1: Conservation Practices in DRB.

Protected Land from WeConservePA

We obtained a detailed database of protected parcels in the DRB – specifically federal, state, local, and private protected lands – from a WeConservePA data product[2] that is specific to the DRB. For the area outside of the DRB (i.e., part of the Kirkwood-Cohansey region), we also utilized the Protected Areas of the US or PADUS data product that is included in ModelMW.

Natural Land Protection

Future Prevented Loads

Land protection activities, such as the Delaware River Watershed Protection Fund administered by the Open Space Institute (a land protection program within the DRWI), essentially maintain “natural” land cover conditions in protected areas which ultimately support a variety of water quality-related environmental services, including the prevention of future development in unique and sensitive areas. While such activities do not necessarily reduce pollutant loads in a given area (unless combined with restoration), land protection maintains forests and other natural lands that help to deliver high water quality downstream. Thus, forest land protection helps to prevent water quality degradation due to land conversion in the future. In this study, we call these loads “future prevented loads”.

To estimate future prevented loads, we calculated the cumulative total loads from DRWI-DRWPF land protection projects that were tracked in the FieldDoc web application, covering 26,414 acres of natural lands (Table 2). These projects were primarily within three clusters (Poconos and Kittatinny, Upper Lehigh and Kirkwood - Cohansey Aquifer). We calculated the future prevented loads based on land-use projections using two different scenarios to “develop” each protection parcel and then selected the scenario with the greatest future impact to water quality: (1) best professional judgment of the risk of development if not preserved estimated by the land preservation team at the Open Space Institute; and (2) land development predictions from a future growth model developed by colleagues at Shippensburg University[3], which is embedded and automated within ModelMW.

Table 2: Protection projects in HUC08 sub-basins resulting from DRWPF investments as reported in FieldDocs.

HUC08	Area (acres)
Middle Delaware-Mongaup-Brodhead	12,592
Middle Delaware-Musconetcong	4,098
Lehigh	4,157
Lower Delaware	2,835
Schuylkill	553
Cohansey-Maurice	589
Mullica-Toms	1,590
Grand Total	**26,414**

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[2] Delaware River Watershed Conserved Lands. 2023. https://www.arcgis.com/apps/dashboards/3b01dbbd5cfc4156be24b44d1ed2c826

[3] “The DRB2100 (version 3.1)”, Jantz, C. (Dept. of Geography-Earth Science, Shippensburg University) available at https://drbproject.org/products/

Results from calculating future prevented loads were not displayed in the hotspot maps of pollutant loads reduced by restoration projects, as protection efforts were mostly focused in areas that did not have excess pollution loads and these two strategies are inherently different. In other words, protection projects were designed to keep areas on the maps that are shown as green to stay green forever.

In addition to results presented herein, a companion study[4], explored various methods to quantify the impact of forest land protection on water quality. Those methods quantified (a) how forest protection helps to manage stormwater; (b) how forests (specifically, forested riparian buffers) help treat pollutants carried by overland flow (stormwater runoff) and protect a receiving streams water quality; (c) the downstream dilution benefit derived from forested landscapes; and (d) how forest land protection prevents pollutant loading from future development if the parcel is not preserved. In an effort to better synthesize that work and other past studies on the relationship between forest land protection and water quality, a summary LPIA report was produced to inform the broader land protection community about the strategies utilized during the DRWI[5]. That report is a companion to the results presented herein. Our re-analysis of future pollution prevented by natural land protection is a refinement of the methodological approach described in that previous work and includes a more complete inventory of the forest land parcels protected by DRWI-DRWPF efforts.

Forest Land Protection and the 30x30 Goal

Further exploration of data layers utilized in this modeling effort focused on forest land protection success and future opportunities for protection at various scales and geographies across the DRB.

In January of 2021, the Biden administration release an Executive Order[6] focused on tackling the climate crisis at home and abroad. Within that order, the Biden administration established a national goal to conserve at least 30 percent of U.S. lands and freshwater, in an initiative commonly referred to as 30 by 30 (30x30 or 30% goal herein). The 30x30 initiative seeks to reverse the negative impacts of climate change and biodiversity decline by protecting more natural areas, and to increase access to nature for communities that lack it. After this announcement, the Biden administration released a report[7] outlining how 30x30 will support the efforts of people across the country to achieve the nation's habitat conservation goals.

To this end, we summarized data utilized herein to frame the status and future opportunities to achieve the 30% goal within the greater DRB region. First, the total area of "natural land" was calculated from the 2019 NLCD by merging "forest" (all types), "wetlands" (all types), and "shrub/scrub" categories. We excluded the "grasslands/herbaceous" cover type to ensure that we focus primarily on forest land, wetland, and woody vegetation cover types. Next, all the "natural land" was subdivided into three categories: (a) parcels protected by DRWI projects/activities, (b) all other protected parcels, and (c) the remaining "natural land", that was unprotected. The last step was to subdivide this information into different geographic categories to summarize statistics for (1) DRWI Focus Area and Clusters and (2) each Hydrologic Unit at the HUC12 and HUC08 scales.

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[4] Estimating the Influence of Land Protection on Water Quality. Arscott, D., L. Perez, B. Evans, C. Jantz. 2021. Submitted to the Open Space Institute (NY, NY).

[5] Protecting Forests for Clean Water: Findings from a 10-year initiative inform field-wide best practices. Weinberg, A. 2023. URL Link forthcoming.

[6] Executive Order on Tackling the Climate Crisis at Home and Abroad. January 27, 2021. https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

[7] Conserving and Restoring America the Beautiful. 2021. https://www.doi.gov/sites/doi.gov/files/report-conserving-and-restoring-america-the-beautiful-2021.pdf

To estimate the potential costs to achieve the 30% goal, data provided by OSI on the Fair Market Value of DRWI-DRWPF projects were used to summarize per acre costs for preservation over the last 8+ years of effort (Table 3). We then used the 30% protected level to set the goal for each geographic subdivision and simply calculated the difference in "protected status" from the 30% goal to derive an acreage needed to achieve the 30% goal. We then applied the FMV/Acre estimates to each geography most closely aligned with each estimate that had enough "natural land" to achieve the 30% goal. Therefore, cost estimates are likely to be most relevant/accurate for Cluster geographies and less appropriate/accurate for all other geographies. Please note that the DRWI-DRWPF efforts typically leveraged closing costs at a ratio of >3:1 (i.e., several funding sources were typically involved with purchase of each protected area).

Table 3: Data provided by Open Space Institute on Fair Market Value at time of closing on land protection efforts in various DRWI Cluster geographies. Note: financial data were provided prior to the last update of all completed projects, thus the total acreage presented here is slightly lower than the total achieved through all DRWI activities.

Cluster	Total Acreage Protected	Sum of the Fair Market Value	Average of FMV/Acre
Kirkwood Cohansey	4,721	$5,852,823	$1,389
New Jersey Highlands	3,136	$10,526,511	$5,918
Poconos & Kittatinny	14,976	$34,782,634	$4,150
Schuylkill Highlands	645	$6,329,088	$12,196
Upper Lehigh	2,252	$8,252,737	$3,610
Grand Total	**25,730**	**$65,743,793**	**$5,403**

Opportunities for Headwaters Protection Analysis

The protection of forested/natural headwater areas was a priority for the DRWI-DRWPF re-granting program. Specifically, funding decisions for protection projects were primarily based on each parcels' ability to produce clean and abundant water using a multi-metric approach that captured land cover, terrain, and hydrologic information describing whether a parcel was adjacent to small headwater streams and wetlands (among other factors, but see[8]). To this end, currently unprotected parcels throughout the study geography were filtered and processed using the following criteria (parcel data provided by the Academy of Natural Sciences of Drexel U.):

- Select all NHDPlus catchments that contain 1st to 3rd order streams that drain only to 1st to 4th order streams (using Strahler stream order definitions and the NHDPlus stream network map);
- Of the catchments identified above, only select catchments with >75% forest cover and >90% "natural land" cover;
- Overlay parcel data and select all parcels meeting these same criteria (note that only parcels exceeding 50 and less than 2,500 acres were included);
    - most parcels overlapped multiple NHDPlus catchments and were subsequently split and partitioned spatially into their relevant NHDPlus catchments.

This resulted in the identification of 4,380 parcels (Table 4 and Fig. 4) that met the criteria described above. The final database contained 8,003 polygons of the parcel boundaries due to most parcels being split/partitioned into adjacent NHDPlus catchment areas. Most parcels were between 75 and 200 acres in size (before they were partitioned into NHDPlus catchments). The majority of headwater opportunity

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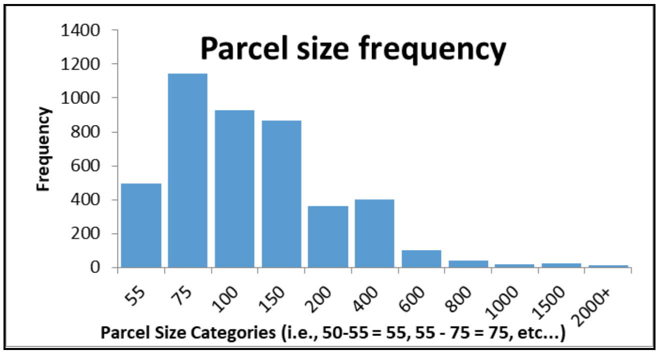
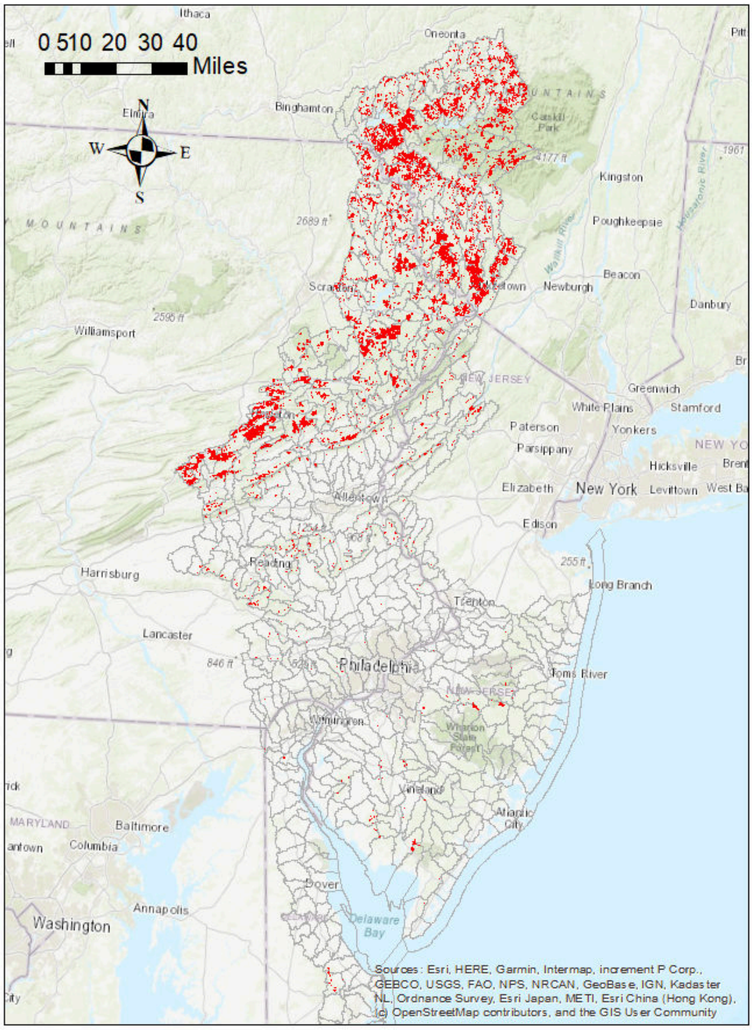
[8] Ability to Produce Clean and Abundant Water - version 2. 2016 - Open Space Institute. https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1613

parcels were located in the northern half of the DRB, north of the Kittatinny Ridge (Fig. 4). These data were utilized in the natural land protection 30% analyses.

Table 4: Summary data on the total number of parcels that met the headwater natural land criteria and their size-frequency distribution (right) (see text above).

Metric	Result	Units
Total acres	573,170	Acres
Total parcels	4,380	Count
Average parcel size	134	Acres
Minimum parcel size	50	Acres
Maximum parcel size	2,441	Acres





Sources: Esri, HERE, Garmin, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), (c) OpenStreetMap contributors, and the GIS User Community

Figure 4: Headwater "natural area" parcels identified from parcel-level data within the study geography. Parcels were only selected if they: were within an NHDPlus sub-basin that contained 1st - 3rd order streams that only drain to 1st - 4th order streams (Strahler stream orders defined by NHDPlusHR stream network) AND the parcel contained >75% forest and >90% "natural land".

Strength and Limitations

Modeling vs. Monitoring

Both water quality monitoring and water quality modeling are useful and important components of a comprehensive water quality management/assessment program such as the Delaware River Watershed Initiative. Although water quality monitoring (i.e., instream sampling) can provide very accurate information on the current state of water quality conditions (e.g., nutrient concentrations, dissolved oxygen, BOD, etc.) within a given water body (i.e., stream), such sampling must typically be done over long time frames (i.e., 5-10 years) and include sampling during the entire range of flow conditions (i.e., low flow during dry weather to high storm flow during extreme weather events) in order to accurately represent water quality over widely variable flow and temperature conditions. For example, sampling conducted solely during low flow events may be heavily influenced by point source discharges and not adequately reflect loads coming from nonpoint sources such as cropland and urban areas during periods of heavy precipitation.

Unfortunately, instream monitoring programs extensive enough to achieve high levels of spatial and temporal accuracy in very large areas like the DRB can be prohibitively expensive. Additionally, in-stream samples cannot adequately ascertain the source of pollutant loads from various sources since such sampling only provides information on the “combined” effects of pollutant loads from a variety of sources once they have entered the stream. Consequently, complex watershed models like Model My Watershed are used or developed to help answer questions that are difficult to address using water quality monitoring alone.

With models such as Model My Watershed, a combination of data sets, algorithms and routines are used to simulate the generation and delivery of pollutant loads from point and nonpoint sources as comprehensively as possible for longer time frames than typically represented by sampling (i.e., monthly, seasonally, annually and long-term average). When “trained” during a process of calibration as was done with the model developed for the DRB in Stage 1, such a model can provide useful information on how loads differ for regions and smaller watersheds within a larger watershed such as the DRB having different landscapes and levels of BMP implementation.

One of the primary purposes of watershed modeling is to predict the magnitude of average annual pollutant loads within a given area such as the DRB under existing and/or future conditions. To enable useful predictions, models are calibrated through a process of iteratively comparing predicted loads against loads generated using in-stream sample data, and then adjusting model routines and algorithms as needed to better predict pollutant loads from various sources. For the work conducted as part of Stage 1, a limited amount of calibration was conducted due to financial constraints. However, even with limited calibration, the model predictions when compared against observed TN, TP and TSS loading rates for six sub-basins within the DRB were determined to be fairly close with combined R-squared values of 0.93, 0.91, and 0.97, respectively. In general, for projects such as the one described in this report, simulation modeling is considered to be more appropriate for assessing long-term average benefits and impacts

Estimate of uncertainties

The modeling and analysis framework implemented by this DRWI Pollution Assessment is among the most comprehensive conservation planning and assessment frameworks of its scale in the nation. Other than the federally-supported Chesapeake Bay Model and associated Chesapeake Assessment Scenario Tool (CAST), we are not aware of any other conservation decision support tool that combines all of the following:

- A watershed modeling system (GWLF-E, the core of ModelMW) approved by EPA, PADEP, and other states for Total Maximum Daily Load (TMDL) allocations and MS4 permitting.
- Model input datasets all updated to the latest, high-resolution federally supported data (see Datasets Supporting Models)
- Comprehensive, integrated assessment of implemented BMPs or future land use/cover change.

Uncertainties in models and complex analyses come from two sources, uncertainties in the input datasets and uncertainties in the mathematical representations of natural processes (i.e., models) and the simplifications that must be made to simulate our complex and highly heterogeneous natural systems. For all of these data inputs and algorithms, the goal is to achieve random uncertainties, where the average of repeated measurements equals the true value. When uncertainties are random, with no systemic bias, then summing and averaging results yields summary outputs with minimal uncertainties.

We have taken much care to follow all of these steps for our Pollution Assessment, by making the effort to update all data inputs to use the most accurate available input datasets, incorporating the best available process simulations (i.e., mixing, accumulating, and attenuating stream loads through the stream network), and by doing extensive local calibrations of model outputs to high quality monitoring data, where it is available (calibration details are available in ModelMW documentation[9]). Initial calibration work was first completed to support Stage 1 analyses. As various model input datasets such as the stream hydrography, daily weather data, and land use/cover were updated an additional round of calibration was conducted as described in Appendix 4. Finally, we make all of our conclusions from summing and averaging our results, which substantially reduces overall errors. Model My Watershed outputs the annual average of 20 years of daily pollution load estimates. We then summarized those outputs by HUC08.

Research Advisors Input

The Pollution Assessment was launched in July of 2021 and proceeded in several “stages'' of effort. During and nearing the end of Stage 1 (Nov. 2021) and throughout Stage 2 (Dec. 2021 - Jan. 2024), input and advice was received by convening three different groups over multiple meetings: (1) staff from the William Penn Foundation, (2) the DRWI’s Technical User Group (TUG) and the Data, GIS, and Modeling Work Group, and (3) staff from the Open Space Institute (OSI). All advisory audiences provided critical feedback on our development of the Healthy Water goal (pollution threshold targets), our preliminary results quantifying both restoration and protection efforts, the decision to focus primarily on phosphorus loading, presentation graphics and relevant information, decision making specific to the approaches used to estimate future prevented loads, and the approaches used to project future costs for achieving the healthy water goal.

All discussions, feedback, and decisions have been tracked with detailed notes in two public Google Documents:

- 2021-2023_DRWI-PollutionAssessment-Notes
- TUG Agenda/Notes

We thank the following for their contributions to this process:

- William Penn Foundation staff: Clare Billet, Liz Thompson, Hilary Rhodes, Nate Boon, and Stuart Clarke

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[9] Model calibration details are available in ModelMW documentation provided at https://wikiwatershed.org/knowledge-base/water-quantity-and-quality-models/#7-2-6-model-calibration

- DRWI's Technical User Group: Lin Perez (co-chair) (Academy of Natural Sciences), David Arscott (co-chair) (Stroud Water Research Center), John Dawes (Chesapeake Commons), Matt Ehrhart (Stroud Water Research Center), Anthony Aufdenkampe (LimnoTech), Barry Evans (Academy of Natural Sciences), Clare Billett (WPF), Chris Pollard (Del. Valley Regional Planning Commission), Claire Jantz (Shippensburg Univ.), Irina Beal (WeConservePA), Megan Boatright (Natural Lands), Abigail Weinberg and Hallie Schwab (Open Space Institute), Jenny Egan (Univ. Maryland), Franklin Egan (RegenALL), and Tim Maguire (Academy of Natural Sciences)
- Open Space Institute: Abigail Weinberg, Hallie Schwab, Bill Rawlyk, and Peter Howell

PROJECT CHANGES

The **Stage 1 Pollution Assessment: Rapid Assessment** (report submitted to WPF in Feb. 2022) provided contextual framing of DRWI achievements to date for a review of initiative strategy by the Foundation. The Assessment was developed from existing tools such as, Model My Watershed (ModelMW) and the Focus Area Evaluation Tool (FAET) that had datasets in need of updates (land cover from 2011 and weather from 1960-1990) and not all implemented DRWI project data available. The Stage 1 timeline was too short to update these datasets.

The **Stage 2 Pollution Assessment: Refined Assessment**, reported herein, was designed to:

- Provide more robust and dynamic assessment system for much more accurate future program assessments and conservation planning
- Update key datasets:
    - Land cover from 2011 to 2019 product (2001-2019)
    - Weather data from 1960-90 to 2000-19
    - Higher-resolution stream networks
    - Conservation projects from more sources and further back in time
- Develop assessment system based on previously-developed tools to:
    - Rapidly reanalyze progress toward achieving acceptable water quality
    - Interactively explore hotspot maps and summaries to inform focus area targets and opportunities, and to estimate future costs to achieve a beneficial water quality goal
    - Iteratively re-do assessments based on changing input and targets/objectives

Stage 1 → Stage 2

Part of our effort during the second stage of this work was to update several of the underlying data layers used in our water quality modeling of restoration and protection outcomes in the DRB. Specifically, the following datasets were updated in Model My Watershed and within our "back end" modeling algorithms:

- The National Land Cover Data layer was updated from 2011 to 2019 within all modeling frameworks based; further, we added 2003, 2006, 2011, and 2016 data layers from the NLCD 2019 data product (released in 2022) to ModelMW to allow any user to summarize these data and implement modeling scenarios based on any of these NLCD datalayers with the Watershed Multi-Year Model;
- Weather datasets (daily temperature and precipitation) utilized within ModelMW were updated from 1960-90 to 2000-2019 for the Watershed Multi-Year Model. These datasets, specific to 11 locations in and around the DRB are now available to all ModelMW users for any project area

that is within or near the DRB (i.e., users can select either time periods for modeling water quantity/quality outcomes);

- The National Hydrologic Dataset (NHD) within ModelMW (and utilized by the Watershed Multi-Year Model) was updated from the "medium-resolution stream network" to the "National Hydrography Dataset Plus (NHDplus) v2 High Resolution stream network" released in 2019. This datalayer is now the default layer for the Watershed Multi-Year Model runs in ModelMW;
- During the course of model calibration undertaken as part of Stage 1, several errors in the "point source data" layer within ModelMW (errors within the original dataset) were discovered that had to be corrected. Primarily, the monthly nitrogen and phosphorus loads were reversed for several wastewater treatment plants. In all, 38 out of 812 point source records for plants located throughout the DRB had to be corrected. Of particular significance is that almost half of these plants are located in the Schuylkill River HUC8 which caused overestimates of phosphorus loads in several sub-basins located therein until the nutrient discharges were corrected.
- To support the initial water quality modeling effort conducted for Stage 1, rough estimates of the implementation levels of various agricultural and urban stormwater best management practices (BMPs) were assigned based on a general knowledge of the implementation of these BMPs within the Chesapeake Bay watershed. For Stage 2, these initial estimates were refined based on more detailed data available for Pennsylvania and New Jersey. For example, in Pennsylvania information on urban stormwater BMPs implemented by municipalities is compiled annually by PADEP for the entire state at the site level (e.g., latitude and longitude) and information on agricultural BMPs implemented by state, federal and other groups (e.g., non-profits) are collected at both the site and county level. Similar detailed information on BMP locations are not generally available, however, for New Jersey. In this case, estimates of current implementation levels of assorted BMPs across central and southern counties in the DRB were obtained from various NRCS offices in New Jersey.

These updates and changes to the underlying data used in our water quality modeling efforts generally increased our estimates of surface runoff, subsurface flow, streamflow, and pollution loads from Stage 1 to Stage 2 efforts (due to increased annual precipitation and increasing impervious surface area). For example, based on modeling done in the Schuylkill HUC08 sub-basin via ModelMW, nitrogen, phosphorus and sediment loads increase by approximately 14%, 13%, and 16%, respectively.

FINDINGS

As mentioned in the Background section, we initially focused on excess nonpoint source loading of nitrogen, phosphorus and sediment. After initial synthesis in Stage 1, a decision was made to focus primarily on phosphorus in this report due to it frequently limiting biological productivity and being tightly linked to sediment through transport dynamics. In addition, phosphorus pollution estimates were the furthest from their targets, and given that all conservation approaches typically reduce nitrogen, phosphorus, and sediment loads, then addressing phosphorus would also lead to addressing the other pollutants. Although we focus on phosphorus for most of our findings, for completeness we also include summary level data on nitrogen and total suspended sediment results in some tables (Tables 5, 7, 10, and Appendix 1 and 3).

In the next sections, we explore model results in the context of the study geography (spatial patterns) and project implementation impact on "excess nonpoint source" loading of nutrients and sediment, primarily phosphorus. First we identify geographic "hotspots" of phosphorus loading and illustrate project impact. Second, we estimate the remaining excess nps phosphorus to achieve the "healthy water" goal. Next, restoration outcomes are summarized at various sub-basin scales and cost estimates of future nps-restoration projects are discussed based on theoretical treatment of the remaining excess loads. Last, we explore forest and natural and protection outcomes including future prevented loads achieved by DRWI projects and future 30% goals and opportunities.

Hotspots of Pollution Sources

A series of hotspot maps of total phosphorus loading rates (lbs/acre) from landscape sources within NHDPlus catchments across the study area demonstrate model results in a stepwise fashion (Figs. 5, 6, 7, and 8). The estimated Total Phosphorus loading rates (lbs/acre) for NHDplus catchment indicate generally lower loading rates in the northern portion of the DRB, the DRB estuary edge, and in the southeastern Kirkwood-Cohansey area (Fig. 5). Nonpoint source TP loading rages (Fig. 6) by source area show a view of TP loading from land use sources, after removing point source loads (i.e., nonpoint sources only). The result is a similar spatial pattern but lower loading rates in several catchments (slightly less red color). Point Source loading rates (Fig. 7), primarily from waste water (sewage) treatment plants, introduce very high loads to selected NHDPlus catchments near urban and suburban centers. Fortunately, these large point sources are typically downstream of most DRWI restoration and protection activities and do not detract from their benefits. Furthermore, large point sources are actively being reduced with federal, state, and municipal funds. The final figure in this series (Fig. 8), illustrates the excess nonpoint source (XSNPS) loading rates for TP estimated by subtracting the "healthy water" threshold targets from non-point source annual TP loading rates (lbs/acre) for each NHDPlus catchment. Figure 8 shows that the majority of catchments in the project area are below threshold values (shown as white/empty). Phosphorus loading rates are above threshold values in hotspot maps (shown as yellow, orange, and red) for the central portion of the DRB, the land set back from the western estuary shore area in Delaware, and in areas around major urban centers (e.g., Philadelphia).

The last step in the modeling process was to estimate pollution reductions resulting from all DRWI and non-DRWI restoration efforts deployed throughout the DRWI- and greater study area. These reductions can then be subtracted from our baseline estimates of excess nonpoint source TP (or nitrogen or sediment, not shown but data for TP, TN, and TSS are included in Tables 5, 6, and 7) to calculate remaining loading rates after restoration reductions. Comparing excess nonpoint source (XSNPS) loading rates with remaining loading rates gives a direct estimate of the benefits of restoration activities. For example, Fig. 9 shows a spatial zoom to the Brandywine-Christina Cluster boundary (black boundary) and its Focus Areas within (gray boundaries). The left panel illustrates the baseline excess nonpoint source loading rates for TP and the right panel the remaining excess nps TP loading rates after accounting for DRWI and other restoration practices. Note the change to white/empty color of several of the NHDPlus catchments within three of the four Focus Area boundaries, where an aggregation of DRWI-DRRF restoration projects were implemented (data on TP load reductions for DRWI Clusters in Table 8).

Catchment Loading Rate Maps for Total Phosphorus

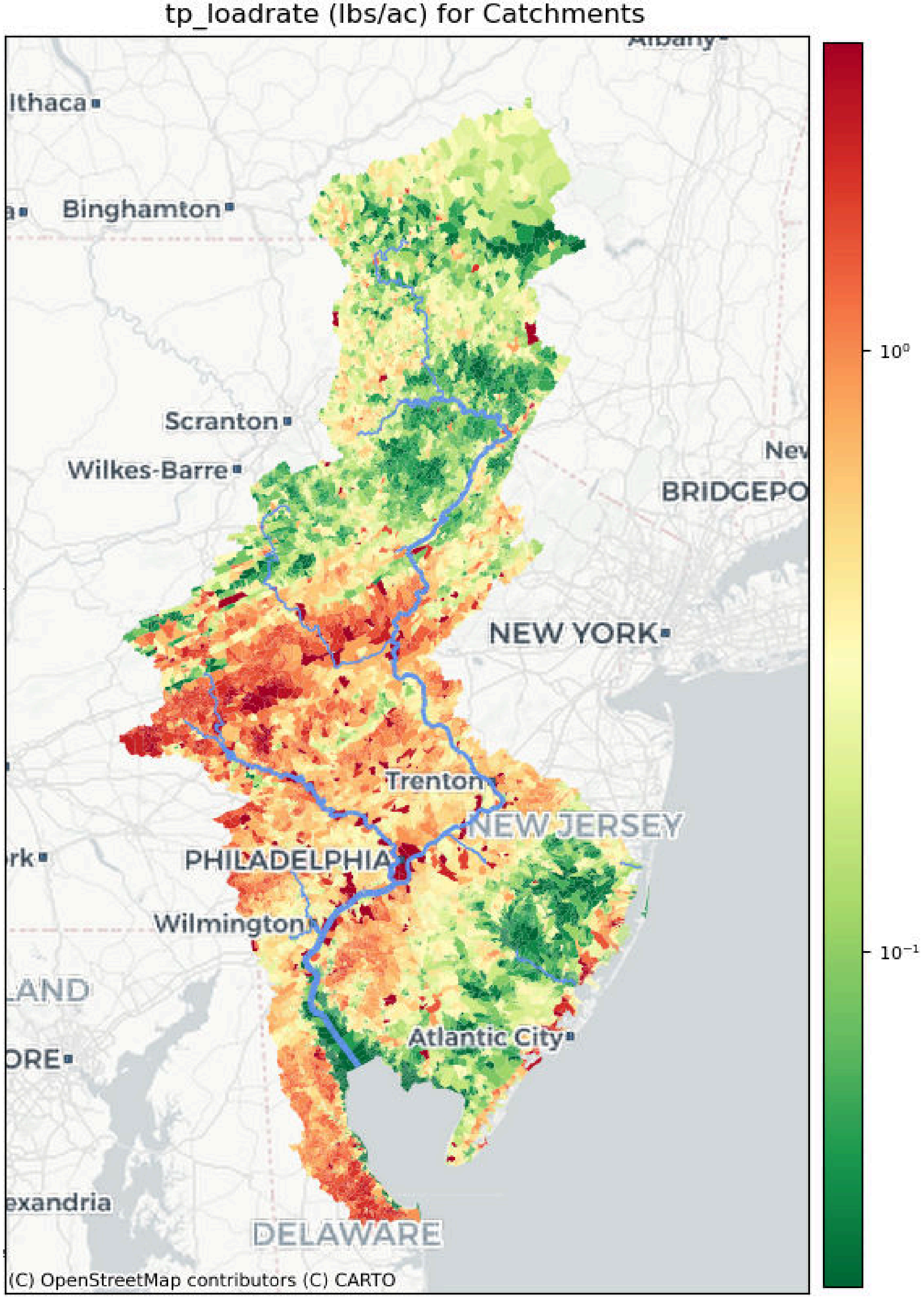

Figure 5: All-source hotspots for Total Phosphorus (TP), estimated from baseline modeling of annual TP loading rates (lbs/acre) from each NHDplus catchment.

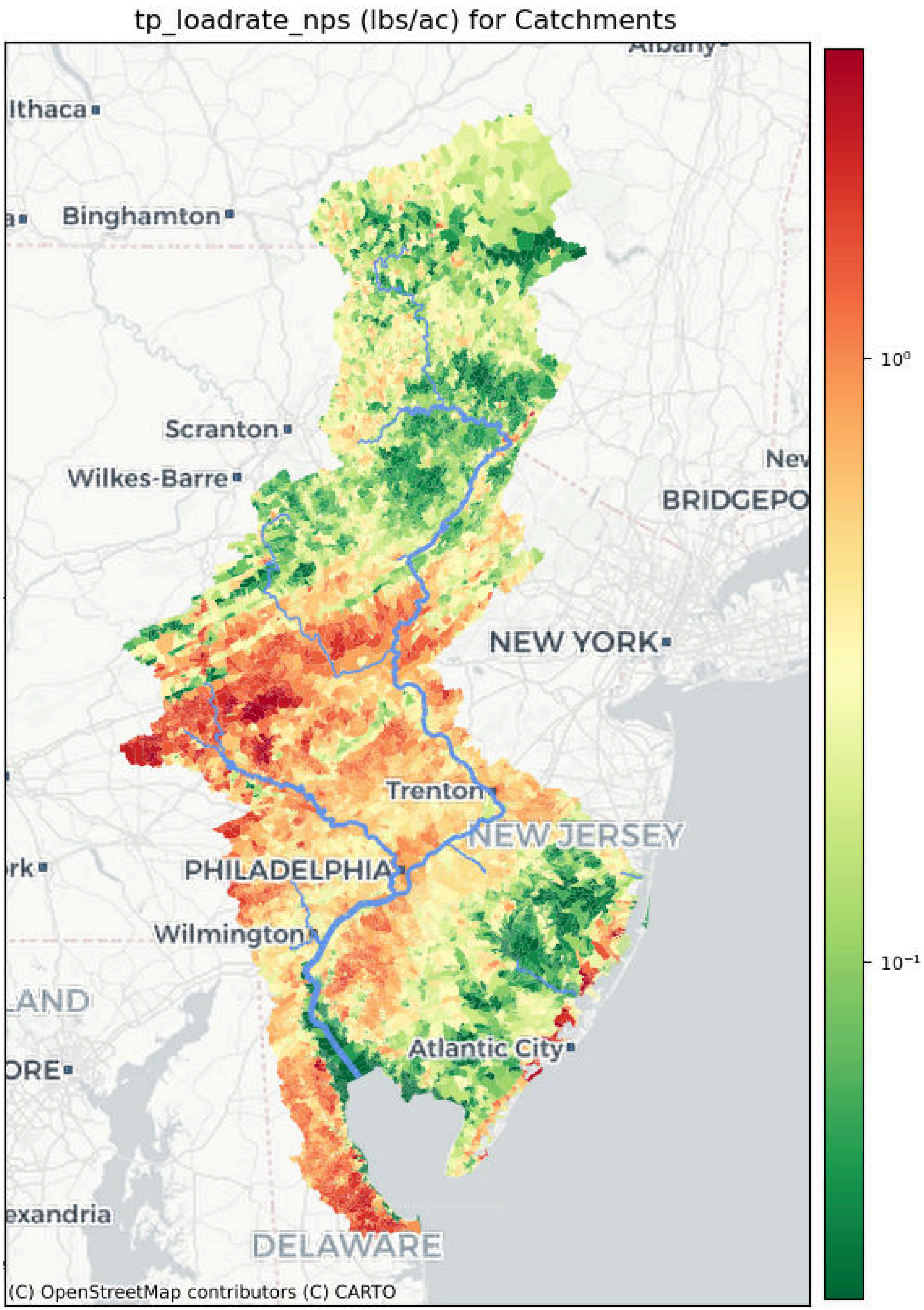

Figure 6: Non-point source (NPS) hotspots for Total Phosphorus (TP), estimated from baseline modeling of annual TP loading rates (lbs/acre) from each NHDplus catchment.

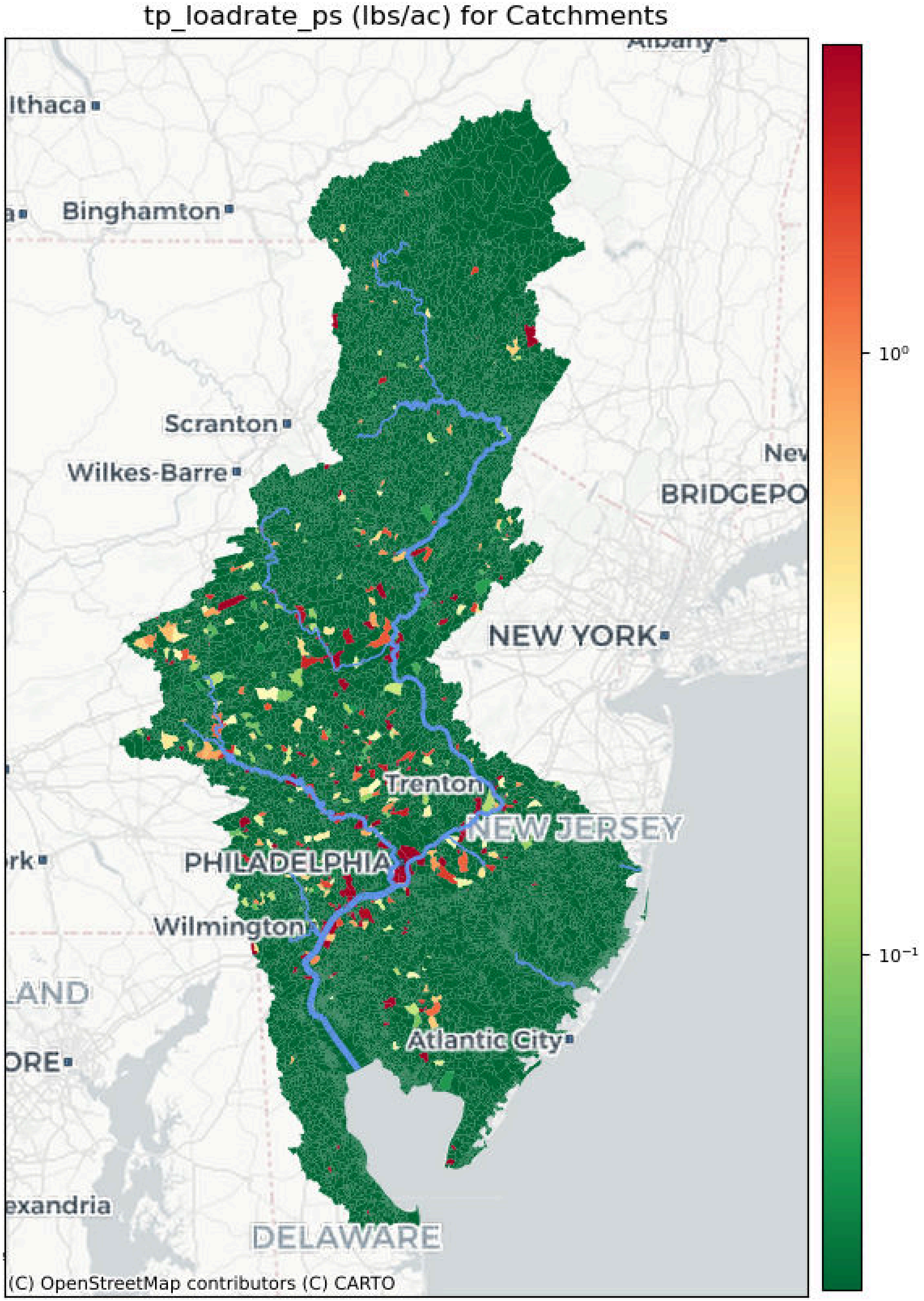

Figure 7: Point source (PS) hotspots for Total Phosphorus (TP), estimated from baseline modeling of annual TP loading rates (lbs/acre) from each NHDplus catchment.

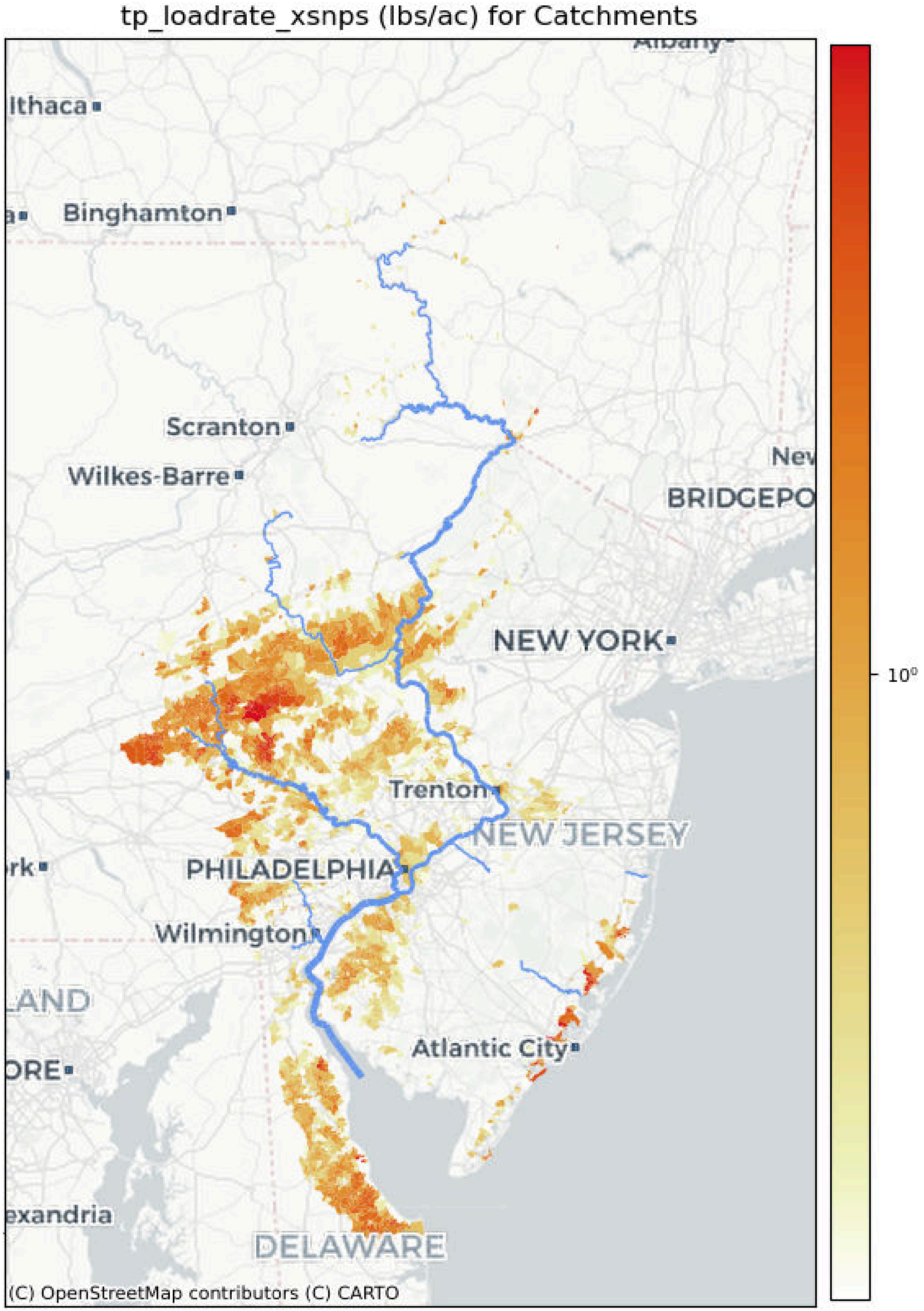

Figure 8: Excess Non-point source (XSNPS) hotspots for Total Phosphorus (TP), estimated by subtracting non-point source annual TP loading rates (lbs/acre) from healthy streams threshold targets for each NHDplus catchment.

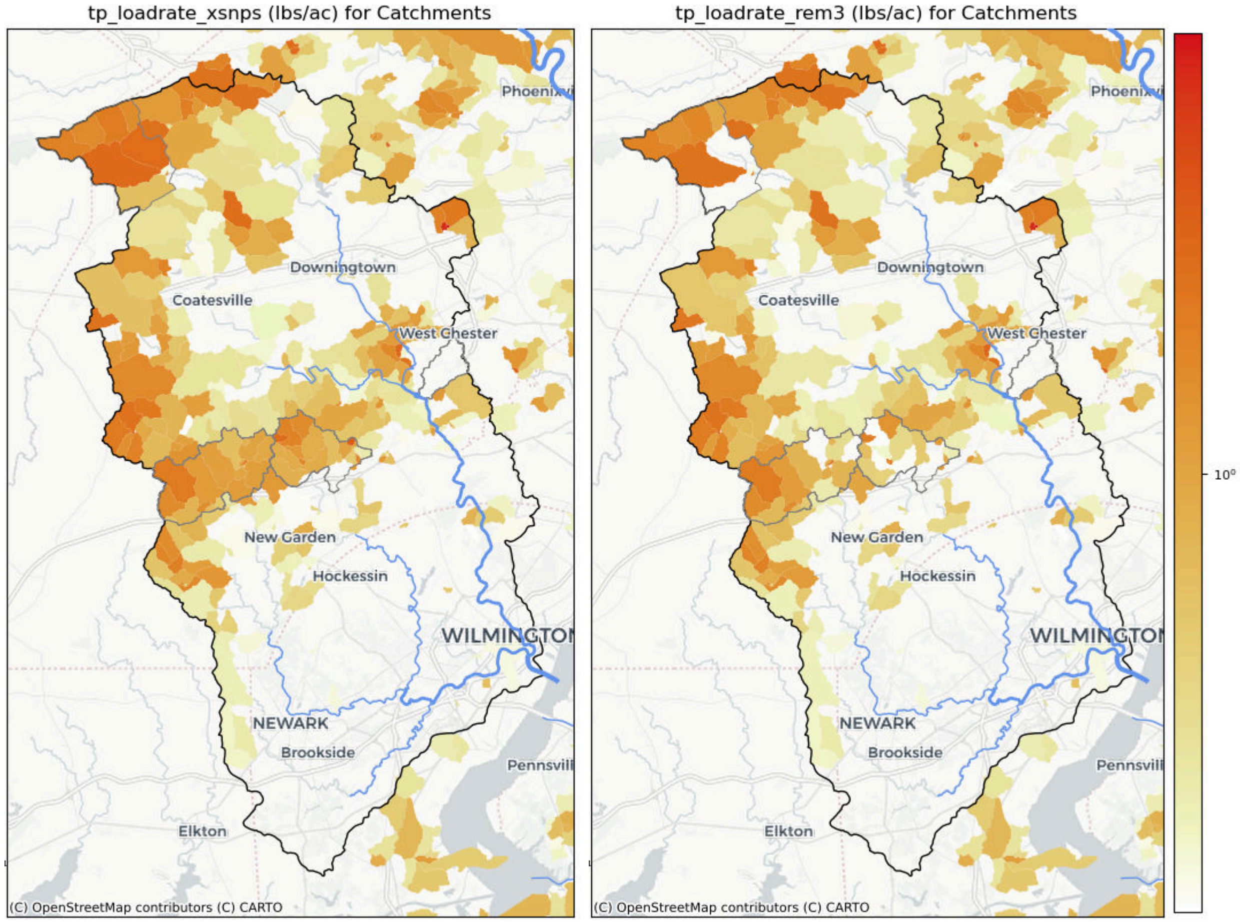

Figure 9: Reductions to Excess Non-Point Source (XSNPS) loading rates from catchments (left) can be seen as the difference with Remaining loading rates after reductions from all DRWI and non-DRWI conservation (right), especially in DRWI Focus Areas (gray outlines). The Brandywine Christina Cluster boundary is a black outline.

Reach Concentration Reductions Downstream of Catchment Restoration

Model results also include estimates of average annual excess nonpoint source (XSNPS) concentrations in stream reaches (Fig. 10), simulated by transporting catchment loading from landscape sources into and down the stream network. The perspective is advantageous to illustrate how portions of the stream network downstream of aggregated restoration efforts see benefits to in-stream concentrations of nps pollution far downstream. For example, note in Fig. 10 how the concentrations (represented by yellow-to-red shading) of streams draining some of the Focus Areas in the left panel (prior to BMP implementation) are reduced in a downstream direction after BMPs are accounted for in the right panel. The stream reaches north of the City of Coatesville are an excellent example, showing how restoration around Honey Brook (10-15 miles upstream) can bring water quality benefits all the way to downtown Coatesville. Estimated average annual stream reach concentration data are not summarized in tabular form in this report, but are available upon request. However, stream reach concentration data (mg/L) are directly driven by catchment loading rates and loads (lbs/acre or lbs/yr), reflecting the patterns seen in Figures 5-8.

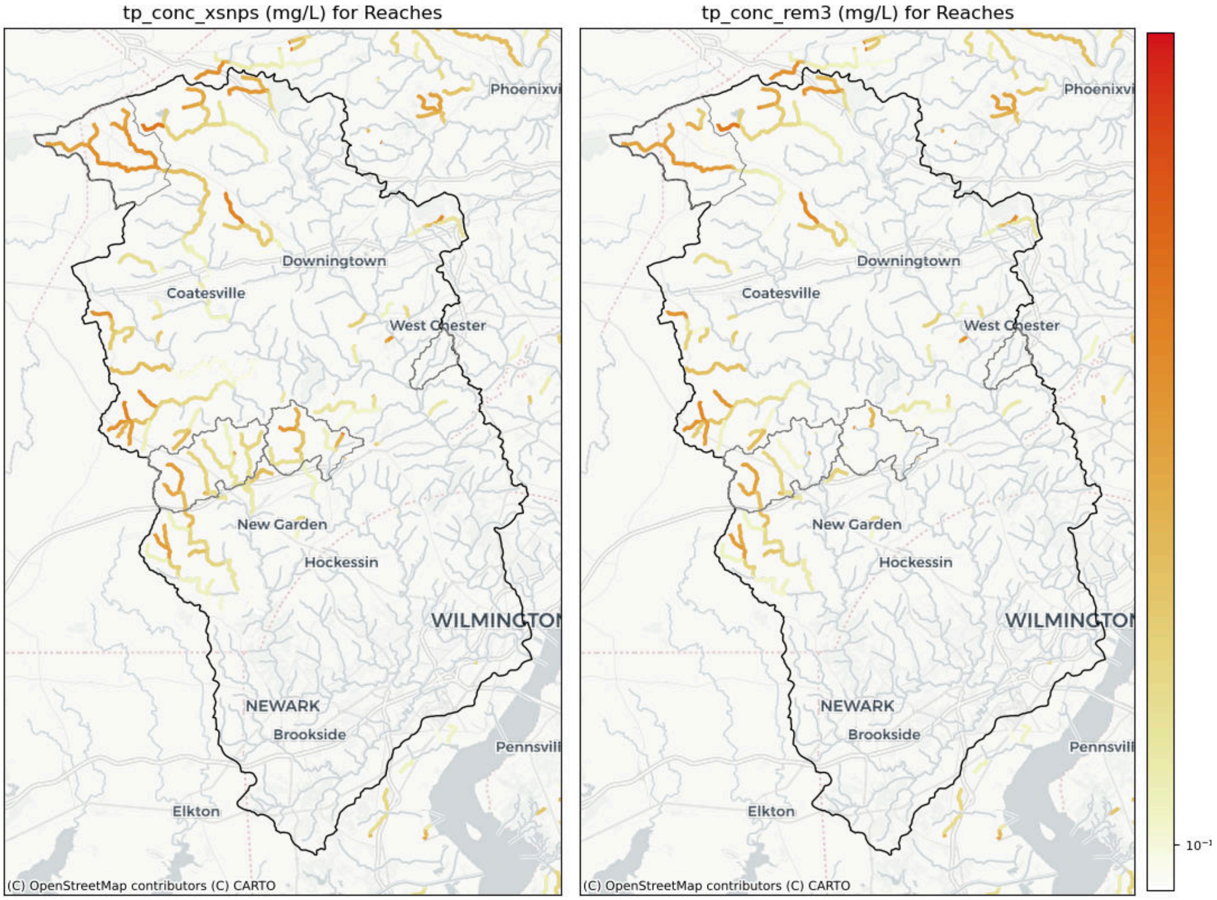

Figure 10: Reductions to Excess Non-Point Source (XSNPS) concentrations in streams reaches (left) can be seen as the difference with Remaining concentrations after reductions from all DRWI and non-DRWI conservation (right), especially within and downstream of DRWI Focus Areas (gray outlines). The Brandywine-Christina Cluster boundary is a black outline.

Pollution Loads Reduced by Restoration

Across the entire study geography (~9.3 million acres), the estimate of total phosphorus loads (lbs/yr) prior to BMP implementation was ~3.6 million pounds per year (Table 6). Point sources accounted for ~ 37.7% of the TP load or 1.36 million pounds per year, with the remaining load of ~ 2.25 million pounds/year characterized as derived from nonpoint sources in the project geography. In aggregate across the geography, the “healthy water” target threshold for total phosphorus load was estimated to be ~1.56 million lbs/yr (Table 6). Therefore, the excess TP load attributable to nonpoint sources was 681,672 lbs/yr (Table 6). The TP reductions attributable to DRWI restoration efforts in aggregate were 45,800 lbs/yr (Fig. 11, blue bars) and the non-DRWI efforts reduced TP loads by 44,012 lbs/yr (Fig. 11, green bars). These load reductions were therefore about 6.7% and 6.5% of the excess TP nonpoint source load, respectively. The remaining excess TP nonpoint source load after accounting for all restoration efforts is 591,860 lbs/yr, or about 86.8% of the original excess TP nonpoint source load (Fig. 11, yellow bar in left panel).

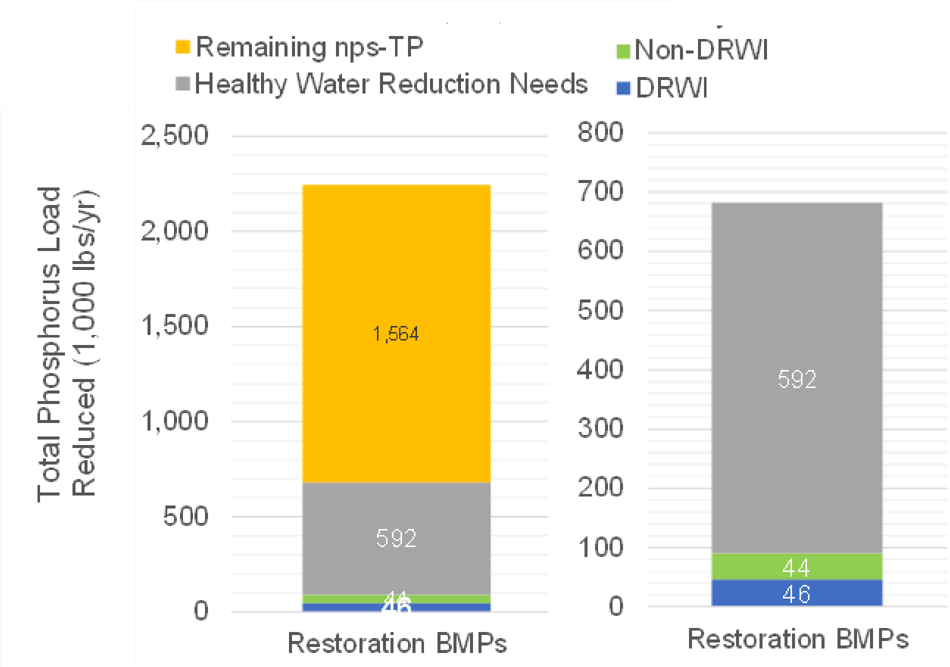

Figure 11: Total phosphorus load reduced by restoration best management practices (BMP) compared to the remaining reductions needed to achieve the "healthy water" goal (gray bar) and the estimated TP load remaining after the "healthy water" goal is achieved (yellow bar in left panel). Estimates of total phosphorus loads (lbs/yr) are partitioned into loads reduced by DRWI-related BMPs (blue bar) and non-DRWI BMPs (green bar), the remaining TP load reduction needed to achieve the "healthy water" goal (gray bar), and the remaining non-point source load (yellow bar).

Summary by HUC08

The Stage 2 Pollution Assessment was reoriented to around analysis of HUC12 geographies, in order to track pollution reductions through a stream network and to demonstrate downstream benefits to upstream restoration and protection projects. These results can be easily aggregated up to larger HUC10 and HUC08 geographies for summary analysis, as described above in our Research Approach: Aggregating by Geography. Results from our modeling efforts are summarized by HUC08s within the project area for Total Nitrogen, Total Phosphorus, and Sediment loads (lbs/yr) in Tables 5, 6, and 7, respectively. The remaining excess nonpoint source Total Nitrogen load before and after accounting for restoration efforts in the DRB was ~3.347 and ~3.165 million lbs/yr (Table 5), with the majority of the excess load remaining attributed to three HUC08 geographies: Schuylkill (~1.48 million lbs/yr), Broadkill-Smyrna (~1.34 million lbs/yr), and the Lower Delaware (~459,000 lbs/yr). The remaining 11 HUC08 catchments had TN loads near, at, or below zero excess TN loads (i.e., at or below the "healthy water" goal for TN). In total, restoration efforts reduced approximately 5% of TN loads throughout the study area, however, the majority of TN loading comes from the three HUC08s just mentioned. Restoration efforts reduced excess nonpoint TN loads by 181,261 lbs/yr, with 135,500 lbs/yr attributed to DRWI projects and 45,761 lbs/yr from non-DRWI projects. DRWI projects reduced the greatest loads in the Schuylkill, Brandywine-Christina, and Middle Delaware-Musconetcong HUC08 sub-basins.

The remaining excess nonpoint source Total Phosphorus load before and after accounting for restoration efforts in the DRB was 681,672 and 591,860 lbs/yr, respectively (Table 6), with the Schuylkill (315,966 lbs/yr) and Lehigh (140,604 lbs/yr) HUC08s having the greatest remaining excess TP loads. Four HUC08s have no excess nonpoint source TP loads remaining above the “healthy water” goal, but 87% of excess nonpoint source TP load remains (591,860 lbs/yr) after BMPs are accounted for in the rest of the study geography. Therefore, restoration efforts reduced approximately 13% of excess nonpoint source TP loads throughout the study area (89,812 lbs/yr), with 45,800 lbs/yr reduced by DRWI projects and 44,012 lbs/yr reduced by non-DRWI projects. DRWI projects reduced the greatest loads in the Schuylkill, Brandywine-Christina, and Middle Delaware-Musconetcong HUC08 sub-basins.

The remaining excess nonpoint source Total Suspended Sediment load before and after accounting for restoration efforts in the DRB was ~61.71 million and 28.199 lbs/yr, respectively (Table 7), with the Schuylkill (18.889 million lbs/yr) and the two Kirkwood-Cohansey HUC08s outside the DRB (totalling 34.236 million lbs/yr) having the greatest remaining excess TSS loads. Ten other HUC08s have no excess nonpoint source TSS loads remaining above the “healthy water” goal, but 46% of excess nonpoint source TP load remains (28.199 million lbs/yr) after all BMPs were accounted for in the rest of the study geography. Therefore, restoration efforts reduced approximately 54% of excess nonpoint source TSS loads throughout the study area (33.512 million lbs/yr), with 29.154 million lbs/yr reduced by DRWI projects and 4.358 million lbs/yr reduced by non-DRWI projects. DRWI projects reduced the greatest TSS loads in the Brandywine-Christina, Schuylkill, and Middle Delaware-Musconetcong HUC08 sub-basins.

Table 5: Total Nitrogen (TN) loads accumulated and attenuated over HUC12 stream networks and summarized by HUC08.

			TN Load(lbs/y)								%	
HUC08	**Name**	*Area (ha)*	*Baseline Total Load*	*Point Sources*	*Target*	*Excess Non-Point Source*	*Reduced by Restoration*	*Reduced by Restoration*	*Reduced by Restoration*	*Remaining Conservation*	*Excess NPS Remaining*	*Prevented by Protection*
					overall goal	XSNPS	DRWI	non-DRWI	Total	to zero XSNPS		future loads
2040101	Upper Delaware	761,337	1,551,519	107,816	1,443,703	0	60	947	1,007	-1,007	0%	0
2040102	East Branch Delaware	537,383	1,420,947	32,711	1,388,236	0	0	0	0	0	0%	0
2040103	Lackawaxen	382,412	1,098,733	286,747	811,986	0	0	2,270	2,270	-2,270	0%	0
2040104	Middle Delaware-Mongaup-Brodhead	978,229	2,043,185	131,822	1,909,050	2,313	0	1,072	1,072	1,242	54%	469
2040105	Middle Delaware-Musconetcong	869,103	4,624,060	1,169,006	3,455,055	0	43,459	5,678	49,137	-49,137	0%	172
2040106	Lehigh	870,833	5,575,287	706,019	4,869,267	0	1,498	6,592	8,090	-8,090	0%	229
2040201	Crosswicks-Neshaminy	346,380	2,654,812	395,881	2,258,931	0	0	3,600	3,600	-3,600	0%	0
2040202	Lower Delaware	738,763	8,101,777	3,622,216	4,016,216	463,345	1,983	2,584	4,567	458,778	99%	24
2040203	Schuylkill	1,222,794	24,744,267	8,229,800	14,968,066	1,546,401	50,166	16,579	66,744	1,479,657	96%	31
2040205	Brandywine-Christina	481,043	5,615,947	844,949	4,770,998	0	34,821	5,661	40,482	-40,482	0%	0
2040206	Cohansey-Maurice	671,831	5,058,922	1,345,074	3,713,848	0	3,514	428	3,942	-3,942	0%	21
2040207	Broadkill-Smyrna	413,049	5,792,669	198,969	4,258,514	1,335,185	0	0	0	1,335,185	100%	0
2040301	Mullica-Toms (outside DRB)	640,927	1,964,118	0	1,964,118	0	0	196	196	-196	0%	53
2040302	Great Egg Harbor (outside DRB)	392,031	1,179,467	0	1,179,467	0	0	153	153	-153	0%	0
	DRB Total	8,273,155	68,282,125	17,071,010	47,863,871	3,347,245	135,499	45,411	180,911	3,166,334	**95%**	946
	HUC08 Total	**9,306,114**	**71,425,710**	**17,071,010**	**51,007,456**	**3,347,245**	**135,500**	**45,761**	**181,261**	**3,165,984**	**95%**	**1,000**

Table 6: Total Phosphorus (TP) loads accumulated and attenuated over HUC12 stream networks and summarized by HUC08.

HUC08	**Name**	*Area (acres)*	**TP Load(lbs/y)**								**%**	
			Baseline Total Load	*Point Sources*	*Target*	*Excess Non-Point Source*	*Reduced by Restoration*	*Reduced by Restoration*	*Reduced by Restoration*	*Remaining Conservation*	*Excess NPS Remaining*	*Prevented by Protection*
					overall goal	XSNPS	DRWI	non-DRWI	Total	to zero XSNPS		future load
2040101	Upper Delaware	761,337	104,776	2,089	102,635	52	36	725	761	-709	0%	0
2040102	East Branch Delaware	537,383	85,772	6,586	79,186	0	0	0	0	0	0%	0
2040103	Lackawaxen	382,412	88,822	23,158	65,664	0	0	1,946	1,946	-1,946	0%	0
2040104	Middle Delaware-Mongaup-Brodhead	978,229	94,513	14,591	79,923	0	0	1,057	1,057	-1,057	0%	4,224
2040105	Middle Delaware-Musconetcong	869,103	289,338	103,218	135,560	50,560	13,713	5,749	19,462	31,097	62%	1,571
2040106	Lehigh	870,833	505,797	149,048	209,246	147,502	514	6,384	6,898	140,604	95%	2,108
2040201	Crosswicks-Neshaminy	346,380	133,946	37,271	91,628	5,047	0	3,468	3,468	1,579	31%	0
2040202	Lower Delaware	738,763	364,227	236,818	120,690	6,718	512	2,029	2,541	4,178	62%	206
2040203	Schuylkill	1,222,794	1,440,035	671,053	418,240	350,741	17,634	17,141	34,776	315,966	90%	287
2040205	Brandywine-Christina	481,043	207,909	56,991	94,745	56,173	12,264	5,216	17,480	38,693	69%	0
2040206	Cohansey-Maurice	671,831	100,891	51,998	44,104	4,789	1,127	238	1,365	3,423	71%	182
2040207	Broadkill-Smyrna	413,049	118,368	4,124	58,504	55,740	0	0	0	55,740	100%	0
2040301	Mullica-Toms (outside DRB)	640,927	39,916	0	37,653	2,263	0	33	33	2,230	99%	469
2040302	Great Egg Harbor (outside DRB)	392,031	27,985	0	25,898	2,087	0	26	26	2,061	99%	0
	DRB Total	8,273,155	3,534,393	1,356,945	1,500,125	677,322	45,800	43,953	89,754	587,569	**87%**	8,578
	HUC08 Total	**9,306,114**	**3,602,295**	**1,356,945**	**1,563,677**	**681,672**	**45,800**	**44,012**	**89,812**	**591,860**	**87%**	**9,047**

Table 7: Total Suspended Sediment (TSS) loads accumulated and attenuated over HUC12 stream networks and summarized by HUC08.

HUC08	**Name**	*Area (ha)*	**TSS Load(lbs/y)**								**%**	
			Baseline Total Load	*Point Sources*	*Target* overall goal	*Excess Non-Point Source* XSNPS	*Reduced by Restoration* DRWI	*Reduced by Restoration* non-DRWI	*Reduced by Restoration* Total	*Remaining Conservation* to zero XSNPS	*Excess NPS Remaining*	*Prevented by Protection* future loads
2040101	Upper Delaware	761,337	65,398,790	0	65,398,790	0	7,252	77,410	84,662	-84,662	0%	0
2040102	East Branch Delaware	537,383	66,801,406	0	66,801,406	0	0	0	0	0	0%	0
2040103	Lackawaxen	382,412	50,047,351	0	50,047,351	0	0	188,029	188,029	-188,029	0%	0
2040104	Middle Delaware-Mongaup-Brodhead	978,229	108,695,991	0	108,695,991	0	0	110,987	110,987	-110,987	0%	197,626
2040105	Middle Delaware-Musconetcong	869,103	195,417,204	0	195,417,204	0	8,274,217	301,333	8,575,550	-8,575,550	0%	68,160
2040106	Lehigh	870,833	293,854,054	0	293,176,496	677,559	273,950	1,023,645	1,297,595	-620,037	0%	88,827
2040201	Crosswicks-Neshaminy	346,380	174,275,949	0	174,275,949	0	0	115,236	115,236	-115,236	0%	0
2040202	Lower Delaware	738,763	340,161,180	0	339,893,560	267,621	371,455	104,755	476,210	-208,589	0%	8,845
2040203	Schuylkill	1,222,794	618,424,768	0	591,926,357	26,498,410	5,870,756	1,738,848	7,609,604	18,888,807	71%	12,752
2040205	Brandywine-Christina	481,043	151,927,272	0	151,927,272	0	13,562,401	634,858	14,197,259	-14,197,259	0%	0
2040206	Cohansey-Maurice	671,831	76,567,694	0	76,567,694	0	794,411	31,391	825,802	-825,802	0%	7,048
2040207	Broadkill-Smyrna	413,049	65,222,168	0	65,222,168	0	0	0	0	0	0%	0
2040301	Mullica-Toms (outside DRB)	640,927	132,374,644	0	112,646,188	19,728,456	0	17,673	17,673	19,710,783	100%	19,105
2040302	Great Egg Harbor (outside DRB)	392,031	80,960,696	0	66,421,942	14,538,754	16	13,465	13,481	14,525,273	100%	0
	DRB Total	8,273,155	2,206,793,827	0	2,179,350,237	27,443,590	29,154,442	4,326,493	33,480,935	-6,037,345	**0%**	383,258
	HUC08 Total	**9,306,114**	**2,420,129,167**	**0**	**2,358,418,367**	**61,710,800**	**29,154,458**	**4,357,631**	**33,512,089**	**28,198,711**	**46%**	**402,363**

Summary by Cluster

Modeling results for Total Phosphorus loading rates are summarized for Cluster Areas in Table 8. The remaining excess nonpoint source TP loads in all Cluster Areas before and after accounting for restoration efforts was 400,445 and 336,02 lbs/yr, respectively (Table 8). Together, DRWI restoration efforts reduced excess nonpoint source TP loads by 44,949 lbs/yr or 11.2% of the excess nps TP load from all Clusters. Non-DRWI projects accounted for 19,470 lbs/yr reductions in Clusters. In total, ~16% of the excess nps TP load was reduced by restoration efforts. The Brandywine-Christina, Middle Schuylkill, and NJ Highlands Clusters accounted for most of the DRWI reductions towards the “healthy water” goal.

Table 8: DRWI Cluster summary for Total Phosphorus (TP) loads accumulated and attenuated over HUC12 stream networks.

				TP Load(lbs/y)								**%**	
DRWI Cluster	*code*	*Cluster Area (ha)*	*HUC12 Total Area (ha)*	*Baseline Total Load*	*Point Sources*	*Target*	*Excess Non-Point Source*	*Reduced by Restoration*	*Reduced by Restoration*	*Reduced by Restoration*	*Remaining Conservation*	*Excess NPS Remaining*	*Prevented by Protection*
						overall goal	XSNPS	DRWI	non-DRWI	Total	to zero XSNPS		future load
Brandywine and Christina	BCC	360,128	360,128	200,365	53,550	90,642	56,173	12,264	5,216	17,480	38,693	69%	0
Kirkwood - Cohansey Aquifer	KCC	1,359,518	1,700,033	204,319	75,260	122,007	7,052	1,119	230	1,349	5,702	81%	857
Middle Schuylkill	MSC	501,520	513,974	771,762	282,912	200,538	288,312	16,658	8,605	25,262	263,050	91%	0
New Jersey Highlands	NJHC	441,445	441,445	103,026	12,684	67,318	23,024	13,619	534	14,153	8,870	39%	1,153
Poconos and Kittatinny	PKC	846,239	846,239	73,661	10,060	63,601	0	0	999	999	-999	0%	4,224
Schuylkill Highlands	SHC	110,839	166,610	54,865	331	39,722	14,812	478	1,223	1,700	13,111	89%	287
Upper Lehigh	ULC	489,340	506,829	113,901	24,921	84,336	4,644	0	2,277	2,277	2,366	51%	2,108
Upstream Suburban Philadelphia	USPC	92,444	125,237	76,766	18,234	52,103	6,429	812	386	1,198	5,231	81%	0
	Clusters Total	**4,201,473**	**4,660,494**	**1,598,665**	**477,952**	**720,268**	**400,445**	**44,949**	**19,470**	**64,419**	**336,025**	**84%**	**8,629**

Remaining Restoration

Reach Loads Accumulated and Attenuated over HUC12 Stream Networks

A spatial illustration of the excess nonpoint source loads for Total Phosphorus remaining after all restoration projects were accounted for highlights the potential priority geographies to focus future restoration efforts (Fig. 12). There continues to be a need for nonpoint source BMP deployment in the HUC12s in the middle of the Schuylkill River watershed area, the lower Lehigh River watershed area, in portions of the middle Delaware River mainstem (NJ and PA sub-basins), in the headwaters of the Brandywine-Christina watershed, areas near and around Philadelphia, and in state of Delaware inland from the western estuary shore.

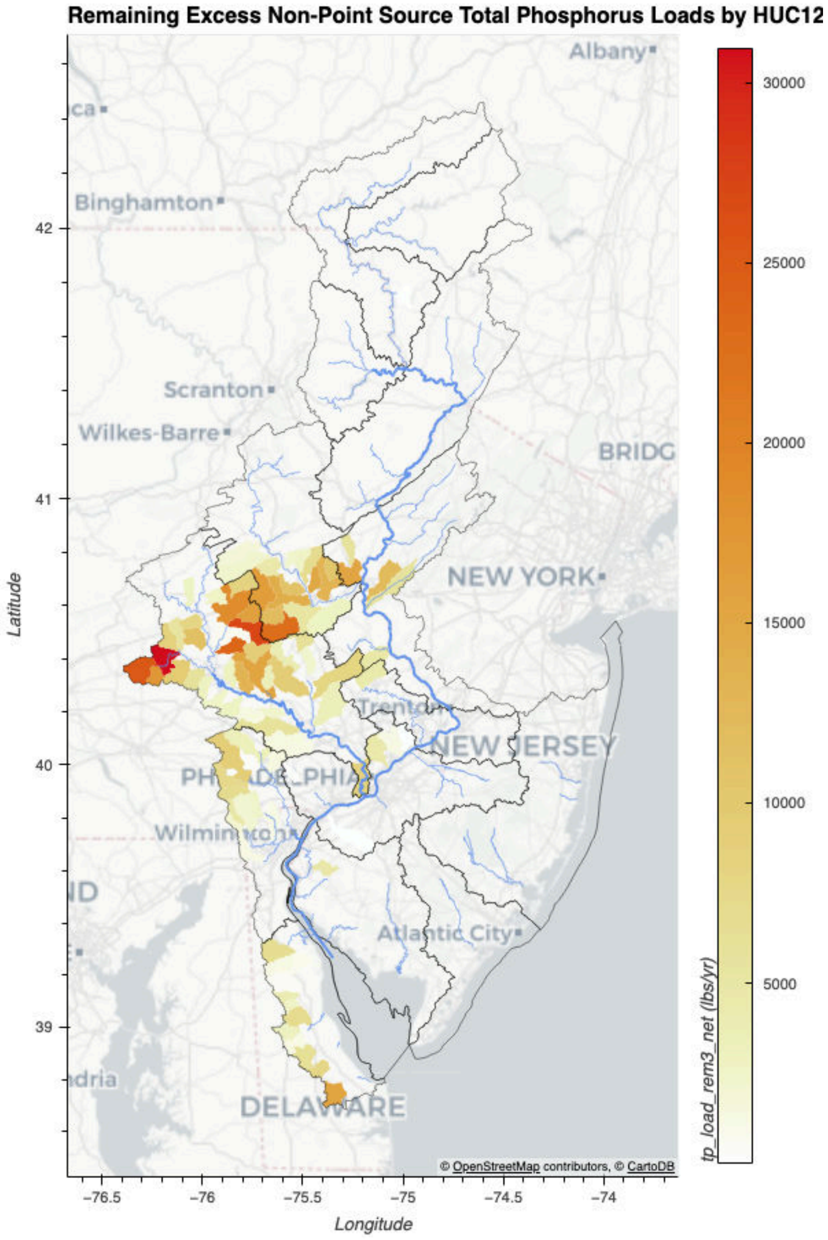

Figure 12: Remaining net excess nonpoint source hotspots for Total Phosphorus (TP), estimated by modeling pollution reductions from all DRWI and non-DRWI restoration activities and by modeling downstream mixing, dilution, accumulation, and attenuation of reach loads through the stream network for each HUC12. Black outlines are shown for HUC08 boundaries impacted by DRWI.

Estimated Costs of Future Restoration

The potential cost of reducing excess, nonpoint source loads of TN, TP and TSS to achieve "acceptable" water quality in smaller catchments throughout the DRB (with an emphasis on phosphorus reduction) was estimated by simulating potential load reductions achieved by implementing a number of representative rural and urban land Best Management Practices (BMPs) such as riparian buffers in agricultural areas, farm animal waste management systems, urban stormwater management, and streambank stabilization. In this case, analyses were completed in which different levels of BMP implementation were simulated proceeding from least expensive (i.e., farm animal waste management) to most expensive (urban stormwater management) until the target reductions were met. Some typical implementation costs and pollutant reduction efficiencies reported by the Chesapeake Bay Program for these types of BMPs are shown in Table 9.

Table 9: BMPs with associated implementation costs and reduction coefficients.

BMP/Restoration Activity	Implementation Cost	TN Reduction Coefficient	TP Reduction Coefficient	TSS Reduction Coefficient
Urban Stormwater Management System	\$2,989 per acre[1]	0.38	0.45	0.62
Animal Waste Management Systems	\$264 per AEU[2]	0.75	0.75	NA
Riparian Forest Buffers in Cropland Areas	\$407 per acre[3]	0.43	0.38	0.51
Streambank Restoration/Protection	\$900 per foot[4]	0.306[5]	0.084[5]	67[5]

[1] Per acre of developed land treated
[2] Animal Equivalent Unit (1000 lbs of animal weight)
[3] Per acre of forest buffer along a stream
[4] Per foot of stream length restored/protected
[5] Pounds reduced per foot of stream length restored/protected

Some of the results of the exercise described above are given in Table 10. Shown in this table are the modeled load reduction targets (e.g., "TP Remaining XNPS") needed to achieve acceptable water quality conditions as well as the estimated load reductions obtained via the simulation of additional BMP implementation (e.g., "Simulated TP Reduction"). In this case, it is assumed that only "excess" nonpoint source loads are treated and that point source loads are addressed separately through existing regulations and control strategies implemented by various government authorities and private water treatment utilities. As can be seen, the results are presented for each of the 12 USGS-designated HUC08 sub-basins that comprise the larger DRB as well as the 2 HUC08s in the southern part of New Jersey. From this table, it appears that phosphorus-based water quality goals (that assume only removal of excess nonpoint source TP) can be achieved via the implementation of future BMPs for all of the HUC08 sub-basins within the entire study area. As can also be seen in Table 10, it appears that the implementation of additional BMPs with an eye towards meeting load reduction goals for phosphorus will also achieve (or make significant progress towards achieving) load reduction targets for nitrogen and sediment in many of the HUC08 sub-basins as well.

Shown in Table 11 are the estimated costs associated with achieving the load reductions reported in the Table 10. In the prior report for Stage 1, it was suggested that these estimated costs might decrease once more precise information on the extent of existing BMPs (both those funded by DRWI and other entities) was used in simulating loads for smaller watersheds throughout the entire study area. In the previous report it was estimated that the cost for future BMP implementation within the DRB alone would be about \$434 million as compared to the \$555 million reported for this area in Table 11. Although it is true that the calculated loads for many sub-basins did decrease after accounting for all BMPs (including those funded by DRWI and implemented by state and federal programs), it is also true that the costs for other areas significantly increased due to the fact that more expensive BMPs such as urban stormwater management and streambank stabilization were required due to the limited amount of cropland and/or farm animal populations in some impaired sub-basins on which cheaper BMPs could be applied. For example, phosphorus loads emanating from the latter nonpoint sources in both the Lehigh River and Schuylkill River HUC08 basins were much smaller percentage-wise in comparison to such loads from other HUC08 basins. In fact, phosphorus loads in these two HUC08 basins predominantly come from point sources as well as developed land areas. Consequently, in these areas, more expensive BMPs such as urban stormwater management must be applied in order to address the remaining excess nonpoint source phosphorus loads.

Across the entire study area in aggregate (i.e., the 14 HUC08 sub-basins within and outside of the DRB), it appears that target reductions for nitrogen (3,275,422 lbs/yr) and sediment (53,133,958 lbs/yr) can also be largely met with an expenditure of about $580 million on future BMP implementation.

As described earlier, for the above analysis, it was assumed that nitrogen and phosphorus loads from point sources would be addressed separately by state and local authorities, and that cost calculations would only focus on the reduction of the remaining "excess" loads from nonpoint sources. For those interested in further discussion on the potential costs associated with upgrading wastewater treatment plants or implementing more expensive nonpoint source mitigation measures in lieu of reducing point source loads, additional material is provided in Appendix 3.

Table 10: Simulated load reductions (lbs/yr) achievable via future BMPs implemented to reduce excess nonpoint source (XSPS) phosphorus.

HUC08 Name/Code	TN Remaining XSNPS	TP Remaining XSNPS	TSS Remaining XSNPS	Simulated TN Reduction	Simulated TP Reduction	Simulated TSS Reduction
Upper Delaware/2040101	0	0	0	0	0	0
East Branch Delaware/2040102	0	0	0	0	0	0
Lackawaxen/2040103	0	0	0	0	0	0
Mid Delaware-MongaupBrod/2040104	1,241	0	0	0	0	0
Mid Delaware-Musconetcong/2040105	0	31,104	0	339,905	31,560	14,915,231
Lehigh/2040106	0	140,628	0	1,001,328	140,600	165,592,964
Crosswicks-Neshaminy/2040201	0	1,579	0	25,413	1,621	602,558
Lower Delaware/2040202	458,856	4,178	0	184,437	4,203	1,131,566
Schuylkill/2040203	1,479,910	316,021	18,892,041	3,886,478	318,940	92,319,183
Brandywine-Christina/2040205	0	38,700	0	394,294	38,971	5,637,854
Cohansey-Maurice/2040206	0	3,424	0	124,269	3,541	1,140,896
Broadkill-Smyrna/2040207	1,335,414	55,749	0	1,144,836	55,870	14,357,725
Mullica-Toms/2040301	0	2,231	19,714,158	190,920	2,282	4,298,257
Great Egg Harbor/2040302	0	2,062	14,527,759	132,924	2,095	3,423,265
Totals for Delaware River Basin	3,275,422	591,383	18,892,041	7,100,960	595,383	295,697,977
Totals for non-DRB Areas	0	4,293	34,241,917	323,844	4,377	7,721,522
Totals for Entire 14-HUC8 Study Area	3,275,422	595,676	53,133,958	7,424,804	599,006	303,419,499

Table 11: Estimated costs for Implementing future BMPs to reduce excess nonpoint source phosphorus (in million $/yr).

HUC08 Name/Code	Cluster in HUC08	Ag Land Reductions	Farm Animal Reductions	Urban SW Reductions	Streambank Reductions	Totals
Upper Delaware/2040101	NA	0	0	0	0	0
East Branch Delaware/2040102	NA	0	0	0	0	0
Lackawaxen/2040103	NA	0	0	0	0	0
Mid Delaware-MongaupBroadhead/2040104	(1)	0	0	0	0	0
Mid Delaware-Musconetcong/2040105	(2)	$17.7	0	$0	0	$17.7
Lehigh/2040106	(3)	$28.0	$1.8	$141.3	$203.8	$374.8
Crosswicks-Neshaminy/2040201	(4)	$1.0	$0.1	0	0	$1.1
Lower Delaware/2040202	(4)	$4.6	$0.2	0	0	$4.8

HUC08 Name/Code	Cluster in HUC08	Ag Land Reductions	Farm Animal Reductions	Urban SW Reductions	Streambank Reductions	Totals
Schuylkill/2040203	(5,6)	$59.0	$13.0	$23.4	0	$95.4
Brandywine-Christina/2040205	(7)	$8.0	$4.4	0	0	$12.4
Cohansey-Maurice/2040206	(8)	$6.1	$0.2	0	0	$6.3
Broadkill-Smyrna/2040207	NA	$29.7	$6.5	$6.5	0	$42.8
Mullica-Toms/2040301	(8)	$5.5	$4.0	$5.1	0	$14.6
Great Egg Harbor/2040302	(8)	$4.2	$1.9	$3.9	0	$9.9
Totals for Delaware River Basin		$154.1	$26.3	$171.1	$203.8	**$555.3**
Totals for non-DRB areas (2 HUC08s)		$9.6	$5.9	$8.9	0	**$24.5**
Totals for entire 14-HUC08 study area		$163.7	$32.2	$180.2	$203.8	**$579.8**

(1) Poconos and Kittatinny
(2) New Jersey Highlands
(3) Upper Lehigh
(4) Upstream Suburban Philadelphia
(5) Middle Schuylkill
(6) Schuylkill Highlands
(7) Brandywine-Christina
(8) Kirkwood-Cohansey

Future Pollution Prevented by Forest Land Protection

- Land protection efforts resulting from the DRWI's Delaware River Watershed Protection Fund permanently protected 26,414 acres of forest land.
- Scenario modeling of potential future development on DRWPF protected acres resulted in an estimated 9,050 lbs/yr of future total phosphorus loads prevented, which is approximately 18% of the DRWI loads reduced by restoration.

Future pollution prevented by preservation can be quantified for each catchment, aggregated by sub-basin geography, and compared to reduced pollution loads from restoration. The aggregated results for the entire project area (DRB and Mullica-Toms and Great Egg Harbor HUC08s) are shown for Total Phosphorus in Figs. 13 (included in Table 6 above) and include a comparison with the loads reduced by restoration projects. Future prevented loads were estimated to be about 18% of the DRWI loads reduced by restoration. Although relatively small compared to "loads reduced by restoration", protected areas prevent any future loading in perpetuity unless environmental conditions drastically change or alter ecosystems due to, for example, wildfire, climate change, disease and invasive species infestations. Figure 14 shows the future prevented load of TP from DRWI-DRWPF efforts within each HUC08 sub-basin (left panel) and from each Cluster (right panel) (see Table 6 for HUC08 data and Table 8 for Cluster data). Middle Delaware-Mongaup-Brodhead, Lehigh, and Middle Delaware-Musconetcong HUC08 had the greatest level of future prevented loads due to land protection among the 14 HUC08 sub-basins. The Poconos and Kittatinny Cluster had the greatest level of future prevented loads followed by the Upper Lehigh, New Jersey Highlands, Kirkwood-Cohansey, and Schuylkill Highlands Clusters.

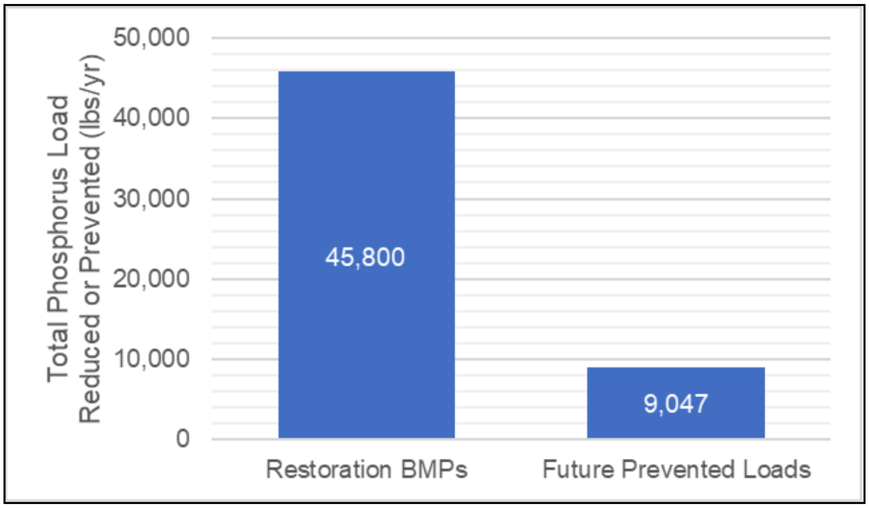

Figure 13: The total phosphorus load reduced by DRWI restoration efforts (left blue bar) and future prevented TP loads by DRWPF efforts (right blue bar) throughout the entire study area.

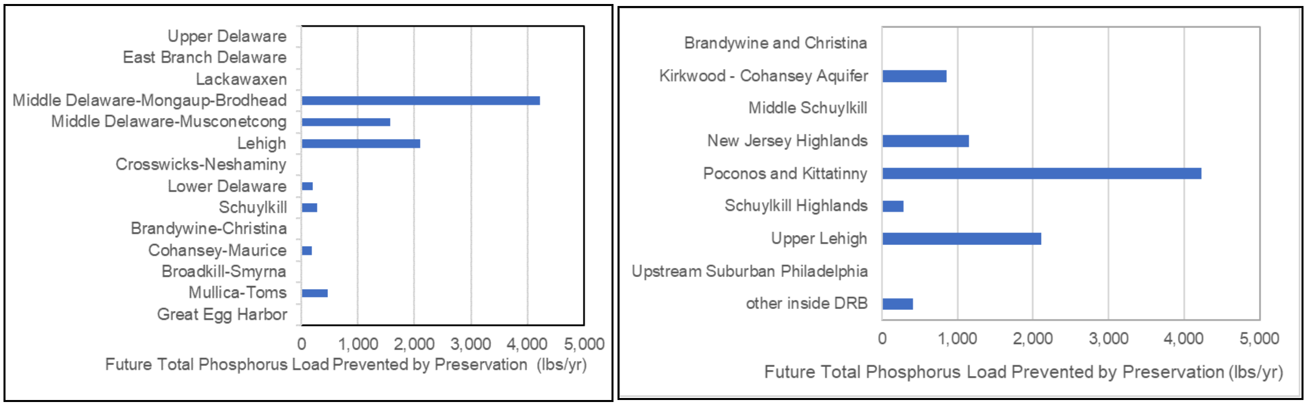

Figure 14: Future prevented loads of total phosphorus estimated from all types of natural land protection efforts for each HUC08 throughout the study area (left panel) and for Cluster Areas (right panel).

Forest Land Protection and the 30 by 30 Goal

The Delaware River Basin (DRB_x), excluding the Delaware Bay, is ~13,135 mi^2 or 8,406,584 acres (Delaware Bay HUC8 is ~513 mi^2 or 264,505 acres);

- 59.9% of the DRB_x is natural land and 45.3% of the DRB_x is forest;
- *19.8% of the DRB_x is protected natural land*.

The HUC8 Kirkwood-Cohansey geographies included in the DRWI are ~1,767 mi^2 or 1,130,800 acres.

- 77.7% of the K-C area is natural land and 31.6% is forested (much of the natural land is wetland area);
- *42.6% of the K-C area is protected natural land*.

DRWI Cluster-Level Summary

There was significant variation in the percent of natural land protected by either DRWI or non-DRWI types of protection across Focus Areas (Fig. 15) and among Clusters (Fig. 16 and Table 12). Of the 66 Focus Area geographies, 26 do not have enough "natural land" to achieve the 30% goal, 18 have already achieved >30% protected, and 22 have enough natural land but have not reached the 30% goal (Fig. 15). For cost estimation purposes, the Focus Area geographies are summarized in aggregate for each Cluster geography (Fig. 16 and Table 12). Two of the Cluster geographies (Brandywine-Christina and Upstream Suburban Philly) do not currently contain enough remaining "natural area" to achieve the 30% goal and three Clusters have exceeded the goal (Upper Lehigh, Schuylkill Highlands, and Kirkwood-Cohansey). In order to achieve the 30% goal in the remaining three remaining Clusters (Poconos-Kittatinny, NJ Highlands, and Middle Schuylkill) an additional 30,332 acres would need to be preserved and, based on past Fair Market Value of land preserved in these clusters, the total cost would be estimated to be ~$217 million (Table 13).

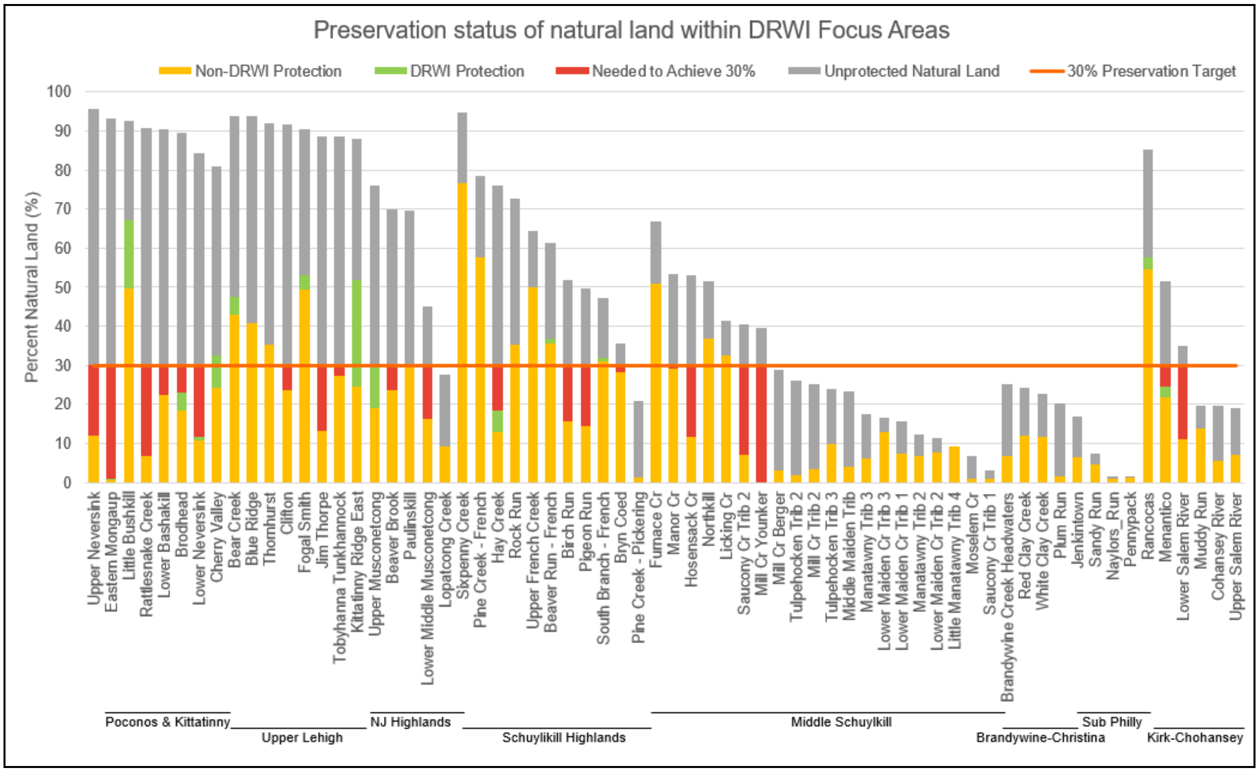

Figure 15: The percent of natural land and its protection status in each of the 66 DRWI Focus Areas (grouped by Cluster). Yellow bars = protected natural land (excluding DRWI preservation), Green bars = DRWI protection, Red bars = remaining preservation needed to achieve the 30% goal, and Grey bars = all other natural land. Red line is the 30% goal.

Table 12: Summary statistics of natural land and total and DRWI protected area for each Cluster geography. Note: DRWI protection projects are only those that were completed within Focus Areas.

Cluster Area	Acres				Percent	
	Area	Natural Area	Protected area (all)	DRWI Protected	Natural Area	Percent Protected
Poconos and Kittatinny	157,168	141,615	34,084	6,733	90.1%	21.7%
Upper Lehigh	91,252	82,817	30,838	3,104	90.8%	33.8%
New Jersey Highlands	147,151	91,036	36,545	2,923	61.9%	24.8%
Schuylkill Highlands	30,004	17,866	9,651	315	59.5%	32.2%
Middle Schuylkill	65,760	23,607	10,064	-	35.9%	15.3%
Brandywine and Christina	31,731	7,525	2,902	-	23.7%	9.1%
Upstream Suburban Philadelphia	5,701	390	197	-	6.8%	3.5%
Kirkwood - Cohansey Aquifer	151,919	78,541	46,243	2,546	51.7%	30.4%
Totals	680,687	443,397	170,524	15,621	65.1%	25.1%

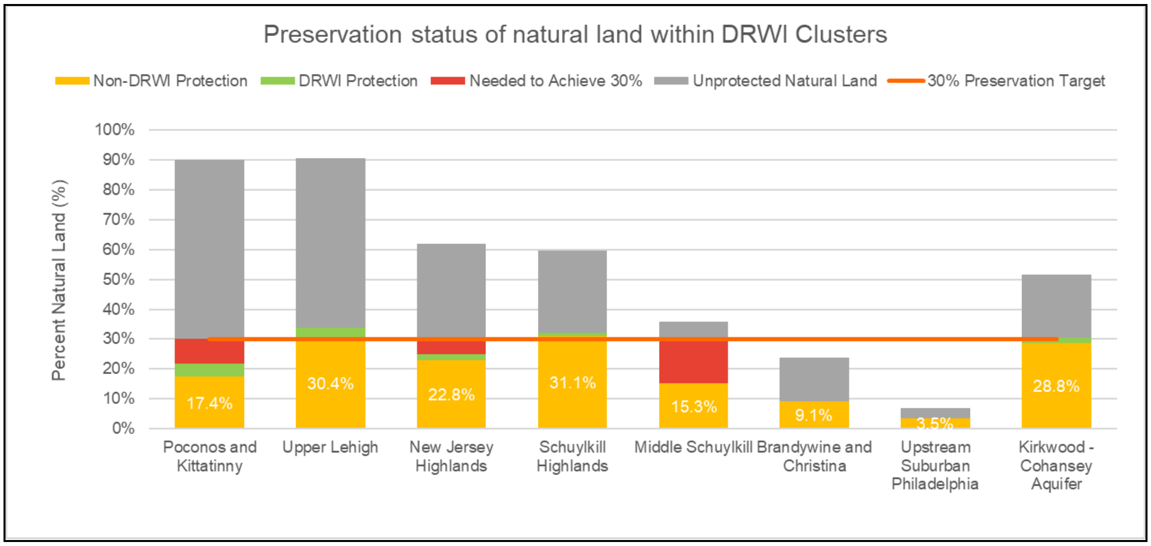

Figure 16: The percent of natural land and its protection status in each DRWI Cluster Area. Yellow bars = protected natural land (excluding DRWI preservation), Green bars = DRWI protection, Red bars = remaining preservation needed to achieve the 30% goal, and Grey bars = all other natural land. Red line is the 30% goal.

Table 13: Acreage and cost estimates for additional natural land protection needed to achieve the 30% goal within DRWI Cluster areas (see Fig. P2 above).

Cluster Area	Additional Natural Land Protection Needed to Achieve 30 % Goal		Cost Estimates
	% of Cluster	Acreage within Cluster	
Poconos and Kittatinny	8.3%	13,067	$ 54,226,155
Upper Lehigh	0.0%	Achieved	
New Jersey Highlands	5.2%	7,601	$ 44,981,751
Schuylkill Highlands	0.0%	Achieved	
Middle Schuylkill	14.7%	9,664	$ 117,867,686
Brandywine and Christina		Not possible	
Upstream Suburban Philadelphia		Not possible	
Kirkwood - Cohansey Aquifer	0.0%	Achieved	
Totals		30,332	$ 217,075,591

Delaware River Basin and Kirkwood-Cohansey Area Summary

Summary statistics of natural land and protection status for the Delaware River Basin (Table 14) excludes the area of Delaware Bay (Delaware Bay HUC08 is ~513 mi^2 or 264,505 acres). This DRB$_x$ area is ~13,135 mi^2 or 8,406,584 acres with about ~60% (5,032,079 acres) of the area composed of "natural land" and approximately 19.8% (1,669,104 acres) of the DRB area is protected natural land. The two HUC08 Kirkwood-Cohansey geographies included in the DRWI are ~1,767 mi^2 or 1,130,800 acres, ~78% natural land and ~43% protected natural land. DRWI protection efforts (supported by the DRWPF administered by OSI) have resulted in 26,415 acres of recently protected lands across all of the study area included herein (DRB and the Kirkwood-Cohansey area) (Table 14).

The relative percentages of natural land and its protection status for each HUC12 sub-basin (Fig. 18, upper panel) are highly variable across the study geography (DRB and K-C area). Of the 480 HUC12 sub-basins, 114 have greater than 30% of the natural area protected, 82 don't have enough natural land remaining to exceed the 30% goal, and 284 are less than 30% protected but have enough natural land remaining to achieve the 30% protected goal. The uneven distribution of remaining natural land across the DRB would thus present a challenge for achieving the 30% goal equally across the HUC12 geographies unless the strategy includes afforestation in some geographies (see the upper panel in Fig. 18 and note the uneven distribution of the red bars across the diagram, representing the acreage needed in each HUC12 to achieve the 30% goal).

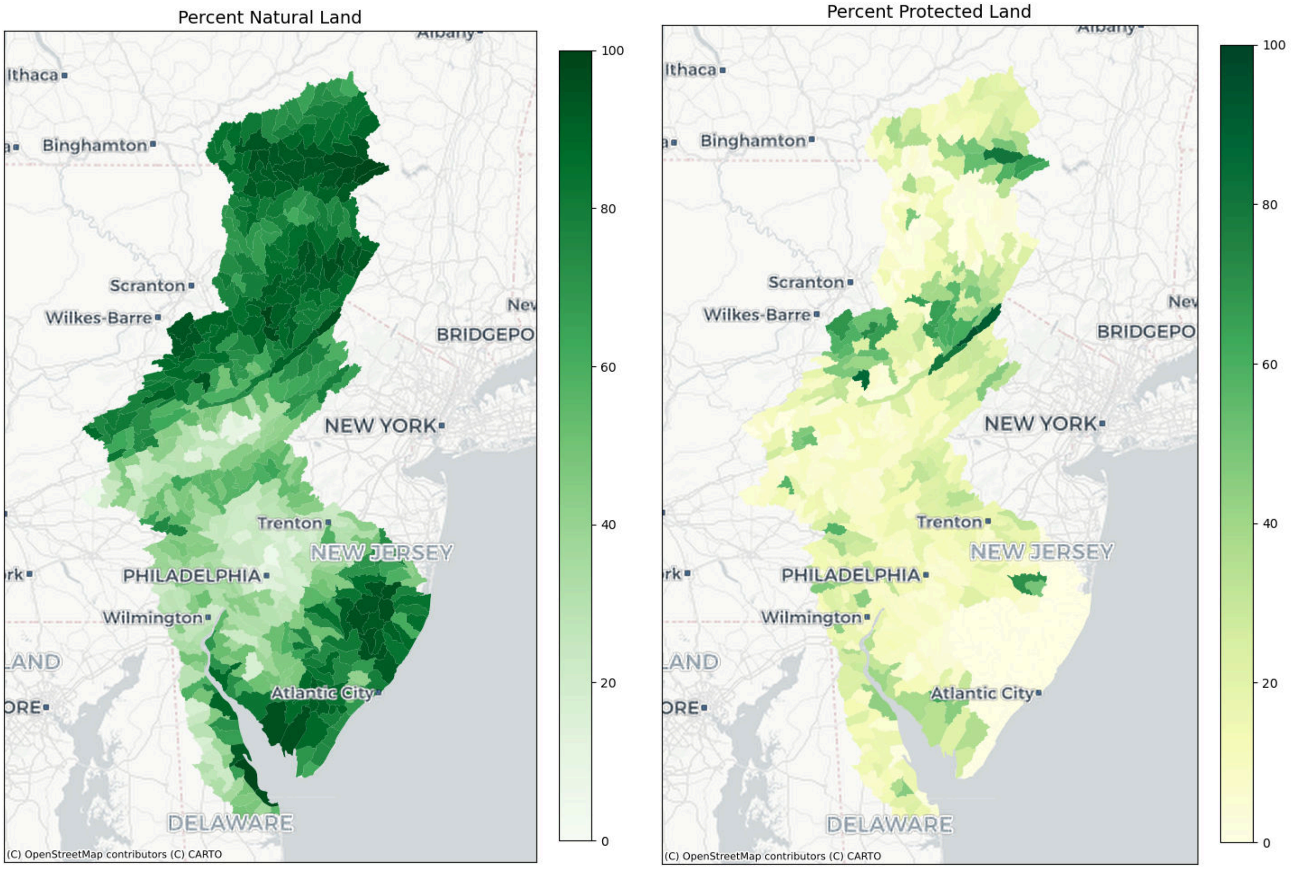

Figure 17: Percent of natural land within each HUC12 in the DRB and K-C area (left panel) and the percentage of natural land already protected in each HUC12 (right panel).

When HUC12s are aggregated into their larger HUC08 sub-basins, a more coarse but hydrologically related scale, the 30% goal for each HUC08 sub-basin is achievable within each of the 14 HUC08s (Fig. 18 lower panel). In fact, two of the 14 HUC08s already have greater than 30% of natural land protected (Middle Delaware-Mongaup-Brodhead at 30.7% and Mullica-Toms at 50.5%) and two other HUC08s have >27% of natural land protected (East Branch Delaware at 27.5% and Great Egg Harbor at 29.1%). The estimated acreage needed to achieve the goal of 30% natural land protected within the DRB is 859,920 acres and about 3,920 acres are needed across the two HUC08s that are outside of the DRB (Table 15). Given the past costs to secure natural land protection experienced by DRWI efforts (Table P1), we estimate ~$7.25 billion and $14.33 million needed to achieve the 30% protected goal in the DRB HUC08s and the two non-DRB HUC08s, respectively (Table 15).

Past strategies for prioritizing how DRWPF funds were deployed emphasized the protection of headwater acreages. Therefore, we identified unprotected natural land parcels in headwater catchments (>90 natural land and containing 1st-3rd streams draining into 1st-4th order streams; as described above) and estimated the acreage and costs of protecting those parcels as a component of achieving the 30% goal in each HUC08 (Table 15). Specifically, the acreage and cost estimates for DRB HUC08s are 278,962 available acres at a cost of ~$ 1.68 billion and for HUC08s outside of the DRB area, 150 available acres at a cost of $548,128.

Last, we include a visual geographic assessment of the potential to achieve even greater levels of natural land protection across the study geography in Fig. 19. Specifically, Fig. 19 shows the percent of natural land available to achieve the 30% goal (left panel), a 55% protection goal (middle panel), and an 85% protection goal (right panel).

Clearly, the costs to achieve the 30% goal across the DRB are large. However, there is enough unprotected natural land available in each HUC08 to achieve the goal equitably across the HUC08s in the DRB.

Table 14: Summary acreages of each HUC08 in the study geography for total area, natural land, total protected area (includes DRWI), DRWI-DRWPF protected areas, and headwater opportunity parcels.

HUC08 Watershed Name	Acres				
	Area	Natural Area	Total Protected	DRWI Protected	Headwater Opportunity
Upper Delaware	759,132	602,238	106,095	-	110,159
East Branch Delaware	536,040	487,240	147,543	-	123,486
Lackawaxen	381,428	299,087	41,509	-	44,768
Middle Delaware-Mongaup-Brodhead	975,825	836,047	299,796	12,592	152,277
Middle Delaware-Musconetcong	867,232	453,949	189,232	4,099	12,956
Lehigh	868,697	535,807	218,843	4,158	71,772
Crosswicks-Neshaminy	346,923	111,340	50,441	-	245
Lower Delaware	734,649	271,460	105,584	2,834	1,698
Schuylkill	1,219,745	531,774	158,580	553	47,988
Brandywine-Christina	482,244	173,520	106,882	-	1,198
Cohansey-Maurice	762,309	498,186	164,459	589	3,856
Broadkill-Smyrna	472,361	231,431	80,140	-	1,060
Mullica-Toms	716,439	572,403	361,758	1,590	1,558
Great Egg Harbor	414,364	306,198	120,388	-	150
Total in Delaware River Basin	8,406,585	5,032,079	1,669,104	24,825	571,463
Total in Non-DRB HUC8s	1,130,803	878,601	482,146	1,590	1,708
Total Throughout	9,537,388	5,910,680	2,151,250	26,415	573,171

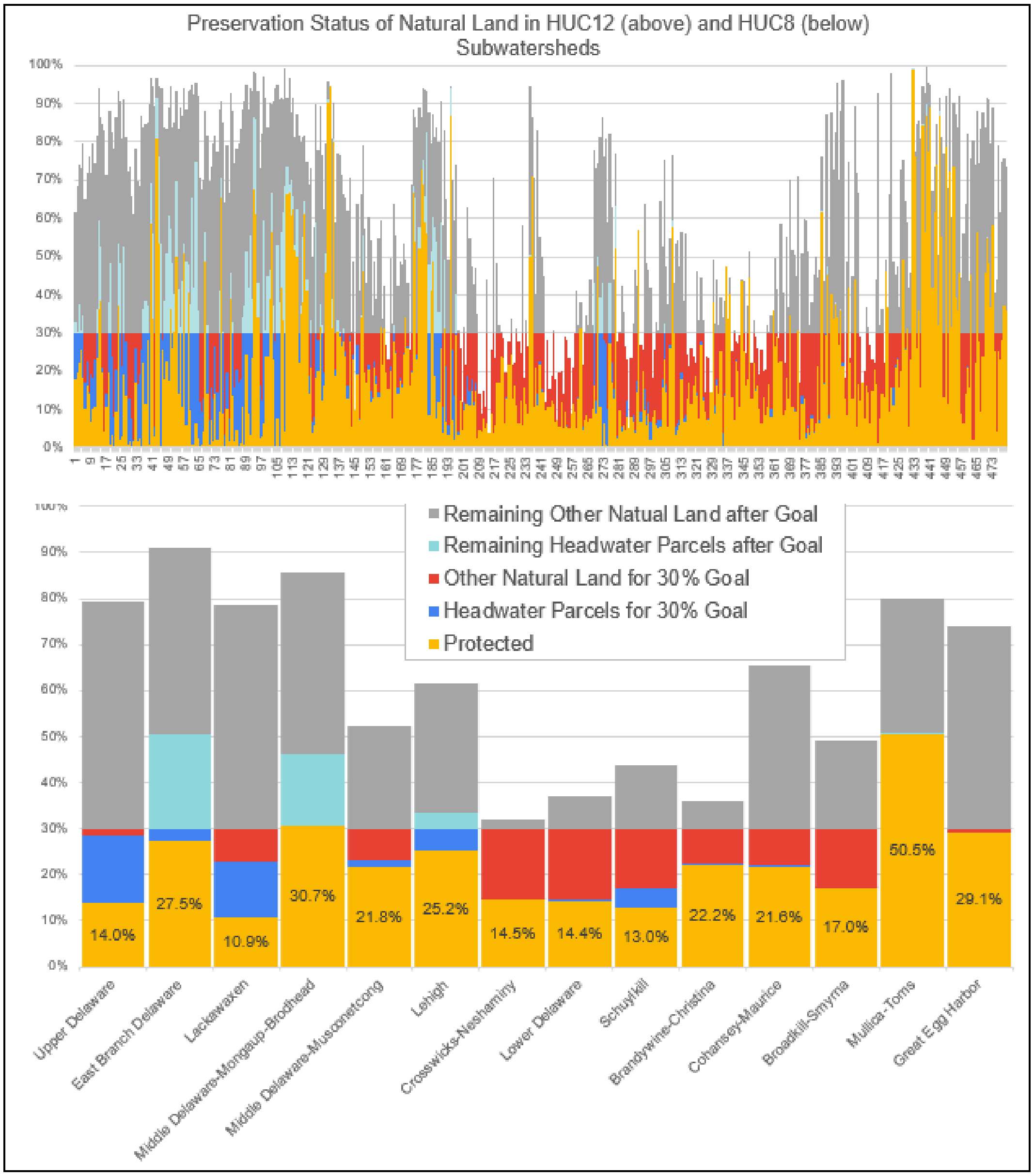

Figure 18: Both panels above show the percent of "natural land" in the project area by either HUC12s (top panel) or HUC08s (lower panel). Subcategories of the relative amount of "natural land" are classified based on protection status and the type of future preservation opportunity. Specifically, "Protected" lands include DRWI-protected and all other local, state, federal, and private protected parcels; "Headwater Parcels" are unprotected natural land parcels located adjacent to small streams (see text below for complete definition) and are further classified based on prioritizing them first to achieve the 30% goal and their residual after achieving 30%; "Other" and "Remaining" natural land categories are currently unprotected (see text for more complete definition) and are classified based on whether they would need to be protected to achieve 30% or not. There are 480 HUC12s (top panel) and 14 HUC08s (12 within the DRB). Of the HUC12s, 55 are outside of the DRB in the two "Kirkwood-Cohansey" HUC08s: Mullica-Toms and Great Egg Harbor. HUC12s (upper panel) are sorted from left to right in their order of belonging to the HUC08s (lower panel).

Table 15: Estimates of the acreage and costs required to achieve 30% natural land protected in each HUC08 throughout the study geography. The fair market values (FMV) per acre were based on data presented in Table x1 and our geographic extrapolation of those cost estimates to each HUC8. Brandywine-Christina FMV costs were estimated based on a recent (2023) purchase of a golf course (Loch Nairn) for permanent protection (106 acres; $1.425M). Last, if natural land protection strategies prioritize land protection in headwater areas (low order streams 1-3), estimates of the acreages available and costs for protection are provided in the last two columns.

HUC08 sub-basin	Acreage to Achieve 30% Goal	Est. FMV per Acre*	Est. Total FMV to Achieve 30% Goal	*Basis of FMV	Headwater Parcels Prioritized for Goal	Headwater Cost Estimates
Upper Delaware	121,645	$ 5,034	$ 612,358,888	ave. PK & NJH	110,159	$ 554,540,761
East Branch Delaware	13,269	$ 5,034	$ 66,795,803	ave. PK & NJH	13,269	$ 66,795,803
Lackawaxen	72,920	$ 4,150	$ 302,616,506	PK	44,768	$ 185,786,922
Middle Delaware-Mongaup-Brodhead	-	$ 5,034	$ -	ave. PK & NJH	-	$ -
Middle Delaware-Musconetcong	70,938	$ 5,918	$ 419,811,340	NJH	12,956	$ 76,675,346
Lehigh	41,766	$ 3,610	$ 150,774,692	UL	41,766	$ 150,774,692
Crosswicks-Neshaminy	53,636	$ 12,196	$ 654,148,326	SH	245	$ 2,989,101
Lower Delaware	114,811	$ 13,443	$ 1,543,453,778	Loch Nairn	1,698	$ 22,824,015
Schuylkill	207,343	$ 12,196	$ 2,528,759,139	SH	47,988	$ 585,261,497
Brandywine-Christina	37,791	$ 13,443	$ 508,041,792	Loch Nairn	1,198	$ 16,098,579
Cohansey-Maurice	64,233	$ 3,654	$ 234,676,679	ave. KC + NJH	3,856	$ 14,088,310
Broadkill-Smyrna	61,568	$ 3,654	$ 224,937,620	ave. KC + NJH	1,060	$ 3,871,220
Mullica-Toms	-	$ 3,654	$ -	ave. KC + NJH	-	$ -
Great Egg Harbor	3,921	$ 3,654	$ 14,325,849	ave. KC + NJH	150	$ 548,128
Total in Delaware River Basin	859,920		$ 7,246,374,562		278,962	$ 1,679,706,248
Total in Kirkwood-Cohansey HUC8s	3,921		$ 14,325,849		150	$ 548,128
Total Throughout	863,841		$ 7,260,700,412		279,112	$ 1,680,254,376

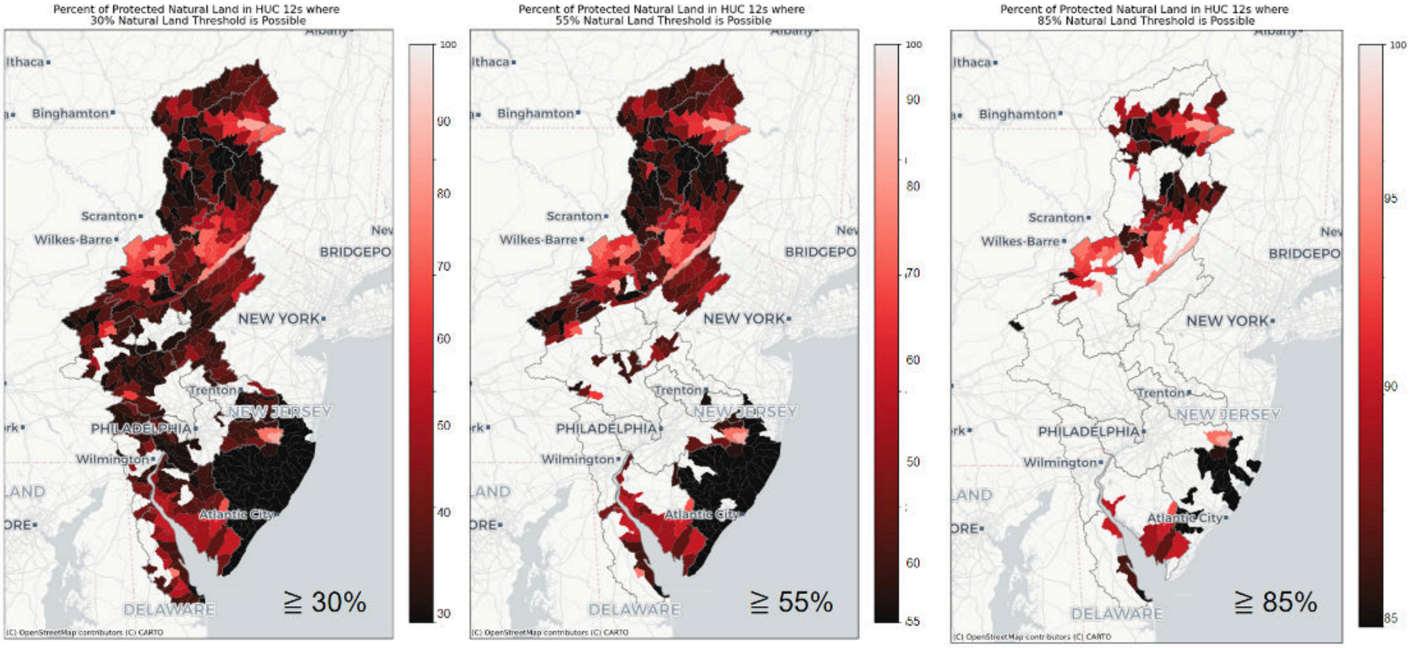

Figure 19: The percent of protected natural in each HUC12 where 30% (left panel), 55% (middle panel), and 85% (right panel) of natural land protection is possible throughout the study geography. Note that the color ramp range is specific to each panel (i.e., 30-100%, 55-100%, and 85-100%, respectively).

IMPLICATIONS

Effectiveness of DRWI Efforts

Based on extensive water quality modeling conducted as part of Stage 1 and Stage 2, it is estimated that phosphorus load reductions of approximately 45,800 lbs/year have occurred as a result of DWRI-funded BMP/restoration projects implemented throughout the Delaware River Basin and the two adjacent HUC08 sub-basins in southern New Jersey (see Table 6 and Fig. 11). Further phosphorus load reductions of at least 44,012 lbs/yr are also estimated to have resulted from additional nonpoint source BMPs implemented via other funding such as state and federal programs. **A key finding is that DRWI efforts resulted in as much of a benefit to water quality as all government-funded projects combined!** Furthermore, the DRWI strategy of focusing work on headwater areas had clear impacts to water quality far downstream from the Focus Area (Fig. 10).

Given the excess nonpoint phosphorus load reduction target of 681,672 lbs/yr, also shown in Table 6 and Fig. 11, these two funding sources have reduced this target load by about 6.7% and 6.5%, respectively, thereby leaving an additional load of about 591,860 lbs/yr in the entire 14-HUC08 study area to be removed in the future in order to meet established water quality goals. This remaining amount is equal to about 87% of the target load reduction of 681,672 lbs/yr.

It is quite likely that our compilation of “non-DWRI” BMPs and restoration projects reported for Pennsylvania and New Jersey are underestimates of what actually exists for a number of reasons. In the case of Pennsylvania, the various databases maintained by PADEP are not necessarily up-to-date with current projects, and many BMPs funded and implemented by various non-profit groups are not reported to any government agency. Similarly, as happens frequently in the Chesapeake Bay Watershed immediately to the west of the DRB, many farmers implement various BMPs (particularly annual management practices such as conservation tillage, cover crops and nutrient management) without any outside funding. Also, given the lack of organized, comprehensive databases in New Jersey that are used to track the funding and implementation of BMPs there, it is assumed that the "non-DWRI" practices are underestimated there as well. Even so, it is evident, and commendable, that the load reductions from DWRI-funded restoration activities described above are similar to those resulting from restoration activities undertaken by other entities.

Since the remaining load of 591,860 lbs/yr is about 13 times greater than the amount reduced to-date from DWRI-funded activities (i.e., 45,800 lbs/yr), it might be reasonable to expect, as a very rough approximation, that an amount equal to 13 times that already spent would be needed to reach load reduction goals for phosphorus in the DRB and adjacent areas in southern New Jersey. However, another more detailed, basin-based approach to estimating future costs for conservation projects is discussed in the section on Estimated Costs of Future Restoration. In this case, the estimated cost for future BMP implementation is estimated to be approximately $555.3 million in the DRB or about $579.8 million if study areas outside of the DRB are included (Table 11).

Land protection efforts have secured more than 26,400 acres of natural land, mostly in landscapes with significant forest and high water quality. These lands and their natural ecosystems services help to produce high water quality downstream now and for future generations. Our approach to estimate the future pollution prevented from these parcels resulted in estimates of about 9,050 lbs/yr or about 18% of the loads reduced by DRWI restoration efforts. Although this is small relative to the loads reduced by restoration, the benefit provided should endure in perpetuity for future generations of people living in the region. This approach represents one dimension of the benefit provided and we encourage readers of this report to explore the multi-faceted approach taken in a companion study led by the Open Space Institute: Protecting Forests for Clean Water: Findings from a 10-year initiative inform field-wide best practices (OSI, 2023; contact Abigail Weinberg).

APPENDICES

Appendix 1: Conservation Practices in DRB

Project Tracking of DRWI-Funded Projects

Since 2019, The Academy of Natural Sciences has facilitated DRWI projects and practice tracking in FieldDoc. Within FieldDoc, capital projects are structured within specific grant programs, which specify the funder(s) and the funding program title and connected goals, as FieldDoc serves conservation project tracking needs for a wide variety of funders across a broad geography. A funded project is often implemented at multiple sites (defined by a place name and a parcel boundary), which in turn can utilize one or more restoration or protection strategies that are typically categorized by practice type or BMP type.

For this DRWI Pollution Assessment analysis we focused solely on restoration and land protection projects within grant programs that support DRWI capital projects: Delaware River Restoration Fund (DRRF) administered by National Fish and Wildlife Foundation (NFWF), and Delaware River Watershed Protection Fund (DRWPF) administered by Open Space Institute (OSI). DRWI grantees were primarily responsible for entering project and practice information, with guidance, QAQC, and oversight provided by the Academy.

Below we've illustrated the data management structure in FieldDoc as it relates to this project.

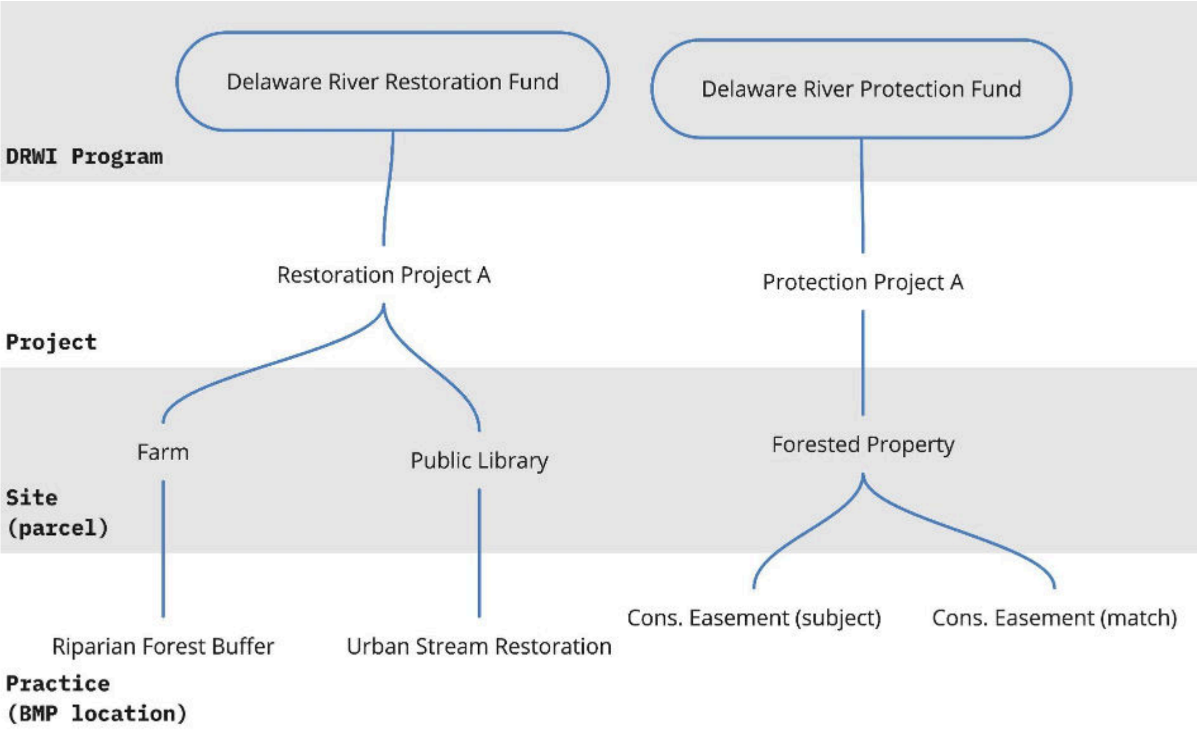

Figure A1-1. DRWI Program-Project-Site-Practice hierarchy that is tracked by FieldDoc and required for this Pollution Assessment. A single grant program defined by a funder can provide many projects managed by grantee(s) to implement one or more conservation practices (Best Management Practice(BMP), conservation easement or fee acquisition) on one or more land parcel sites.

DRWI Restoration Project Summary

The DRWI projects and restoration practices (i.e., BMPs) within this analysis include DRWI Phase 1 and 2 projects implemented between 2014 to present day with funding from the Delaware River Restoration Fund (DRRF), Delaware River Operational Fund, and/or Delaware Watershed Conservation Fund. These DRWI projects resulted in the implementation of 1,446 modelable BMP practices across the DRWI restoration and hybrid strategy sub-basin Clusters and their respective Focus Areas. They were modeled using an automated modeling service developed by Drexel University (Academy of Natural Sciences of Drexel University and The Drexel University College of Computing and Informatics) in support of NFWF's Restoration Project Impact Analysis. The 1,446 BMPs fall within 55 BMP practice types. Modeling methods and documentation can be found in *Appendix A* of the Stage 1 report. Below is a table showing the top 10 implemented BMPs and respective counts. Modeled BMP definitions can be found in *Appendix B* of the Stage 1 report also.

Table A1-1. DRWI restoration projects from Phase 1 and 2, funded by the Delaware River Restoration Fund (DRRF), by type of Best Management Practice (BMP).

Practice Group	Restoration Type	Count	Area (acres)	TN Load Reduced (lbs/yr)	TP Load Reduced (lbs/yr)	TSS Load Reduced (lbs/yr)
Ag Land Erosion Control - Conservation Tillage	Conservation Tillage	15	38,558	706	571	616,520
Ag Land Erosion Control - Other	Crop Rotation	1	102	0	0	0
Ag Land Erosion Control - Other	Diversion	16	0	0	0	0
Ag Land Erosion Control - Other	Grassed Waterway	42	109	756	319	227,328
Ag Land Erosion Control - Other	Grazing Land Protection	8	37,036	38	15	4,064
Ag Land Erosion Control - Other	Heavy Use Area Protection	69	113	596	205	137,165
Ag Land Erosion Control - Other	Prescribed Grazing	9	337	48	24	7,326
Ag Land Erosion Control - Other	Residue and Till Management, No Till	4	64	0	0	0
Ag Land Erosion Control - Other	Roof Runoff Management	3	9	11	3	2,104
Ag Land Erosion Control - Other	Roof Runoff Structure	39	54	207	68	44,480
Ag Land Erosion Control - Other	Roofs and Covers	21	5	94	31	19,532
Ag Land Erosion Control - Other	Soil Conservation and Water Quality Plans	47	3,670	2,874	1,045	704,008
Ag Land Nutrient Management	Comprehensive Nutrient Management Plan	11	1,907	1,197	526	0
Ag Land Nutrient Management	Nutrient Management	9	38,115	1,466	713	0
Animal Waste Management	Access Control	2	207	0	0	0
Animal Waste Management	Barnyard Runoff Controls	27	36,976	296	94	73,458
Animal Waste Management	Waste Storage Facility	57	56	13,389	3,454	0
Animal Waste Management	Waste Storage Pond	1	1	595	133	0
Animal Waste Management	Waste Storage Structure	43	2	15,166	5,680	0
Land Restoration - Forest	Tree and Shrub Establishment	11	37,062	295	75	49,788
Land Restoration - Forest	Tree Planting	5	5	21	4	3,385
Land Restoration - Other	Conservation Cover	22	275	419	233	112,475
Land Restoration - Other	Conservation Easement	2	19,484	40	8	7,176
Land Restoration - Wetland	Constructed Wetland	3	2	85	41	66,840

Practice Group	Restoration Type	Count	Area (acres)	TN Load Reduced (lbs/yr)	TP Load Reduced (lbs/yr)	TSS Load Reduced (lbs/yr)
Land Restoration - Wetland	Wetland Creation - Floodplain	3	2	16	8	6,103
Land Restoration - Wetland	Wetland Restoration	4	10	37	21	12,991
Land Restoration - Wetland	Wetland Restoration - Floodplain	2	1	1	0	75
Miscellaneous	Access Road	13	0	0	0	0
Miscellaneous	Aquatic Organism Passage	1	1	0	0	0
Miscellaneous	In-Field Soil Health Assessment	25	1,482	0	0	0
Miscellaneous	Irrigation System, Microirrigation	2	61	0	0	0
Miscellaneous	Livestock Pipeline	12	1	0	0	0
Miscellaneous	Obstruction Removal	3	0	0	0	0
Miscellaneous	Pollinator Habitat	6	1	0	0	0
Miscellaneous	Pumping Plant	8	0	0	0	0
Miscellaneous	Sprinkler System (Center Pivot)	3	253	0	0	0
Miscellaneous	Stream Crossing	50	1	0	0	1,000
Miscellaneous	Trails and Walkways	31	1	0	0	0
Miscellaneous	Underground Outlet	30	0	0	0	0
Miscellaneous	Waste Facility Closure	6	1	0	0	0
Miscellaneous	Waste Transfer	14	0	0	0	0
Stream Buffers	Forest Buffer	45	520	29,870	6,592	3,597,759
Stream Buffers	Forest Buffer - Narrow	7	266	369	119	107,080
Stream Buffers	Forest Buffer - Streamside with Exclusion Fencing	47	18	29,959	8,555	14,185,172
Stream Buffers	Grass Buffer - Narrow	5	7	419	135	117,014
Stream Buffers	Grass Buffer - Narrow with Exclusion Fencing	1	45	168	25	1,093,422
Stream Buffers	Grass Buffer - Streamside with Exclusion Fencing	2	0	2,250	597	529,095
Stream Buffers	Grass Buffers	2	7	0	0	0
Stream Buffers	Riparian Forest Buffer	62	1,853	3,607	602	516,682
Stream Buffers	Riparian Herbaceous Cover	6	27	228	43	33,332
Streambank Protection	Fence	40	247	3,272	1,784	405,692
Streambank Protection	Non-Urban Stream Restoration	15	82	2,856	1,852	636,578
Streambank Protection	Stream Channel Stabilization	3	0	46	28	5,576
Streambank Protection	Streambank and Shoreline Protection	5	42	735	441	206,932
Streambank Protection	Urban Stream Restoration	2	0	52	44	27,947
Streambank Protection	Watering Facility	19	345	188	104	23,090
Urban Stormwater Management	Bioretention	52	9	183	47	161,247
Urban Stormwater Management	Bioretention/raingarden - C/D soils no underdrain	28	2	64	20	32,931
Urban Stormwater Management	Bioretention/raingardens - A/B soils no underdrain	35	3	25	7	23,029
Urban Stormwater Management	Bioretention/raingardens - C/D soils underdrain	9	4	24	7	29,862
Urban Stormwater Management	Bioswale	15	3	537	148	122,071
Urban Stormwater Management	Cistern	9	0	0	0	0
Urban Stormwater Management	Depaving	1	0	0	0	0
Urban Stormwater Management	Erosion and Sediment Control Level 1	5	0	0	0	0
Urban Stormwater Management	Flow Through Planter	2	0	0	0	0
Urban Stormwater Management	Green Infrastructure Plan	1	11,256	0	0	0
Urban Stormwater Management	Impervious Surface Reduction	2	0	1	0	794

Practice Group	Restoration Type	Count	Area (acres)	TN Load Reduced (lbs/yr)	TP Load Reduced (lbs/yr)	TSS Load Reduced (lbs/yr)
Urban Stormwater Management	Permeable Pavement w/o Sand Veg. - A/B soils no underdrain	5	1	9	2	3,116
Urban Stormwater Management	Urban Infiltration Practices	3	0	1	0	678
Urban Stormwater Management	Vegetated Treatment Area	5	2	0	0	0
Urban Stormwater Management	Wet Pond	1	0	53	26	35,414
ALL		**1,309**	**282,185**	**131,263**	**44,392**	**28,855,990**

Table A1-2. DRWI restoration projects from Phase 1 and 2, funded in part by the Delaware River Operational Fund or the Delaware Watershed Conservation Fund, by type of Best Management Practice (BMP)

Practice Group	Restoration Type	Count	Area (acres)	TN Load Reduced (lbs/yr)	TP Load Reduced (lbs/yr)	TSS Load Reduced (lbs/yr)
Ag Land Erosion Control - Cover Crop	Cover Crop	24	4,932	0	0	0
Ag Land Erosion Control - Other	Residue and Tillage Management, No Till	3	486	0	0	0
Ag Land Erosion Control - Other	Soil Conservation and Water Quality Plans	1	76	0	0	0
Animal Waste Management	Animal Waste Management System	1	0	0	0	0
Animal Waste Management	Barnyard Runoff Control	1	1	0	0	0
Land Restoration - Forest	Forest Planting	2	23	0	0	0
Land Restoration - Forest	Tree and Shrub Establishment	2	8	0	0	0
Land Restoration - Forest	Tree Planting	1	0	0	0	0
Land Restoration - Other	Conservation Cover	4	19	8	3	1,493
Land Restoration - Other	Conservation easement	25	3,428	0	0	0
Land Restoration - Wetland	Wetland Creation - Floodplain	1	5	0	0	77
Land Restoration - Wetland	Wetland Enhancement	4	41	0	0	0
Land Restoration - Wetland	Wetland Restoration	10	32	88	47	31,011
Land Restoration - Wetland	Wetland Restoration - Floodplain	6	9	37	20	7,674
Land Restoration - Wetland	Wetland Restoration - Headwater	1	9	0	0	0
Miscellaneous	Fee acquisition	19	5,456	0	0	0
Stream Buffers	Forest Buffer	8	67	992	102	51,767
Stream Buffers	Forest Buffer - Narrow	2	2	0	0	0
Stream Buffers	Forest Buffer-Streamside with Exclusion Fencing	1	9	0	0	0
Stream Buffers	Grass Buffers	1	23	0	0	0
Stream Buffers	Riparian Forest Buffer	5	9	47	11	4,963
Streambank Protection	Non-Urban Stream Restoration	6	9	617	370	85,329
Streambank Protection	Urban Stream Restoration	3	12	0	0	0
Urban Stormwater Management	Bioretention/rain gardens - A/B soils, no underdrain	1	0	0	0	0
Urban Stormwater Management	Dry Extended Detention Ponds	1	1	0	0	0
ALL		**137**	**14,656**	**1,822**	**573**	**186,784**

Non-DRWI Restoration Project Summary

To support the initial water quality modeling effort conducted as part of the Stage 1 assessment, rough estimates of the implementation levels of various agricultural and urban stormwater best management practices (BMPs) were assigned based on a general knowledge of the implementation of these BMPs within the Chesapeake Bay watershed. For Stage 2, these initial estimates were substantially updated based on more detailed data available for Pennsylvania and New Jersey.

In Pennsylvania, data were available from the Chesapeake Bay Program within PADEP at differing levels of geographic detail. For example, information on urban stormwater BMPs is compiled annually by PADEP for the entire state (including areas within the DRB). This information includes the latitude and longitude of new urban BMP locations in addition to the site area delivering runoff to the particular BMP. Similar information is also available for some state programs that fund the implementation of agricultural BMPs such as the Growing Greener Program. Summaries of these latter two sources are shown in Table A1-3.

Less spatially explicit information on a number of agricultural BMPs is also collected by PADEP from various state and federal sources. In this case, these sources were used to estimate implementation levels at the county level for annual practices such as cover crops, conservation tillage, and nutrient management for PA counties located within the DRB (see Table A1-4). Although the values shown in this latter table are average percent implementation rates across the Pennsylvania portion of the DRB, estimates of these BMPs were actually available by county, and it is these estimates that were used in Stage 2 modeling.

Table A1-3. Non-DRWI project-specific BMP load reductions for DRB from PADEP database.

Restoration Type	Count	Area (acres)	Length (ft)	TN Load Reduced (lbs/yr)	TP Load Reduced (lbs/yr)	TSS Load Reduced (lbs/yr)
Bioretention/raingardens - C/D soils underdrain	1	5	0	3	4	4
Dry Extended Detention Ponds	3	10	0	3	5	7
Fence	24	71,215	71,215	1,424	285	181,598
Grassed Waterway	2	400	400	164	160	216
Grazing Land Protection	1	5	0	2	2	2
Heavy Use Area Protection	1	0	0	0	0	0
Permeable Pavement w/o Sand Veg. - A/B soils no underdrain	1	1	0	0	0	1
Riparian Forest Buffer	49	192	0	79	77	104
Soil Conservation and Water Quality Plans	1	32	0	3	3	3
Stream Channel Stabilization	51	32,742	32,737	1,637	982	1,193,104
Urban Infiltration Practices	2,718	37,725	0	22,635	26,407	28,293
ALL	**2,852**	**142,326**	**104,352**	**25,950**	**27,925**	**1,403,331**

Unfortunately, information on BMPs similar to that described for Pennsylvania above are not as readily available for New Jersey. In this case, an offer was made by Laura Tessieri of the North Jersey RC&D to reach out to various NRCS offices in New Jersey to obtain estimates from them on current implementation levels for cover crops, conservation tillage and nutrient management in central and southern New Jersey. It is these estimates that were used to develop the county-level values used in the DRB that are also shown in Table A1-3. Unlike Pennsylvania, no locational information on urban stormwater BMPs is available for New Jersey. Consequently, such levels were estimated by quantifying the difference in acres of high- and medium-density land between the 2011 and 2019 NLCD layers for each NHD catchment within the New Jersey portion of the DRB. While not ideal, these estimates are better than assuming zero implementation of this type of BMP. (Note: although regulations regarding the implementation of stormwater BMPs were established in late 2006, they were subject to challenges and revisions for several years after, which resulted in little regulated urban BMP implementation until 2009 or 2010).

Table A1-4. Non-DRWI county-level BMP load reductions for DRB from PA and NJ.

County	State	Agricultural Load Reduced (lbs/yr)			Developed Load Reduced (lbs/yr)		
		TN	TP	TSS	TN	TP	TSS
Atlantic County	NJ	0	0	15	108	18	9,941
Burlington County	NJ	11	7	289	310	53	26,955
Camden County	NJ	0	0	7	151	26	13,264
Cape May County	NJ	0	0	0	36	6	3,123
Cumberland County	NJ	5	2	250	63	11	5,758
Gloucester County	NJ	37	24	2,112	216	37	18,307
Hunterdon County	NJ	204	188	33,144	2	0	224
Mercer County	NJ	5	4	313	139	24	12,359
Monmouth County	NJ	2	1	126	199	34	18,300
Morris County	NJ	1	1	74	6	1	568
Ocean County	NJ	0	0	10	393	67	36,424
Salem County	NJ	325	231	23,270	27	5	2,316
Sussex County	NJ	0	0	0	23	4	2,081
Warren County	NJ	83	68	3,907	21	4	1,886
Berks County	PA	2,724	3,176	691,941	118	20	10,297
Bucks County	PA	4,650	4,798	337,954	256	44	22,772
Carbon County	PA	763	685	158,817	6	1	529
Chester County	PA	2,613	2,008	386,765	222	38	19,846
Delaware County	PA	77	56	25,546	150	26	13,043
Lackawanna County	PA	72	71	7,128	2	0	198
Lancaster County	PA	11	9	2,163	0	0	6
Lebanon County	PA	446	266	100,891	7	1	647
Lehigh County	PA	1,890	1,851	527,427	257	44	22,153
Luzerne County	PA	5	5	343	3	0	233
Monroe County	PA	1,185	1,028	322,551	66	12	5,793
Montgomery County	PA	2,121	2,053	327,625	396	68	35,407
Northampton County	PA	1,269	1,238	129,750	265	45	23,261
Philadelphia County	PA	3	3	508	269	46	21,287
Pike County	PA	29	24	3,723	10	2	895
Schuylkill County	PA	1,111	900	319,543	14	2	1,256
Wayne County	PA	3,049	2,544	257,366	7	1	624
ALL		**22,692**	**21,240**	**3,663,559**	**3,742**	**639**	**329,753**

Appendix 2: Methodology

Overview of the Modeling and Analysis framework

A suite of modeling tools previously funded via DRWI (including Model My Watershed and derivatives thereof) were used to estimate current nitrogen, phosphorus and sediment loads from all sources throughout the DRB.

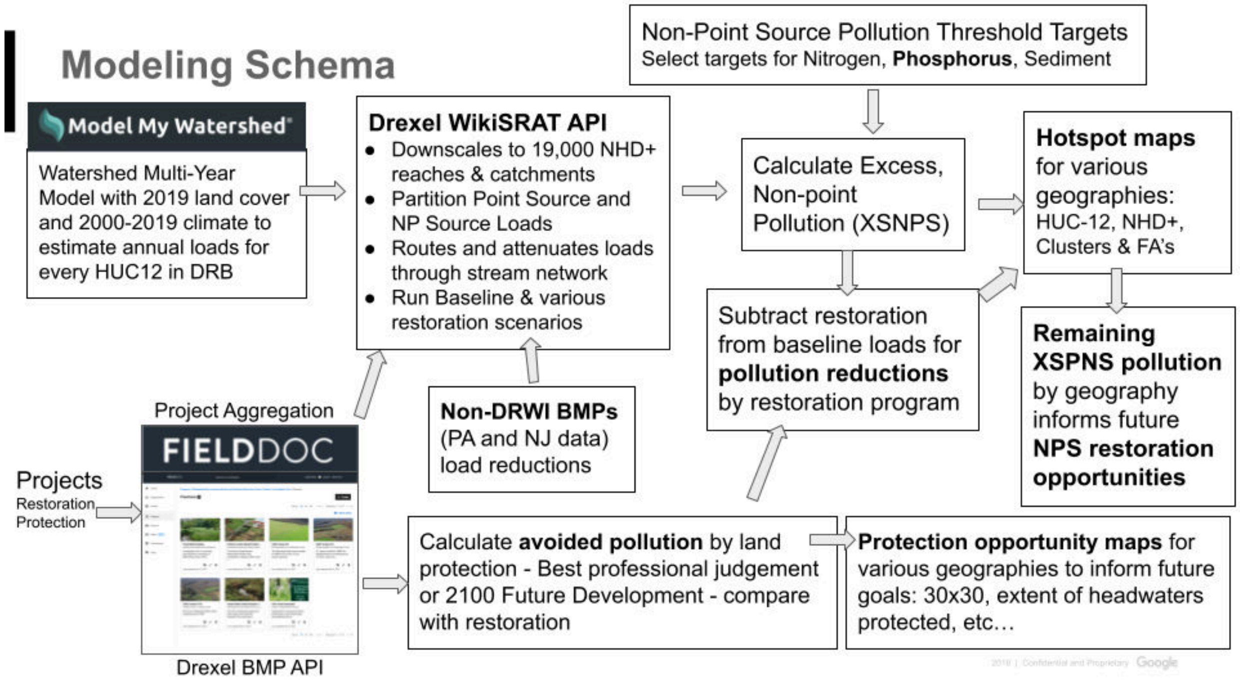

Figure A2-1. Framework for modeling and analysis used by the DRWI Pollution Assessment project. The editable version of Fig. 2 can be found in DRWI-PollutionAssessment-ProjectUpdate-GISWorkGroup , and a detailed Data Flow Diagram is available at https://miro.com/app/board/uXjVOapsR_E=/

Methods for Modeling Baseline Pollution

Combined Sewer Overflows (CSOs) cannot be directly modeled by ModelMW. CSOs are essentially underground pipe networks that collect both stormwater runoff and sanitary wastes and then transport these loads to wastewater treatment plants for subsequent treatment. A characteristic feature of CSOs is that these loads are only discharged as "overflow" to a given stream outlet when the capacity of the treatment plant is exceeded, such as during very heavy rainfalls. Because of the random nature of these events, such discharged loads are not often monitored, and are therefore typically unknown. In ModelMW, however, the loads delivered to CSOs (i.e., urban stormwater runoff and sanitary sewer loads) are simulated and are included in the various "urban development" and "point source" categories. Also, with respect to urban stormwater runoff, ModelMW does have the ability to simulate treatment of this load via use of the "urban stormwater management" BMP shown in Table A1-2 in Appendix 1.

Appendix 3: Additional cost considerations regarding point and nonpoint source controls

As indicated earlier in the Findings section, the cost estimates shown in Table 11 are based on simulations of future BMP implementation focused on achieving phosphorus-based water quality improvement goals. That is, the extent of simulated BMP implementation was increased until various nonpoint source phosphorus loads were decreased to the point where they met or exceeded water quality targets based on removing excess nonpoint source phosphorus loads from each sub-basin within the larger study area encompassing the entire DRB as well as two HUC08 sub-basins outside the DRB.

This BMP simulation exercise also assumed that point source loads would be addressed separately to reduce water quality impacts to streams located throughout the region, particularly in sub-basins located within the Lehigh River, Schuylkill River, Lower Delaware, Cohansey-Maurice and Middle Delaware-Musconetcong HUC08 sub-basins where point source discharges range from about 30-65% of the entire phosphorus loads to streams. However, in the event that controls on such sources are not implemented in the future, an additional simulation was performed to assess what the increased financial cost might be to reduce excess phosphorus loads sufficiently to meet load reduction targets solely via the use of nonpoint source BMPs such as those shown in Table 9. In this instance, the nitrogen and phosphorus point source loads within each of the HUC08 sub-basins were added to the “remaining” TN and TP loads in Table 10, and the BMP simulations were subsequently re-run to see what the new estimated costs might be to achieve these “elevated” reduction targets. In essence, this additional analysis was conducted to quantify what the upper bounds of the nonpoint source control costs might be in the absence of future point source reductions. The results of this second analysis are shown in Tables A3-1 and A3-2. As can be seen, the estimated costs to achieve acceptable water quality conditions solely through the control of nonpoint sources of pollution would be significantly (and probably prohibitively) more expensive. At a cost of $10.3 billion, this cost is about 20 times higher than it would be if only excess nonpoint source loads were addressed as was done in the previous exercise.

However, it is likely that upgrades to existing wastewater treatment plants would actually be far less costly than implementing additional relatively expensive nonpoint source BMP measures such as urban stormwater control and streambank stabilization. For example, in an earlier study completed by Evans (2008)[10] for the Connecticut River Basin (which is similar in size to the DRB),it was estimated that about $746 million would be required to upgrade 141 wastewater treatment plants in that basin to achieve stated water quality goals for that area. (In this latter case, the pollutant of concern was nitrogen; but the costs for upgrading such plants for phosphorus reduction are believed to be close enough for approximation purposes in this instance). Allowing for cost increases since 2008, and considering that about 160 wastewater treatment plants in the DRB discharge approximately 95% of the phosphorus load in that basin, it would be reasonable to estimate that it might cost about $1-2 billion in order to upgrade such plants in the DRB. Therefore, it might be reasonable to expect that the total costs for achieving acceptable water quality conditions would be a combination of those shown in Table A3-2 and the estimated treatment plant upgrade costs above, for a range of roughly $1.5-2.5 billion.

For some context, it is useful to compare the “clean-up” costs given herein to costs provided elsewhere for large-scale watershed water quality improvement. For example, it has been estimated that water-quality restoration efforts for the Chesapeake Bay watershed will be over $15 billion, and that

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[10] Evans, B., 2008. An Evaluation of Potential Nitrogen Load Reductions to Long Island Sound from the Connecticut River Basin. Final report to the New England Interstate Water Pollution Control Commission.

similar costs for the Connecticut River Basin will be in the range of $4-5 billion. Unlike the cost estimates for the DRB shown earlier in Table 11, the projected costs for these other areas also include significant reductions to point source loads.

Table A3-1: Simulated load reductions (lbs/yr) achievable via future BMP implementation without future point source controls.

HUC8 Name/Code	TN Reduction Target	TP Reduction Target	TSS Reduction Target	Simulated TN Reduction	Simulated TP Reduction	Simulated TSS Reduction
Upper Delaware/2040101	106,828	1,378	0	20,176	1,424	310,755
East Branch Delaware/2040102	32,716	6,586	0	35,752	6,619	1,865,492
Lackawaxen/2040103	284,524	21,214	0	117,562	21,448	10,706,770
Mid Delaware-MongaupBrod/2040104	133,085	13,536	0	283,947	13,629	17,813,780
Mid Delaware-Musconetcong/2040105	1,120,061	134,340	0	1,087,907	134,635	157,540,573
Lehigh/2040106	698,050	289,702	0	1,562,756	293,785	286,764,711
Crosswicks-Neshaminy/2040201	392,349	38,857	0	423,603	39,163	62,953,065
Lower Delaware/2040202	4,081,691	241,037	0	1,756,503	242,060	514,799,238
Schuylkill/2040203	9,711,118	987,190	18,892,041	5,842,000	812,417	615,335,734
Brandywine-Christina/2040205	804,607	95,701	0	1,004,159	96,063	141,676,002
Cohansey-Maurice/2040206	1,341,361	55,431	0	760,465	56,078	80,283,344
Broadkill-Smyrna/2040207	1,534,418	59,875	0	1,235,536	59,967	30,941,943
Mullica-Toms/2040301	0	2,231	19,714,158	190,920	2,282	4,298,257
Great Egg Harbor/2040302	0	2,062	14,527,759	132,924	2,095	3,423,265
Totals for Delaware River Basin	20,240,806	1,944,847	18,892,041	14,130,365	1,777,290	1,920,991,407
Totals for non-DRB Areas	0	4,293	34,241,917	323,844	4,377	7,721,522
Totals for Entire 14 HUC8 Study Area	20,240,806	1,949,141	53,133,958	14,454,209	1,781,666	1,928,712,929

Table A3-2: Estimated costs for implementing future BMPs without future point source controls (in million $/yr).

HUC8 Name/Code	Cluster in HUC8	Ag Land Reductions	Farm Animal Reductions	Urban SW Reductions	Streambank Reductions	Totals
Upper Delaware/2040101	NA	$2.1	0	0	0	$2.1
East Branch Delaware/2040102	NA	$1.9	$0.4	0	0	$2.3
Lackawaxen/2040103	NA	$4.8	$1.3	$12.0	$3.3	$21.4
Mid Delaware-MongaupBroadhead/2040104	(1)	$5.3	$1.2	$16.5	0	$23.0
Mid Delaware-Musconetcong/2040105	(2)	$45.5	$3.5	$135.0	$191.7	$375.7
Lehigh/2040106	(3)	$28.0	$1.6	$141.3	$1852.4	$2023.2
Crosswicks-Neshaminy/2040201	(4)	$14.4	$0.8	$59.3	$91.8	$166.4
Lower Delaware/2040202	(4)	$14.6	$1.5	$469.8	$1447.9	$1933.9
Schuylkill/2040203	(5,6)	$62.5	$14.0	$234.4	$4690.7	$5001.6
Brandywine-Christina/2040205	(7)	$24.1	$4.5	$139.1	$155.4	$323.2
Cohansey-Maurice/2040206	(8)	$30.6	$1.5	$69.9	$275.2	$377.2
Broadkill-Smyrna/2040207	NA	$33.0	$6.5	$26.2	0	$65.7
Mullica-Toms/2040301	(8)	$5.5	$4.0	$5.1	0	$14.6
Great Egg Harbor/2040302	(8)	$4.2	$1.9	$3.9	0	$9.9
Totals for Delaware River Basin		$266.9	$36.9	$1303.5	$8708.2	**$10,315.6**
Totals for non-DRB Areas		$9.6	$5.9	$8.9	0	**$24.5**
Totals for Entire 14 HUC8 Study Area		$276.5	$42.8	$1312.5	$8708.2	**$10,340.1**

(9) Poconos and Kittatinny
(10) New Jersey Highlands
(11) Upper Lehigh
(12) Upstream Suburban Philadelphia
(13) Middle Schuylkill
(14) Schuylkill Highlands
(15) Brandywine-Christina
(16) Kirkwood-Cohansey

Appendix 4: Additional model calibration work conducted to support data updates completed as part of Stage 2

As described previously, a limited amount of calibration was undertaken to assess the accuracy of watershed-based pollutant loads estimated by the sub-basin attenuation routine implemented within the initial version of Model My Watershed (specifically, the “multi-year” model). This initial version utilized 2011-vintage land cover (NLCD) data as well as the “medium-resolution” NHD stream network data that was available from USGS at the time. In early 2022, however, these two data layers were replaced with more current 2019 NLCD data and high-resolution NHD stream data, respectively. Given this change in input data, it was decided to conduct additional calibration to determine if any of the attenuation coefficients used in the sub-basin routine needed to be updated. Due to limited resources and the source of funding provided for this effort, calibration was focused on the Delaware River Basin (DRB); the area for which the initial SRAT calibration was performed.

Similar to what was done for the earlier SRAT calibration, recent stream flow and water quality sample data were retrieved from USGS (see https://waterdata.usgs.gov/nwis) for a number of watersheds located throughout the DRB. Specifically, the six HUC08 and HUC10 basins shown in Figure A4-1 below were used based on the availability of current stream sample data. From these data, “observed” loads for total N, total P and sediment were calculated for each basin which could be compared against model-simulated loads. It should be noted here that more recent weather data (i.e., daily precipitation and temperature for the period 2000-2019) was also used in the multi-year model runs to allow for a more direct comparison between “current” simulated and observed loads.

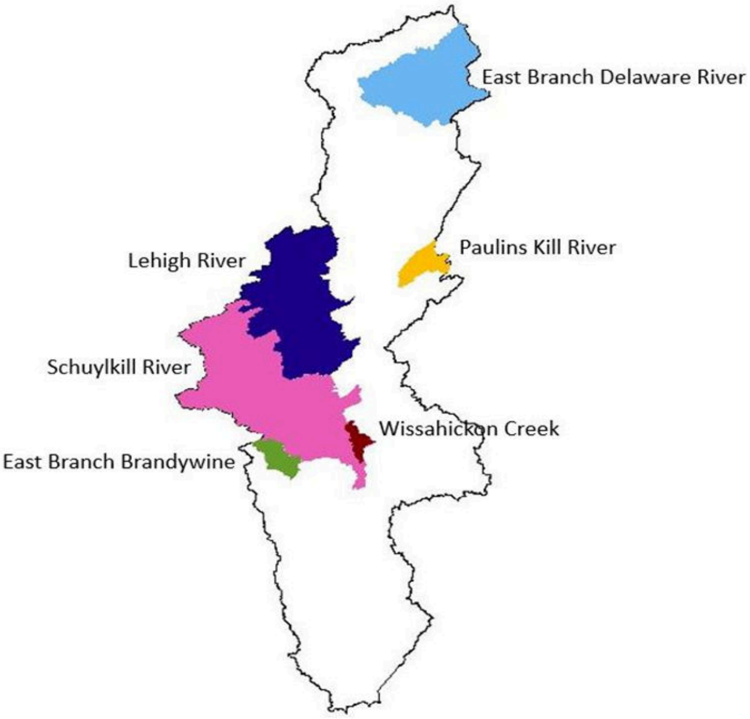

Figure A4-1: New calibration watersheds in the Delaware River Basin.

The results of this recent calibration effort are summarized in Table A4-1 and in Figs. A4-2, A4-3 and A4-4 below. As can be seen from these results, the simulated loads (expressed as loads per unit area) were generally fairly close to calculated observed loads, although some watersheds were more problematic than others. For example, the modeled loads for TN and TP in the Wissahickon Creek watershed were much lower than expected. In this instance, the TN and TP loads from point source discharges were roughly half of the total loads simulated, and it may be that the underestimation of nutrient loads in this area are due to the relatively poor quality of data for point sources in comparison to other data sources. Nonetheless, based on this calibration, it is believed that the sub-basin/attenuation routine is performing reasonably well within the DRB.

With the sub-basin modeling routine implemented in Model My Watershed, nutrient and sediment loads are attenuated (i.e., reduced) as the loads move from upstream NHD catchments to downstream NHD catchments based on the presence (percent) of open water and wetland areas within each intervening catchment and average attenuation coefficients established for the DRB. During the initial calibration process, the attenuation coefficients were incrementally adjusted in successive model runs until a “best fit” was achieved across all of the test sites in terms of matching observed and simulated loads. As a result of this first calibration effort, these attenuation factors were set at 0 for TN, 0.13 for TP, and 0.10 for TSS. As a result of this most recent calibration (which also resulted in some modifications to the original attenuation algorithm), these attenuation coefficients were re-set to 0.01 for TN, 0.22 for TP, and 0.11 for TSS. Table A4-1 shows the observed and final simulated loads (expressed as loading rates in kg/ha) for each of the calibration sites.

Table A4-1: Loads expressed in kg/ha

Calibration Watershed	HUC Size	Observed TN	Observed TP	Observed TSS	Simulated TN	Simulated TP	Simulated TSS
East Branch Brandywine	HUC10	18.63	0.60	702.0	22.86	1.00	515.8
Schuylkill River	HUC8	18.72	1.33	686.7	19.67	1.53	595.5
Lehigh River	HUC8	14.50	0.76	572.0	10.50	0.97	418.6
Wissahickon Creek	HUC10	19.33	1.19	775.0	11.77	0.74	842.1
Paulins Kill River	HUC10	5.65	0.20	326.0	7.51	0.29	271.5
East Branch Delaware River	HUC8	2.06	0.13	107.3	2.33	0.17	119.4

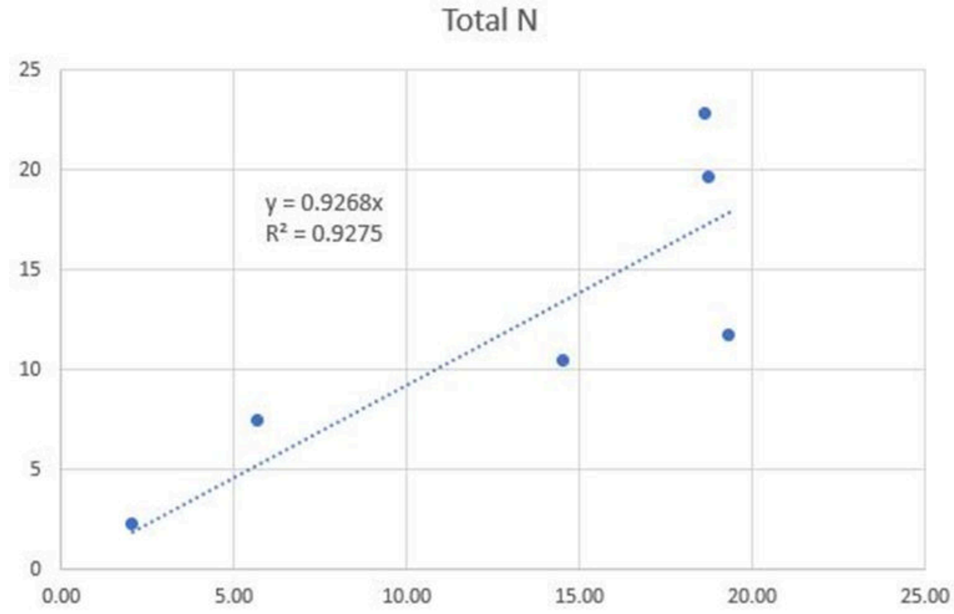

Figure A4-2: Observed vs simulated TN loads (kg/ha).

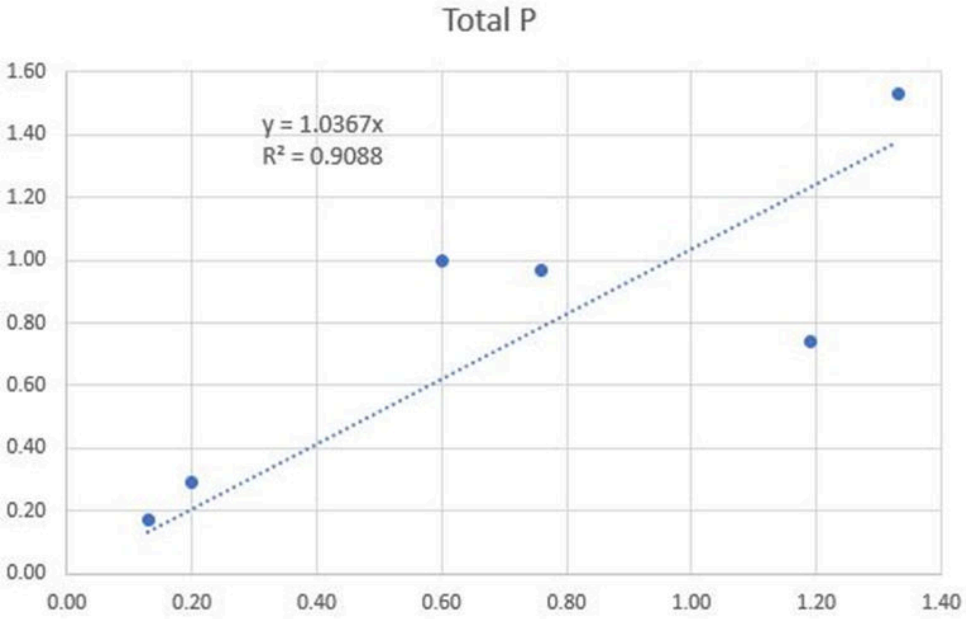

Figure A4-3: Observed vs simulated TP loads (kg/ha).

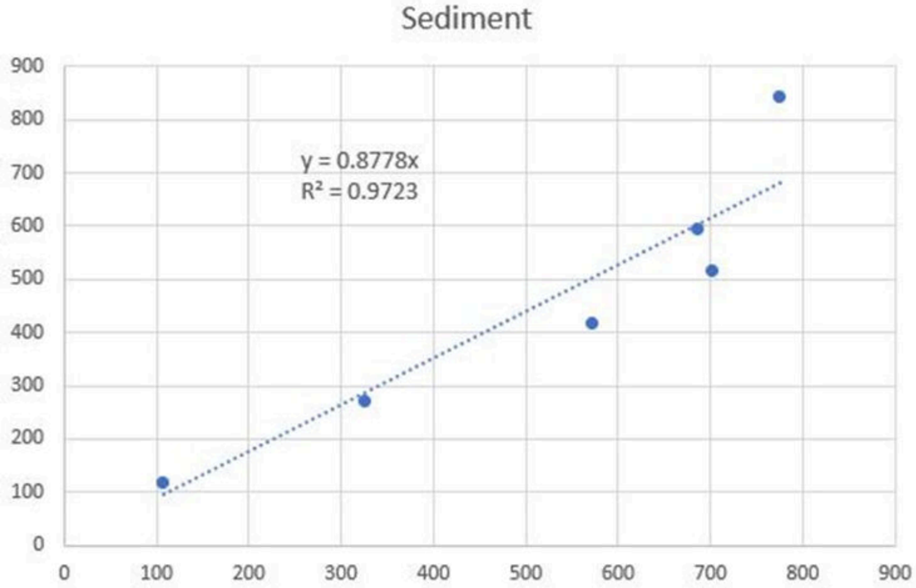

Figure A4-4: Observed vs simulated sediment loads (kg/ha).