DELAWARE RIVER WATERSHED INITIATIVE
POLLUTION ASSESSMENT

Stage 1: A Rapid Assessment for Contextual Framing for Strategy Review

Stage 1 Project Report
for the William Penn Foundation

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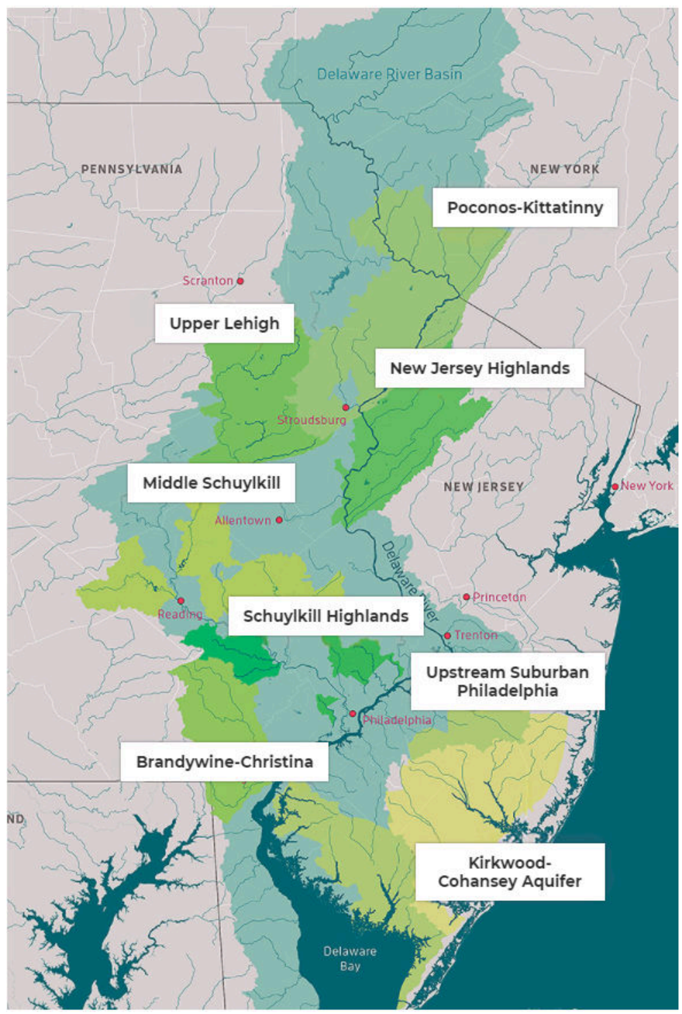
Executive Summary

The Delaware River Watershed Initiative

The Delaware River Watershed Initiative (DRWI; https://4states1source.org/) is a multidisciplinary collaboration of more than 60 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), facilitates 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 have worked since 2014 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 (see figure at right). These priority locations include 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.



A DRWI coordinating committee helps 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 include 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).

Project implementation and environmental outcomes are tracked and monitored at more than 300 locations across the basin. All organizations contribute 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 ~24,000 acres of protected forests and more than 900 best management practices, 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 prevent and/or reduce pollution in stormwater runoff, reduce flood risk and erosion, provide critical habitat for native flora and fauna, and help deliver cleaner water to rivers and streams throughout the basin (among other benefits).

The William Penn Foundation initially committed to supporting the DRWI for at least 10 years. In order to inform the Foundation and other stakeholders about progress after 7 years, 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 utilize water quality modeling tools to estimate the impact of water pollution reduction and forest protection strategies from these efforts and then relate these outcomes to broader estimates of total water pollution in the DRB. We specifically focus on the excess nutrients (nitrogen and phosphorus) and sediment that result from our 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). Efforts described here to quantify pollution reduction outcomes and forest protection success from these projects represents a first step (stage 1) in our assessment and will be refined over the next 10 months (stage 2) by improving our pollutant loading and cost estimates, improving our automation 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.

Goals and Objectives for Pollution Assessment

The overall goals of the DRWI Pollution Assessment are to:

A. Identify hotspots of excess nonpoint source pollution (nitrogen, phosphorus, sediment) in stream reaches and catchments of the Delaware River Watershed.
B. Quantify progress toward improving water quality by DRWI-style land protection and restoration activities, answering questions such as:
    - What fraction of excess nonpoint source pollution has already been reduced?
    - 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
    - Focus Areas

The DRWI Pollution Assessment has been intended to be conducted in two stages.

The **Stage 1 Pollution Assessment: Rapid Assessment**, reported here, was designed to:

- Provide contextual framing for WPF’s upcoming strategy review for DRWI.
- Complete in 4-5 months (June to October 2021)
- Develop from existing tools:
    - Model My Watershed (ModelMW)

    - Focus Area Evaluation Tool (FAET)
- Use datasets currently integrated into these tools:
    - Land cover from 2011
    - DRWI-only Conservation projects complete for Phase 2

The **Stage 2 Pollution Assessment: Refined Assessment**, proposed for 2022, is designed to:

- Provide more robust and dynamic assessment system for much more accurate future program assessments and conservation planning
- Complete in 12 months (2022)
- Update key datasets:
    - Land cover to 2019 product (2001-2019)
    - 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 refine focus area targets and opportunities, and to estimate costs and timelines (for all DRWI partners).
    - Iteratively re-do assessments based on changing input and targets/objectives

This Stage 1 Report describes findings from the rapid pollution assessment, in which the ModelMW underlying datasets and model and FAET concept were leveraged to produce estimates of:

- Nitrogen, phosphorus, and sediment annual loads from point and nonpoint sources (NPS) for catchments throughout the Delaware River Basin (Task 3), including:
    - Maps of hotspots for these pollution loads;
- Excess NPS pollution concentrations and loads that could be addressable by DRWI-style land protection and restoration activities (i.e., from nonpoint sources) (Task 3), where:
    - Excess NPS pollution was calculated based on the concentrations and area-normalized loading rates that exceed water quality threshold targets selected during this project (Task 1);
- Rough estimates of the costs and time required to achieve acceptable water quality targets by subbasin and by cluster (Task 4), including:
    - Identification of catchments where conservation efforts are not likely to improve water quality due to point source loads, including combined sewer overflows, overwhelming total loads from sources that can be mitigated by protection and restoration practices.

These analyses will provide the contextual framing the Foundation needs as part of its upcoming strategy review.

> This Stage 1 Rapid Pollution Assessment provides a first cut.

The Stage 1 Rapid Assessment has several important shortcomings that limit the accuracy of the findings. These shortcomings are due to the compressed timeline for completing a set of geospatial calculations not fully built into existing modeling tools and also due to outdated or incomplete datasets currently integrated into these tools. For this reason, we developed our two-stage pollution assessment proposal in spring of 2021 when the Foundation requested the Pollution Assessment, including postponing the requested update of land cover datasets (Task 2). A refined and much more accurate Pollution Assessment will therefore only be available at the completion of Stage 2 work, in September 2022.

Summary of Findings

Pollution Threshold Targets

Pollution threshold targets were established (Task 1) for nitrogen, phosphorus, sediment because their concentrations are typically elevated in impaired streams and the delivery of nutrients and sediment to downstream waters can drive eutrophication and other water quality issues. Nitrogen, phosphorus, and sediment occur naturally at certain levels in healthy streams, but impaired streams typically have substantially elevated concentrations of these pollutants. It is important to note that stream health is most commonly assessed for "impairment" by measuring diversity and abundance of biological communities (typically aquatic macroinvertebrates). The cause of impairment is typically determined by results from follow-up studies on potential stressors and "best professional judgment". Across the U.S., the cause of impairment is most commonly judged to be excess non-point source pollutants (nutrients and sediment), particularly in rural, agriculturally influenced locales (see USEPA National Rivers and Streams Assessment). Task 1 was to review the literature and other data sources in order to set threshold target concentrations and loads of nitrogen, phosphorus and sediment within the DRB and, more specifically, for DRWI-related projects in targeted geographies (i.e., clusters and focus areas within clusters).

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;
- **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 a study by Sheeder and Evans (2004). Streams and catchments below these threshold values are only 5% likely to be impaired.

Modeled Pollution

Pollution concentrations, sub-area loads and loading rates were estimated using Model My Watershed (https://modelmywatershed.org) and the Watershed Multi-Year Model (a.k.a. Mapshed or GWLF-E), which has become the watershed modeling system recommended by Pennsylvania Department of Environmental Protection (PA DEP).

> Phosphorus is the pollutant most often above threshold values in freshwaters.

For Task 3, we ran ModelMW for each of the 484 USGS Hydrologic Units at Code-level 12 (HUC12) in the DRB. These watershed model simulations were for baseline conditions without any restoration or protection activities (based on 2011 land cover).

The baseline model results show the spatial variability and distribution of pollution (Table 4, Figure 3). As expected, the highest loads occur in areas where agricultural activities, urban development, and point source discharges predominate.

Total phosphorus was the pollutant with baseline loads most often above threshold target values for streams and rivers in the DRWI. This is true for the majority of freshwater systems throughout the world. As such, most water quality mitigation efforts throughout the nation focus on reducing phosphorus loads. Fortunately, many water quality restoration and protection practices also reduce nitrogen and suspended sediments, so once watershed targets are met for phosphorus, they are most commonly also met for nitrogen and suspended sediments.

We therefore focus this Pollution Assessment report primarily on phosphorus.

Total nitrogen levels were below threshold target values for both stream reaches and catchments for most of the DRWI area (i.e., green or yellow in Figure 3). Although nitrogen is typically the most important pollutant when considering water quality impacts to an estuarine system such as Delaware Bay, it was not the focus of this particular assessment that addressed pollutant loads in sub-watersheds draining to the Bay.

Total suspended sediment (TSS) loads occasionally exceed threshold values (primarily in areas with extensive urban development).

Hotspots of Excess Nonpoint Source Pollution

Excess pollution is the amount of pollution above threshold target values established in Task 1. Streams and their catchments that have positive values of excess pollution are likely impaired. Excess pollution values also indicate how much pollution needs to be reduced to improve water quality to a level that the stream is no longer impaired.

Nitrogen and phosphorus pollution have point sources – such as waste water treatment plants (WWTP) – that are actively and effectively 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. DWRI thus focuses exclusively on reducing and preventing nonpoint sources of pollution. To estimate the amount of pollution that is addressable by DRWI-style restoration and land protection activities, we must subtract out the point source pollution from the excess pollution.

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

For Task 3a and 3b, we calculated excess pollution and excess nonpoint source pollution. Model My Watershed was not designed to directly make these calculations, so we downloaded model runs for the entire DRWI area and processed them through model algorithms developed for the Stream Reach Assessment Tool (SRAT) and utilized for the Focus Area Evaluation Tool (FAET). We then used these outputs to perform all subsequent Pollution Assessment calculations outside the modeling system. We were able to perform most of these calculations with precision, but some calculations required substantial simplifications or were not even

> Excess nonpoint source
> = pollution above threshold
> minus treated waste waters

possible without modifying the core models (i.e., ModelMW or SRAT). For the Stage 2 Pollution Assessment, we have proposed to modify the core models to properly 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.

Hotspot maps of excess pollution (Figure 4) show that the majority of stream reaches and catchments in the DRWI area are below threshold values (shown as green). This is especially true for nitrogen and suspended sediment. Phosphorus concentrations are above threshold values in hotspot maps (shown as yellow, orange, and red) for the central portion of the DRWI area. We believe that this analysis represents the first time excess pollution has been calculated and mapped for the DRWI in such a spatially explicit manner.

A comparison of excess pollution with excess nonpoint source pollution (Figure 5) shows that catchments with the "hottest" pollution loads are those with large point sources. These are most noticeable when the maps are zoomed to Task 3 Results by Cluster and Focus Area, and viewed by clicking through the Stage 1 Report Executive Summary Slide Deck.

Fortunately, these large point sources are typically downstream of DRWI restoration protection activities and do not detract from their benefits. Furthermore, large point sources are actively being reduced with federal, state, and municipal funds.

Remaining Excess Nonpoint Source Pollution after Reductions by Restoration

For Task 3C we ran a second set of simulations that incorporated the pollution reductions from each of 918 DRWI restoration practices implemented in Phase 1 and Phase 2 of DRWI activities (Table 2). Detailed information for each of these DRWI restoration practices were tracked in the FieldDoc web application, and exported for use in this pollution assessment (See Task 3: Project Tracking).

Restoration pollution reductions were calculated using ModelMW algorithms, applied to the stream reach and catchment at the project site(s), and routed and attenuated downstream through the stream network using SRAT algorithms. Pollution avoided due to land protection projects were analyzed separately from this analysis of remaining excess pollution and presented below.

Hotspot maps of remaining excess nonpoint source pollution for the entire DRWI (Figure 6) display important differences relative to excess pollution maps (Figure 4) and XSNPS pollution maps (Figure 5). These differences are more easily discerned in hotspot maps zoomed to DRWI Clusters showing the Focus Areas (Task 3 Results by Cluster and Focus Area), where the majority of DRWI restoration projects were implemented. We recommend viewing differences by clicking through the Stage 1 Report Executive Summary Slide Deck.

Note that these hotspot maps represent an incomplete picture of all pollution reductions due to DRWI-style restoration activities. Restoration reductions are at least 7-10 times larger than from restoration projects funded by DRWI.

> Pollution reductions are likely 7-10 times higher if we consider all funding sources beyond DRWI.

Avoided Pollution by Land Protection

Land protection activities, such as those funded via DRWI, essentially maintain "natural" land cover conditions in protected areas for a variety of water quality-related reasons, including the prevention of future development in unique and sensitive areas. While such activities do not necessarily reduce pollutant loads in a given area, land protection can result in smaller future loads in areas that might otherwise be developed. In this study, these are referred to as “avoided” loads.

For Task 3C, we calculated the cumulative total avoided loads from 54 DRWI land protection projects that were tracked in the FieldDoc web application, covering 9,794 hectares (24,201 acres) of natural lands (Table 3), primarily within three clusters (Kirkwood - Cohansey Aquifer, Poconos and Kittatinny, and Upper Lehigh). For this Stage 1 Rapid Assessment, we applied the simple presumption that these lands might someday be built-out 100% with medium-density development. For the Stage 2 Refined Assessment, we will use future land-use projections following the approach developed by OSI for the Land Protection Impact Assessment (LPIA).

Results from avoided loads were not displayed in hotspot maps, as they were focused in areas that did not have any excess pollution load. In other words, land protection projects were designed to keep areas on the maps that are shown as green to stay green forever.

Avoided pollution loads can be quantified for each catchment, aggregated by geography, and compared to reduced pollution loads from restoration. These aggregated results are presented with Task 3D, below.

Aggregate Pollution Loads by Geography

Pollution is naturally accumulated within watersheds as it is transported downstream, mixed with incoming tributaries, and then attenuated over time by natural processes such as biological uptake, de-nitrification and sediment deposition both within the aquatic system (i.e., streams, reservoirs, lakes), and also within adjacent terrestrial systems (i.e., wetlands, floodplains, and other riparian ecosystems). As a result, the impact of a pollutant load from a particular source decreases the farther it travels downstream from the source. This is especially true for phosphorus and sediment, where attenuation commonly reduces in-stream loads by 10 to 90 percent, depending on the distance traveled and the degree to which such loads are intercepted by quiescent water bodies such as reservoirs, ponds and wetlands.

Our Stage 1 findings do not account for this downstream routing and attenuation when aggregating results, because our calculations of excess pollution and excess nonpoint source pollution were run outside the modeling system, as described above. For Stage 2, the modeling system will be improved so that aggregation of results will take into account routing and attenuation.

For Task 3D, we aggregated results for each pollutant by simple summation over the entire DRWI (Tables 6, 7, 8) , by Cluster, and by Focus Area (Task 3 Results by Cluster and Focus Area). As phosphorus pollution is the pollutant in greatest excess throughout the DRWI, we will focus on Total Phosphorus (TP) results for this summary.

Point sources of TP accounted for about 64% of the total load DRWI-wide (or about 56% of the load delivered to Delaware Bay after attenuation), and ranged between 22% to 72% of the source load within clusters (Table 7). Properly accounting for the downstream routing and attenuation of point sources in Stage 2 will be critical for mapping where it is not possible to improve water quality by reducing or avoiding nonpoint sources of pollution (a goal of this Pollution Assessment). Point sources are geographically concentrated, which appear only as small red dots in hotspot maps of catchments, yet their impacts extend far downstream, which do not appear on our Stage 1 hotspot maps of stream reaches.

The 918 DRWI-funded restoration projects reduced approximately 6.2% of the excess nonpoint source TP pollution load over the entire DRWI-area or about 6% to 14% within clusters (Table 7). This equates to roughly 16,106 kg (35,508 lbs) at the local level. Within Focus Areas, which ranged in size from about 900 to 5,000 ha (2,220-12,350 acres), the benefits of restoration were much more dramatic (Task 3 Results by Cluster and Focus Area). DRWI-funded restoration projects within three Focus Areas reduced more than 100% of excess nonpoint source TP pollution, and reductions within 13 Focus Areas were more than 20%. The proportion of excess nonpoint source pollution remaining is the balance of the proportion reduced, as presented in the percentages above and in Table 7.

The 54 DRWI-funded land protection projects avoided 11,942 kg (26,328 lbs) of TP pollution over the entire DRWI area, or equivalent to 74% of the reductions from restoration (Table 7). Land protection projects targeted areas with health watersheds that already meet threshold targets, and in the three DRWI clusters that prioritized land protection, those benefits were equivalent to 151% to 277% of the reductions from DRWI restoration projects. This represents a significant impact on preserving water quality for these and downstream areas. Given that land protection projects targeted clean watersheds that typically did not have excess pollution, it is not appropriate to include them in calculations of remaining pollution.

Projected Restoration Costs

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 was estimated by a manual optimization process (Table 11). Phosphorus pollution was first reduced as much as possible with the least expensive rural restoration and Best Management Practices (BMPs). Remaining sediment pollution was then addressed with streambank restoration and urban stormwater practices. Excess, nonpoint source nitrogen pollution was fully reduced by addressing the other pollutants. These costs assume that point source loads would be addressed through regulatory requirements.

DRWI-style restoration – such as $165M for riparian forest buffers in croplands and $55M for animal waste management systems – could together reduce 96% of the excess nonpoint source phosphorus. Urban stormwater practices and streambank restoration could together reduce all remaining pollutants for $214M. These costs are presently being borne by developers, cities, and state governments. The total estimated cost of $434 million also does not take into consideration load reductions that have already been achieved through the implementation of BMPs funded by other entities such as state and federal agencies (e.g., PADEP, USEPA, NRCS, etc.), municipalities (as required by existing or updated NPDES permits or state requirements), and various other private groups and foundations.

> $218M in DRWI-style restoration eliminates 96% of remaining excess nonpoint phosphorus.
>
> How much of this is already done by others?

It is our intent in Stage 2 to compile readily available information on the type and extent of these “other” existing urban and rural BMPs in order to better estimate total load reductions that are, and have been, occurring as a result of these “missing” BMPs. Based on some knowledge of previously-implemented BMPs, it is estimated that the extent of such BMPs is perhaps 10 times the amount funded by DRWI, and that pollutant loads within the DRB may be 10-20 percent less than those modeled as part of the current study, which suggests we have overestimated remaining costs. However, future climate and future land cover changes may together increase future costs. We will consider such changing future conditions for our Stage 2 Pollution Assessment.

Remaining land protection costs have not been estimated for this Stage 1 assessment, as it also requires consideration of projected future land use change and future real-estate costs. We will more thoroughly address projected protection costs for Stage 2, including considering the federal initiative to protect 30% of our nation's lands by 2030.

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 similar costs for the Connecticut River Basin will be in the range of $4-5 billion. These costs include reductions to point sources.

Contributors and Acknowledgments

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LimnoTech contributors included Anthony Aufdenkampe and Sarah Jordan.

Stroud Water Research Center contributors included David Arscott.

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 this project.

Task 1: Establish Pollution Threshold Targets via Literature Review

Description of Task 1

Establish credible external thresholds for the three focal "nonpoint source" pollutants (phosphorus, nitrogen, and sediment) from among those already recommended by the EPA or other reputable researchers to define "healthy" water vis-à-vis these pollutants (please see disclaimer, below).

A. We will review the scientific literature, state and federal stream water quality criteria, information from several TMDL studies, and other materials to arrive at recommendations for NPS annual load or average concentrations that define acceptable values or ranges.
B. *Disclaimer*: there is no definitive concentration/load(s) for nitrogen, phosphorus, or sediment that has been identified by the federal, state, or scientific community that defines a "healthy stream". Most federal and state regulatory programs designed to reduce nonpoint source pollutants (i.e., TMDL programs) state: "The ultimate goal of implementing the TMDLs is to restore the water quality of all streams to the point that they achieve the state's water quality standards and are removed from the state's listing of "impaired" streams. It is unknown whether the pollutant reductions stated within the TMDLs will be sufficient (or if they overstate) reductions needed for all streams to meet their state water quality standards and be removed from the state's listings of "impaired" streams {emphasis added}. If the TMDL reductions are fully

achieved, but the streams remain impaired, then USEPA and/or PADEP will establish further TMDLs to be implemented until the streams achieve the state's water quality standards."

Background

Water quality criteria for pollutants can be set either by the pollutant concentration or by the pollutant load. These are different quantities, the choice to use one or the other depends on the designated use for the water body (i.e., drinking water vs. swimming) or the purpose for the criteria (i.e., health to aquatic life vs. human health when consuming aquatic organisms). A pollutant concentration represents an instantaneous property of the water, whereas a pollutant load typically represents a long-term average (e.g., annual average). It is important to understand the differences between concentrations and loads.

Concentration is a measure of pollutant amount per unit water volume, often in units of milligrams per liter. Concentrations are typically directly measured by monitoring studies, and each measurement represents an instantaneous snapshot of the conditions in that water body at that specific time. Concentrations are directly comparable from one location to the other. However, concentrations vary with weather, by season, and even between day and night. Therefore, repeated measurements over long time periods are required to assess the average water quality for a site, and monitoring periods of more than a decade are typically necessary to detect changes in water quality.

Load is a measure of pollutant amount per unit time, often in units of kilograms per year. Loads can be calculated from a time series of monitoring concentration and also water flow, as loads equal concentrations multiplied by flow. Because most of the water leaves a watershed during storms, and because concentrations vary rapidly during storms, calculating loads requires high-resolution monitoring data that requires substantial effort to collect (Figure 1). A load represents transport to downstream water bodies and is therefore used to to estimate the proportion attributable to different sources. Such calculations are best accomplished with a watershed model. Modeled loads better represent long-term average conditions. Note that loads get larger as watersheds get larger, and are therefore not directly comparable from one site to the next. A **loading rate**, or yield, that normalizes a load by watershed area, often in units of kilograms per year per hectare, is used to compare pollution sources among different areas.

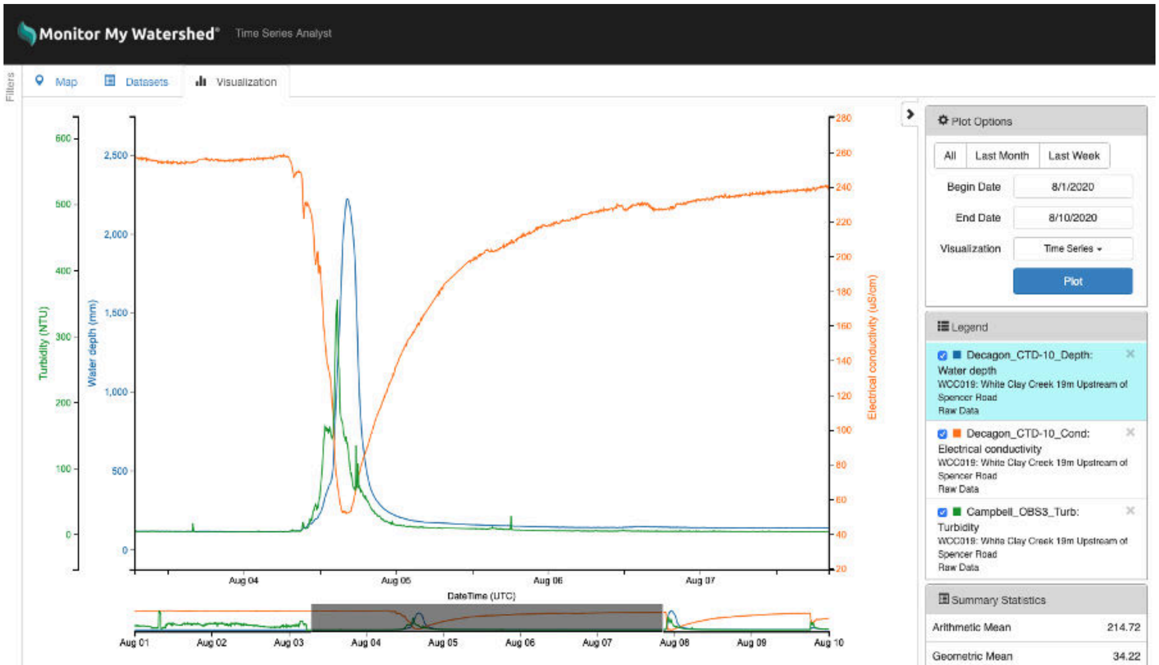


Figure 1. Turbidity concentrations (green), conductivity concentrations (orange), and water depth (blue; a proxy for water flow) monitored continuously during a typical storm, to illustrate the complications of calculating mean annual concentrations or loads from monitoring data (i.e., continuous monitoring would be required).

Since its inception the DRWI has focused on evaluating long-term water quality conditions that promote “healthy” streams and aquatic community health. Beginning in 2017 during the planning of Phase 2, the DRWI has relied on understanding pollution sources to most effectively target restoration and protection activities. As such, the DRWI Pollution Assessment will quantify water quality as assessed by average annual pollutant loads estimated from watershed modeling. These loads can in turn be used to calculate long-term average concentrations. However, such concentrations largely reflect conditions simulated during storms and can not be directly compared to monitoring data that is most commonly collected during baseflow. Monitoring data is indispensable for understanding the conditions for aquatic life, but it has not yet been collected for sufficient time to detect change due to DRWI activities.

Note that this assessment did not consider water quality conditions in Delaware Bay itself, which would require additional use of an “estuarine model” to determine “acceptable” pollutant loads delivered to the Bay (primarily nitrogen) for the purpose of achieving “healthy” water quality therein.

As described above, modeling results based on the use of Model My Watershed and other related tools are used as the basis for most of the analyses conducted as part of this assessment. Although in-stream monitoring would be useful for making comparisons between existing stream conditions and threshold water quality values, the extensive amount of monitoring data needed to make such comparisons over hundreds (if not thousands) of stream reaches (with each having up to a hundred samples or more representing a wide range of precipitation events over all seasons) would be prohibitively expensive. Consequently, simulation modeling based on good underlying datasets representing known landscape, terrain, weather, and other conditions is typically used and preferred. Also, monitoring data do not provide useful information on the sources of various pollutant loads (e.g., point sources, agricultural land, farm animals, urban developments, etc.), whereas modeling predictions do.

Pollution Thresholds

To help support the evaluation of “excess pollution” with respect to nitrogen, phosphorus and sediment loads within the DRB, a review of recent reports on threshold values that represent transition points between “impaired” and “non-impaired” streams was undertaken. 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) 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;
- **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 a study by Sheeder and Evans (2004). Streams and catchments below these threshold values are only 5% likely to be impaired.

Table 1. Pollution Threshold Values for Impaired Streams

Pollutant	Target Concentration (mg/L)	Target Loading Rate (kg/ha/y)
Total Nitrogen (TN)	4.725	17.07
Total Phosphorus (TP)	0.09	0.31
Total Suspended Sediment (TSS)	237.3	923.8

Task 2: Update Land Cover Data (Postponed to Stage 2)

Description of Task 2

Update the underlying land use/cover data at the one-meter or 30-meter level. Please provide a summary explaining the limitations and costs associated with using the 2011 vs 2016/2019 data sets, as well as the differences between the 1m and 30m data sources. In addition, please comment on the potential for sharing the costs of updating the landcover data to either 1m/30m for 2016/2019 with PA DEP.

Rational For Postponing

- We have previously presented/described the possibility of creating a "hybrid" land cover dataset at 10-meter resolution derived from a "merge" of the high-resolution land cover data layer (1-meter) produced by UVM and Shippensburg and the National Land Cover Dataset (30-meter) [work would be led by C. Jantz at Shippensburg and P. Claggett from USGS]. However, that work would be outside the cost structure of this contract. Further, the TUG may recommend that our use of land cover data sets to inform water quality modeling should remain sourced from federally available data that are regularly updated by federal agencies.
- Additional note: ANS and Stroud are currently funded by PADEP to update Model My Watershed land cover data sets to the 2016 and 2019 products. We anticipate that this work will be completed by December 2021.

Task 3: Develop a Pollution Assessment with DRWI Modeling and Data Tools

Description of Task 3

Use the updated models to:

A. Identify "hotspots" across the basin where modeled NPS levels exceed the identified thresholds for healthy waters.
   a. First, we will utilize NPS loads estimated from the Focus Area Evaluation Tool that are specific to the 2011 National Land Cover Database and available for all NHD+ subwatersheds and linked in the nested hierarchy of progressive watershed size with an "attenuation algorithm" to account for downstream attenuation of NPS sourced from upper watersheds.
   b. Second, we will utilize values/metrics/ranges of NPS loads/concentrations that define "healthy water quality" (section 1 above) to determine the differentials between 2011 loads and "healthy WQ". These differentials will then be presented geographically across the DRB to illustrate "hot spots" of areas exceeding the "healthy WQ" criteria and those subwatersheds with high WQ (thus, those areas that may be important for land protection)
B. Estimate the amount of excess nonpoint and point source pollution contributing to each hotspot and identify subwatersheds where point source loads override the ability of nonpoint source pollution interventions (i.e., non-urban BMPs) to achieve the "established" DRWI healthy water thresholds.
   a. This analysis will utilize output from 3.a. (above) to determine the load/concentration attributed to point sources and provide the ratio of non-point source - to - point source load.
C. In order to address the question "What proportion of the NPS within the cluster boundaries could be addressed by DRWI land protection and ag restoration tactics", the remaining load

(non-point source load) that is in excess of the “healthy WQ” criteria will be compared to the cumulative load reductions from all DRWI BMP investments that have been tracked to date (reported to FieldDocs).

a. We will address this question more thoroughly in Stage 2. However, in Stage 1 (herein), we will provide an estimate of the load reductions needed in cluster areas to achieve “healthy WQ”. Further, we will estimate a range of costs/investment needed to achieve “healthy WQ” based on at least one of the following: 1) total dollars invested by WPF for DRWI to achieve the currently estimated load reductions; 2) total cost of BMP implementation reported in FieldDoc by partners (data may be incomplete); or 3) a derived average cost per pound reduced for a suite of BMPs that are estimated by the Chesapeake Bay Foundation’s Cast database

D. Aggregate pollution estimates from all hotspots to produce subbasin (HUC 12) and DRWI cluster-specific estimates of 1) total NPS average annual loads, 2) non-point NPS average annual loads and 3) point-source NPS average annual loads.

a. This will be done in conjunction with 3.a.i (above).

Background

Project Tracking

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.

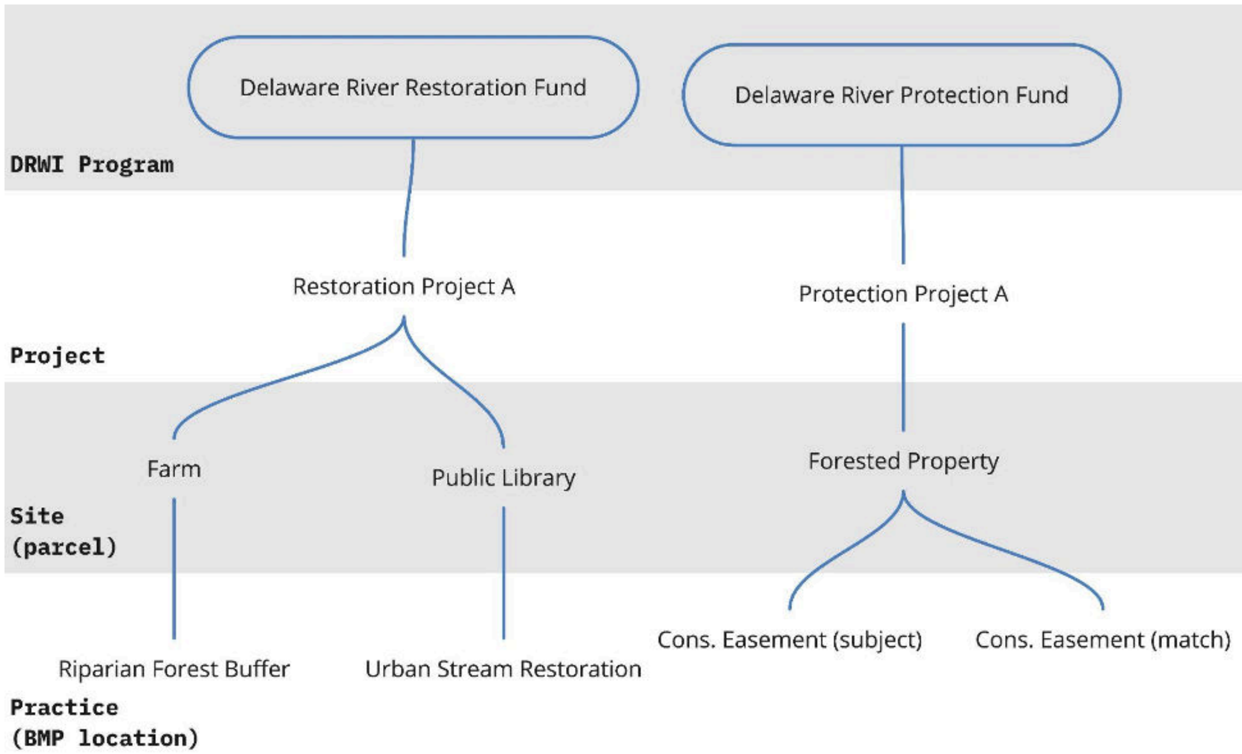


Figure 2. DRWI Program-Project-Site-Practice hierarchy that is tracked by FieldDoc and required for this Pollution Assessment. A single grant program defined by a funder can provide many projects managed by grantee(s) to implement one or more conservation practices (Best Management Practice(BMP), conservation easement or fee acquisition) on one or more land parcel sites.

Restoration Projects

The DRRF projects and restoration practices (i.e., BMPs) within this analysis include DRWI Phase 1 and 2 projects funded and implemented between 2014 to present day, totaling 918 modelable BMP practices across the DRWI restoration and hybrid strategy sub-watershed clusters and their respective focus areas. These 918 BMPs represent 622 completed (installed and fully implemented) and 296 active (not yet completed) practices. 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 918 BMPs fall within 55 BMP practice types. Modeling methods and documentation can be found in *Appendix A*. Below is a table showing the top 10 implemented BMPs and respective counts. Modelled BMP definitions can be found in *Appendix B.*

Table 2. DRWI restoration projects from Phase 1 and 2, by type of Best Management Practice (BMP).

BMP Type	Count
Cover Crop	120
Riparian Forest Buffer	72
Bioretention	54
Heavy Use Area Protection (for farm animal operations)	53
Bioretention/rain gardens - A/B soils no underdrain	49
Forest Buffer	49
Waste Storage Facility	49
Forest Buffer - Streamside with Exclusion Fencing	41
Non-Urban Stream Restoration	41
Roof Runoff Structure	35

Protection Projects

Protection projects within this analysis include DRWI Phase 1 and 2 DRWPF Forestland Capital Grants projects that have closed or are approved for funding (active) between 2014 to present day, along with active projects that have been entered into FieldDoc. Note that many active projects have not yet been entered into FieldDoc, and for Stage 2 we will work with OSI to add all active protection projects to FieldDoc.

Land protection projects fall within two major categories: Conservation Easements and Fee Acquisitions. All DRWI and DRWFP land protection projects fall within DRWI clusters and most within their respective focus areas.

Table 3. DRWI protection projects from Phase 1 and 2, by type, area and project status.

Protection Type	Status	Count	Area (hectares)	Area (acres)
Conservation easement	closed	29	7,004	17,308
Conservation easement	active	1	491	1,214
Fee acquisition	closed	22	2,188	5,406
Fee acquisition	active	2	111	273
All	**All**	**54**	**9,794**	**24,201**

Modeled Baseline Pollution

Water quality problems throughout the Delaware River Basin (DRB) are caused by pollutant loads delivered to streams, ponds and other water bodies from a number of point and nonpoint sources. Within the DRB, point sources include both municipal and industrial wastewater treatment systems. For the purposes of this assessment, the pollutants of primary concern from point sources are nitrogen and phosphorus. With respect to non-point sources, the pollutants of primary concern are nitrogen, phosphorus and sediment. These pollutants can come from any area on the landscape, but the largest loads typically come from developed and agricultural land that is cultivated and/or contains large populations of farm animals such as dairy and beef cows, poultry, pigs, etc. Another important nonpoint source includes eroded streambanks, particularly those downstream of highly-developed areas. In this latter case, excess runoff from impervious surfaces has been shown to cause extreme erosion of stream banks due to higher water volumes after heavy rainfall events.

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. Table 4 provides the distribution of pollutant loads within the DRB as determined using the results from ModelMW. In terms of their spatial distribution, these loads are highest in areas where agricultural activity and urban development dominate. It should be noted here that the loads shown in this table represent "attenuated" loads as delivered to Delaware Bay. That is, they account for in-stream losses due to deposition, plant uptake, de-nitrification, etc., and are somewhat less than those loads given in Tables 5, 6 and 7, which do not account for attenuation. In general, attenuated load estimates are more useful when trying to determine pollutant reductions that might be necessary to alleviate water quality issues in the Bay itself, whereas un-attenuated load estimates are more useful when addressing potential impacts on local streams, as is the primary focus of the work described in this report.

As can be seen in Table 4, 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 shown in Table 4. 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 A-2 in Appendix A.

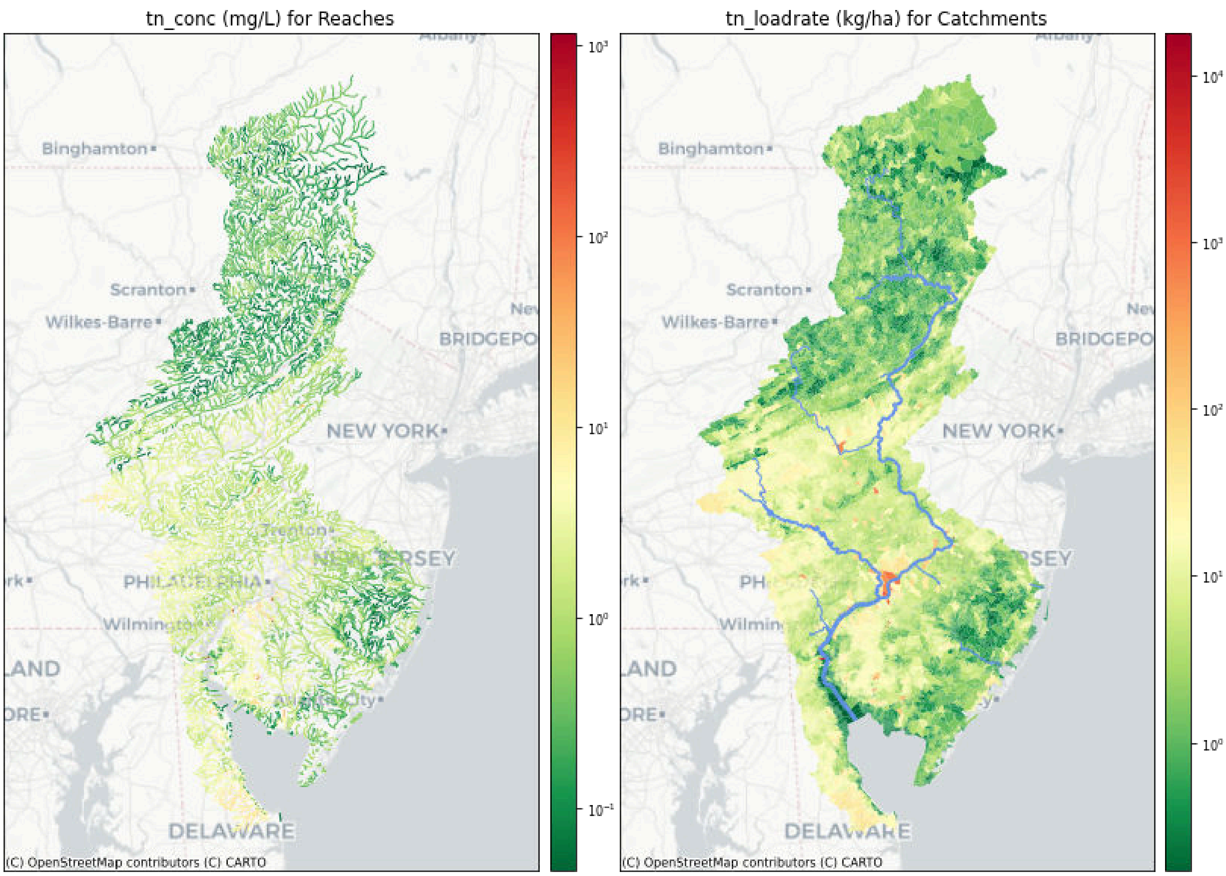
Following this table are a series of maps that graphically illustrate the distribution of pollutant loads and concentrations in different areas across the DRB.

Table 4. Distribution of pollutant loads within the DRB, representing the sum of the attenuated stream loads discharging from each of twelve HUC-8 areas that drain the DRB, estimated from subbasin modeling with Model My Watershed.

Source	TN Load (kg/yr)	% of Total DRB TN Load	TP Load (kg/yr)	% of Total DRB TP Load	Sediment Load (kg/yr)	% of Total DRB TSS Load
Hay/Pasture	256,339	0.60	94,478	3.17	24,516,768	1.70
Cropland	1,694,328	3.95	437,709	14.70	288,724,776	20.02
Wooded Areas	177,197	0.41	10,916	0.37	2,669,478	0.19
Wetlands	101823	0.24	3,322	0.11	166,382	0.01
Open Land	14,651	0.03	1,242	0.04	884,440	0.06
Barren Areas	5,218	0.01	148	0.00	7,266	0.00
Low-Density Mixed	62,114	0.14	5,448	0.18	2,086,385	0.14
Medium-Density Mixed	140,175	0.33	12,051	0.40	5,643,191	0.39
High-Density Mixed	65,394	0.15	5,738	0.19	2,565,312	0.18
Low-Density Open Space	116,645	0.27	10,260	0.34	4,067,696	0.28
Farm Animals	1,245,534	2.90	248,034	8.33	0	0.00
Stream Bank Erosion	688,660	1.60	284,649	9.56	1,110,812,503	77.03
Subsurface/Groundwater Flow	17,105,336	39.83	197,284	6.63	0	0.00
Point Source Discharges	20,945,465	48.77	1,666,567	55.97	0	0.00
Septic Systems	328,310	0.76	0	0.00	0	0.00
TOTALS	**42,947,189**	**100.00**	**2,977,846**	**100.00**	**1,442,144,197**	**100.00**

Modeled baseline pollution concentrations and load rates are displayed as hotspot maps in Figure 3. Threshold values set to yellow, with stream reaches (in left panes) and catchments (in right panes) that are colored orange or red having values that exceed thresholds. Green reaches and catchments have values below thresholds.

The baseline model results show the spatial variability and distribution of pollution (Table 4, Figure 3). As expected, the highest loads occur in areas where agricultural activities, urban development, and point source discharges predominate.



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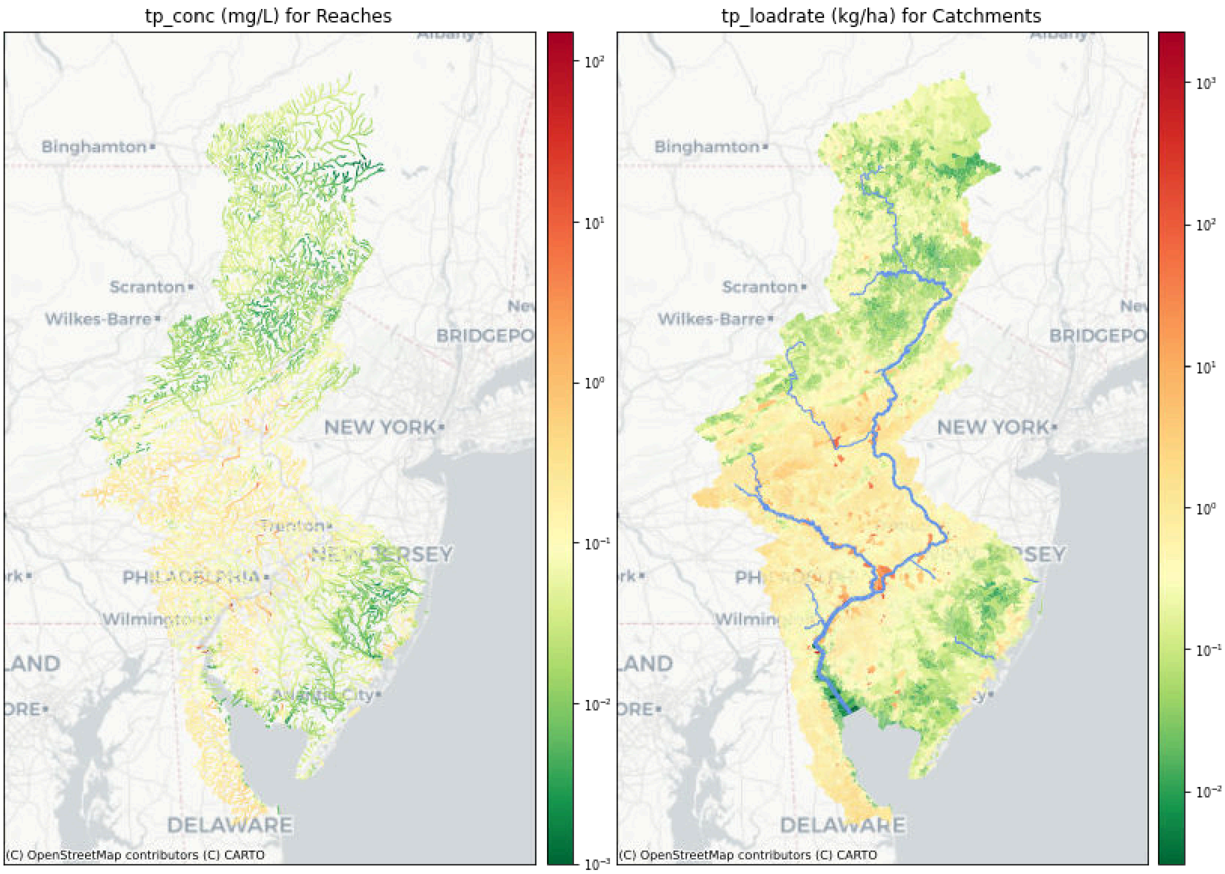
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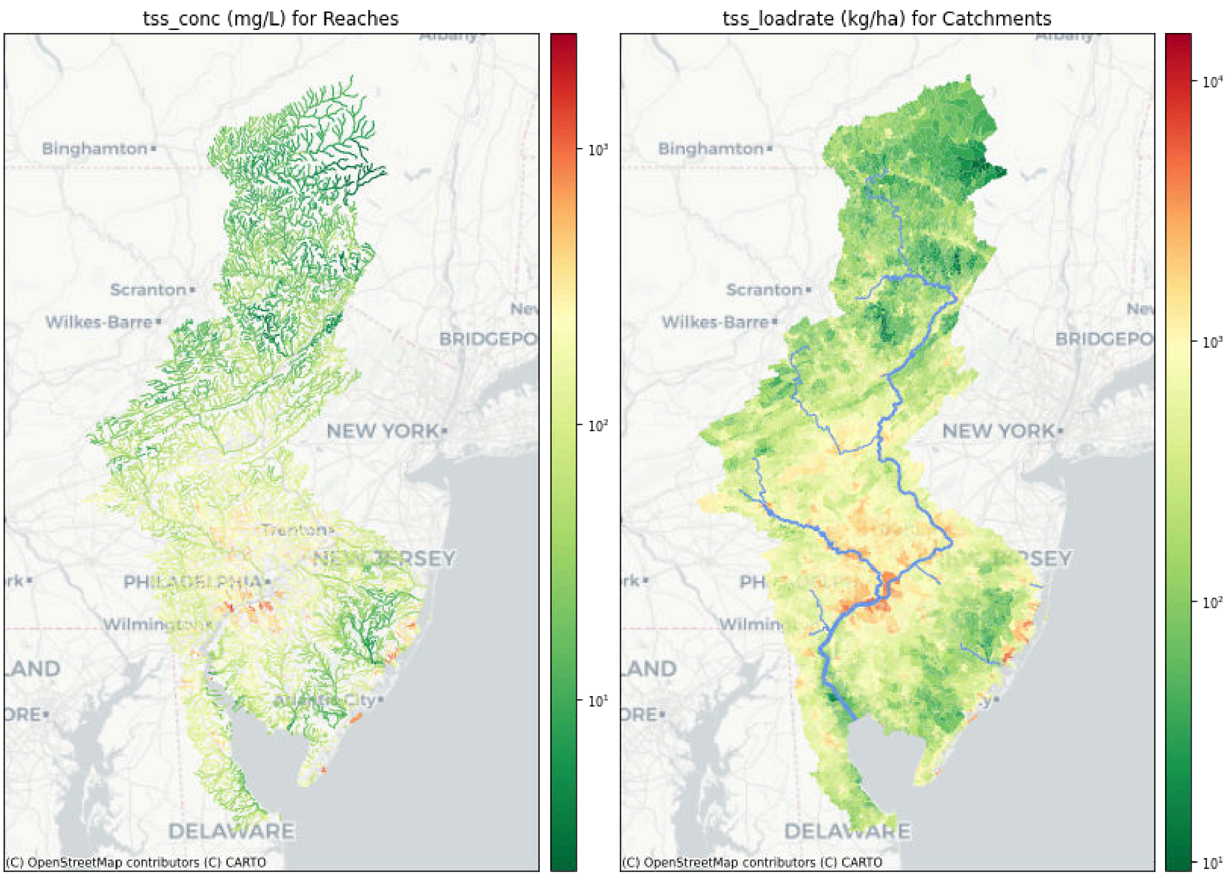


Figure 3. Hotspot maps for the entire DRWI area for stream concentrations (left) and catchment load rates (right), for (A) total nitrogen, (B) total phosphorus, and (C) total suspended sediments. Color bars are set on a log scale (i.e. 10^1=10, 10^2=100, 10^3=1000) with green set to the minimum value, yellow set to the threshold target, and red set to the maximum value.

In freshwater systems such as these (typically local streams and ponds), phosphorus and sediment loads are typically the cause for impairment. Although excess phosphorus and sediment are more important than sediment with respect to local water quality impacts throughout the DRB, it should be noted that restoration practices funded by DRWI (and others) also reduce nitrogen loads delivered to the Bay, thereby helping to mitigate water quality problems there as well.

Typically nitrogen concentrations alone do not cause aquatic life impairments in streams/rivers (high total nitrogen may cause impairment for drinking water uses). Once nitrogen is elevated somewhat, it can drive some excess algal growth (on the stream bottom), but algae quickly become limited by phosphorus concentrations. The constant flushing action of the streamflow can abrade and remove excess algae (unless in drought conditions with very low flows). In lakes and estuaries, nitrogen can drive higher algae concentrations (especially when phosphorus loading is also high) and excess planktonic algae growth then dies and consumes oxygen as it decomposes, this causes "dead zones'' where aquatic life does not have enough oxygen (especially in areas with little/no current). In streams/rivers the constant flow re-aerates oxygen in the water column, thus preventing oxygen depletion.

3A. Hotspots of Excess Pollution

Task 3A: Identify "hotspots" across the basin where modeled NPS levels exceed the identified thresholds for healthy waters.

Excess pollution is the amount of pollution above threshold target values established in Task 1.

Excess pollution = modeled pollution – threshold value

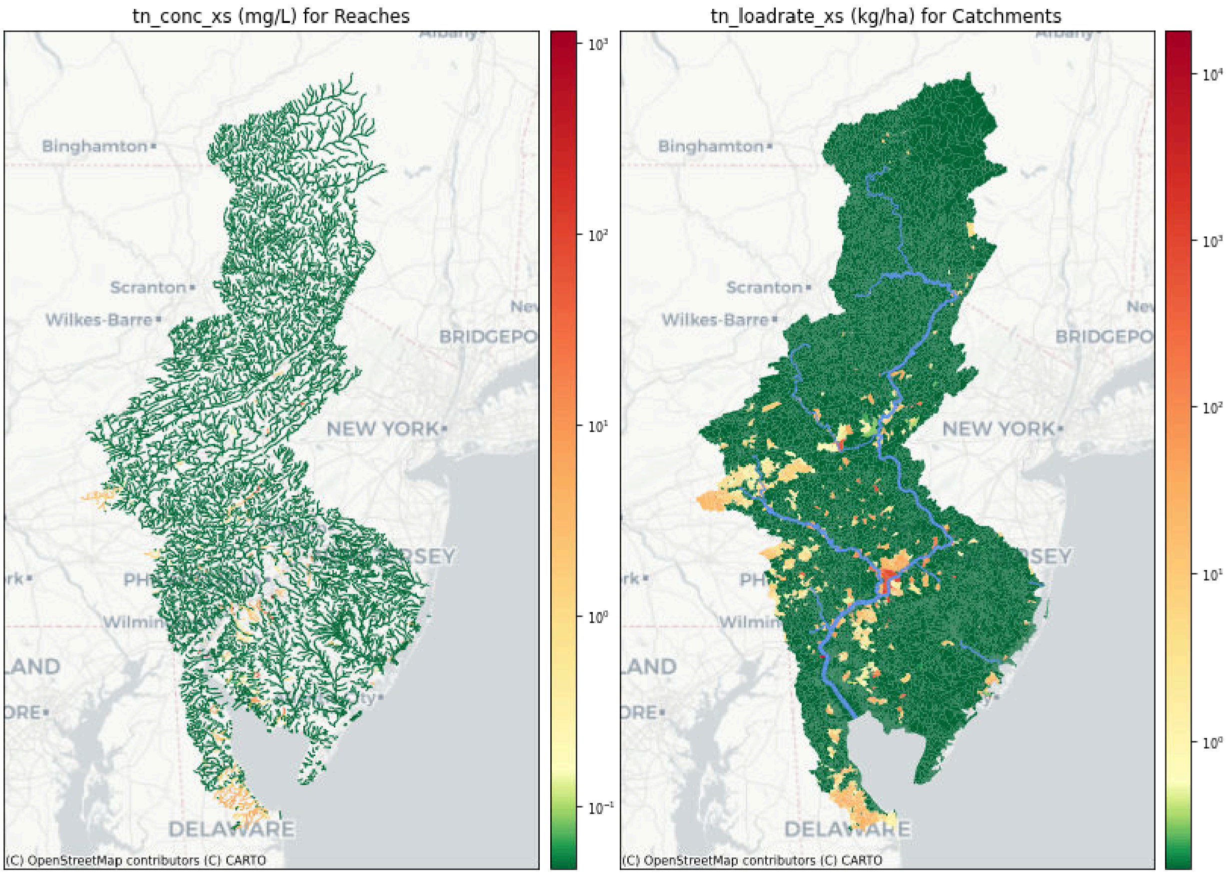
Modeled and excess pollution both include nonpoint source pollution.

Streams and their catchments that have positive values of excess pollution are likely impaired. Excess pollution values also indicate how much pollution needs to be reduced to improve water quality to a level that the stream is no longer impaired.

Model My Watershed was not designed to directly make these calculations, so we downloaded all 484 model runs and processed them through model algorithms developed for the Stream Reach Assessment Tool (SRAT) and utilized for the Focus Area Evaluation Tool (FAET), which distribute results down to the 19,496 stream reaches and catchments defined by the National Hydrography Dataset Plus version 2 (NHDplus v2) and within the DRWI area. The SRAT model algorithms include routing pollution from one stream reach to the next, both accumulating pollutants downstream and also simulating attenuation due to natural processes. We then downloaded these outputs to perform all subsequent Pollution Assessment calculations outside the modeling system. We were able to perform most of these calculations with precision, but some calculations required substantial simplifications or were not even possible without modifying the core models (i.e., MMW or SRAT). Most importantly, because existing SRAT model algorithms do not independently keep track of pollution loads from each contributing source (e.g., point source pollution or loads from cropland) as these loads are accumulated, mixed, routed and attenuated through the stream network, we were not able to calculate the concentrations of excess nonpoint source pollution in stream reaches. Although this capability is proposed for the Stage 2 Pollution Assessment, we were able in Stage 1 to calculate loading rates of excess nonpoint source pollution within successive catchments as loads were transported downstream towards Delaware Bay.

The hotspot maps of excess pollution (Figure 4) show all stream reaches and catchments as dark green where pollution is less than threshold values (i.e., excess pollution < 0). Colors fade to yellow as values increase to 30% above excess target values. Above this, colors darken to orange and red with increasing values.

The hotspot maps of excess pollution show that the majority of stream reaches and catchments in the DRWI area are below threshold values (shown as green). This is especially true for nitrogen and suspended sediment. Phosphorus concentrations are above threshold values in hotspot maps (shown as yellow, orange, and red) for the central portion of the DRWI area. This analysis is the first time excess pollution has been calculated and mapped for the DRWI.



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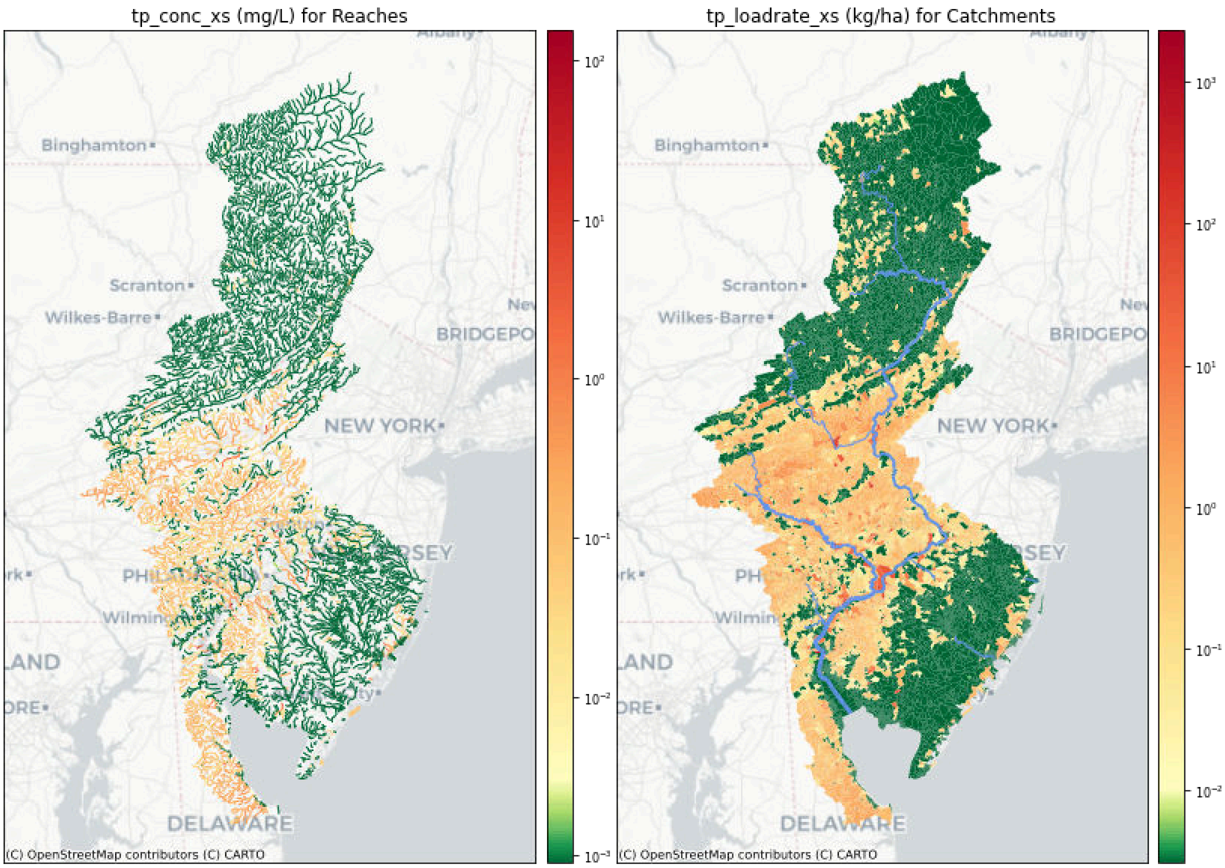
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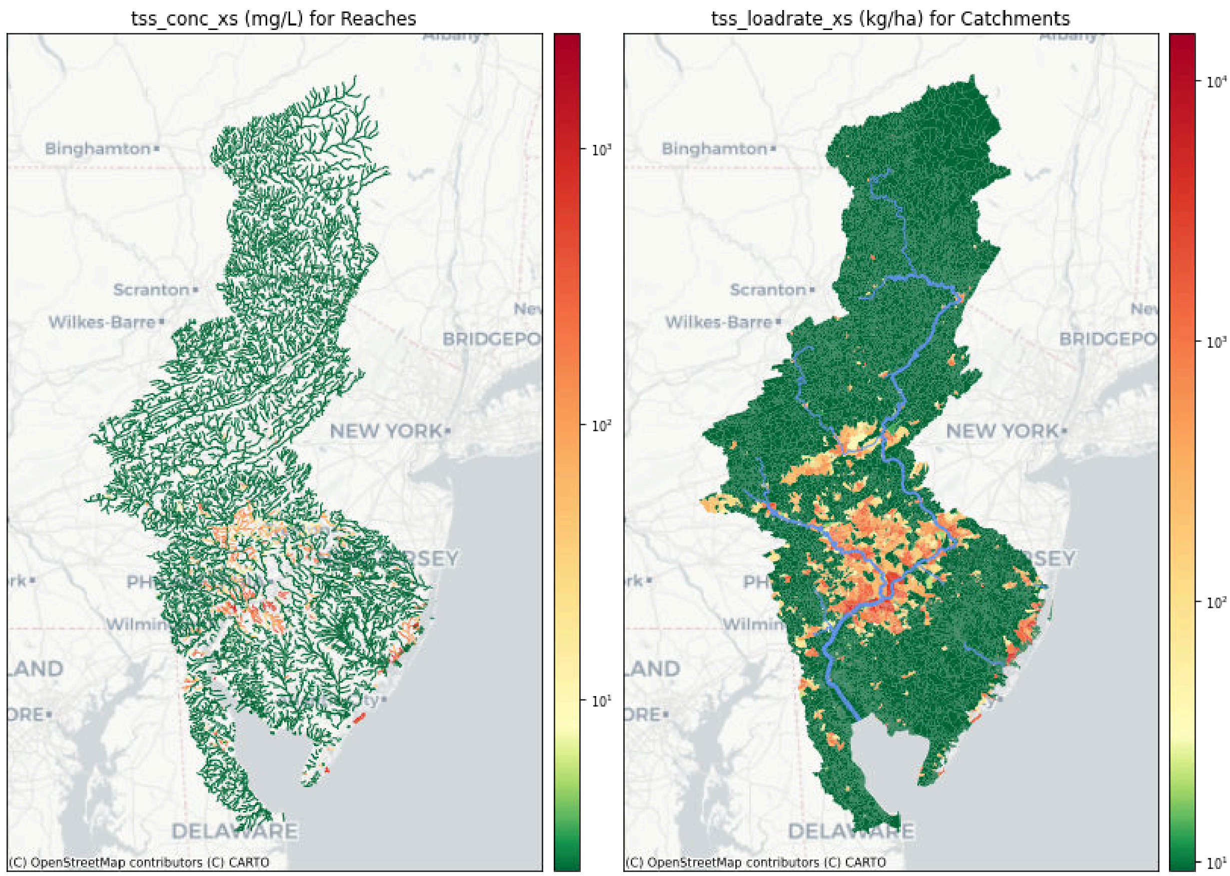


Figure 4. Hotspot maps for the entire DRWI area for *excess* (XS) stream concentrations (left) and *excess* catchment load rates (right), for (A) total nitrogen, (B) total phosphorus, and (C) total suspended sediments. Color bars for maps of excess pollution (i.e. baseline minus target values) are set on a log scale (i.e. 10^1=10, 10^2=100, 10^3=1000) with green set to values at or below the threshold target, bright yellow set to 30% above the target, and red set to the maximum value.

3B. Hotspots of Excess Non Point Source Pollution

Task 3B: Estimate the amount of excess nonpoint and point source pollution contributing to each hotspot and identify subwatersheds where point source loads override the ability of nonpoint source pollution interventions (i.e., non-urban BMPs) to achieve the "established" DRWI healthy water thresholds.

Nitrogen and phosphorus pollution have point sources – such as waste water treatment plants (WWTP) – that are actively and effectively 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. DWRI thus focuses exclusively on nonpoint sources of pollution. To estimate the amount of pollution that is addressable by DRWI-style restoration and land protection activities, we must subtract out the point source pollution from the excess pollution.

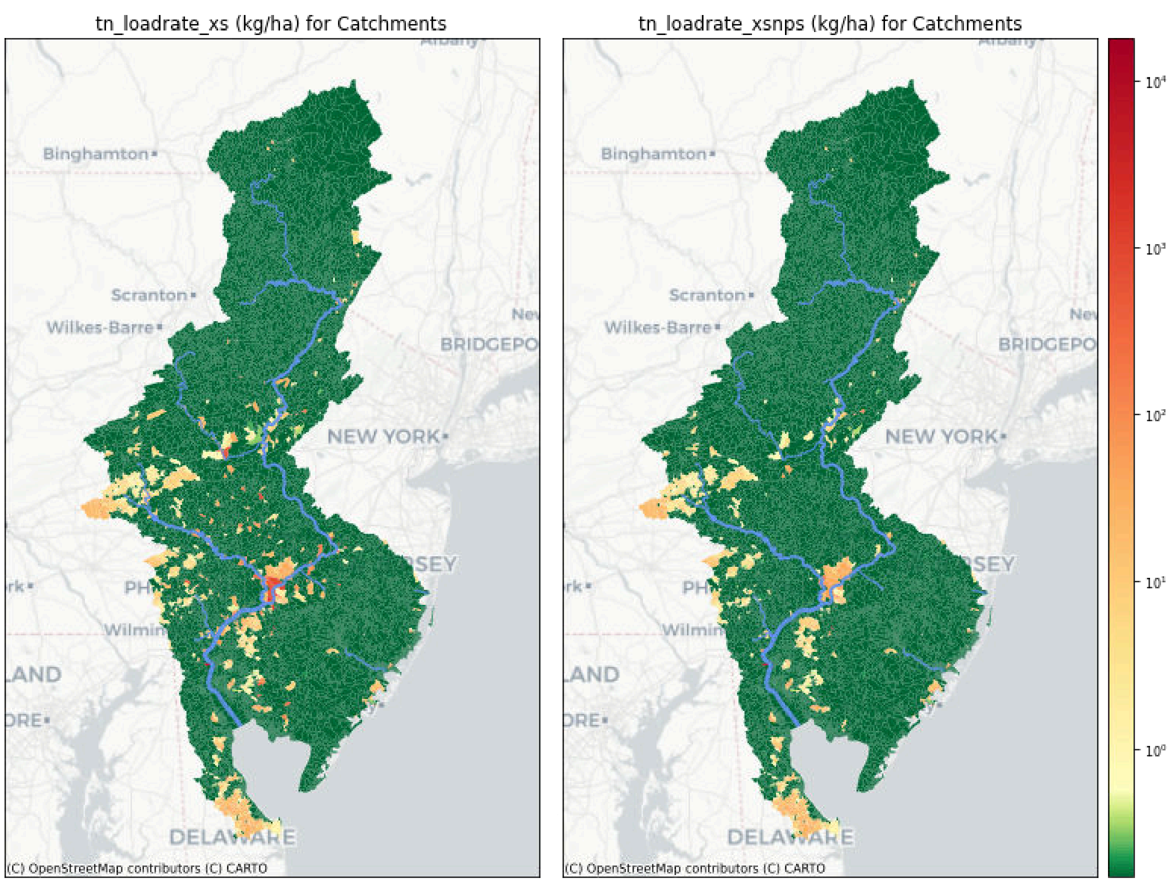
Excess nonpoint source (XSNPS) pollution is thus excess pollution minus point source pollution.

Excess nonpoint source pollution = excess pollution – point source pollution

The hotspot maps of excess nonpoint source pollution (XSNPS, Figure 5 right panels only) show all catchments as dark green where nonpoint source pollution is less than threshold values (i.e., Excess nonpoint source pollution < 0). Colors fade to yellow as values increase to 30% above XSNPS values. Above this, colors darken to orange and red with increasing values.

A comparison of excess pollution (Figure 5 left panels) with excess nonpoint source pollution (Figure 5 right panels) shows that most of the "hottest" pollution loads are catchments with large point sources (i.e., they do not appear on the right panel). Fortunately, these large point sources are typically downstream of DRWI restoration protection activities and do not detract from their benefits. Furthermore, large point sources are actively being reduced with federal, state, and municipal funds.

The hotspot map of excess nonpoint source pollution (XSNPS, Figure 5 right panels only) directly shows the catchments (in yellow, orange, and red) that might be addressed by DRWI-style restoration activities. Hotspot maps of XSNPS pollution no longer show the impacts of point source pollution.



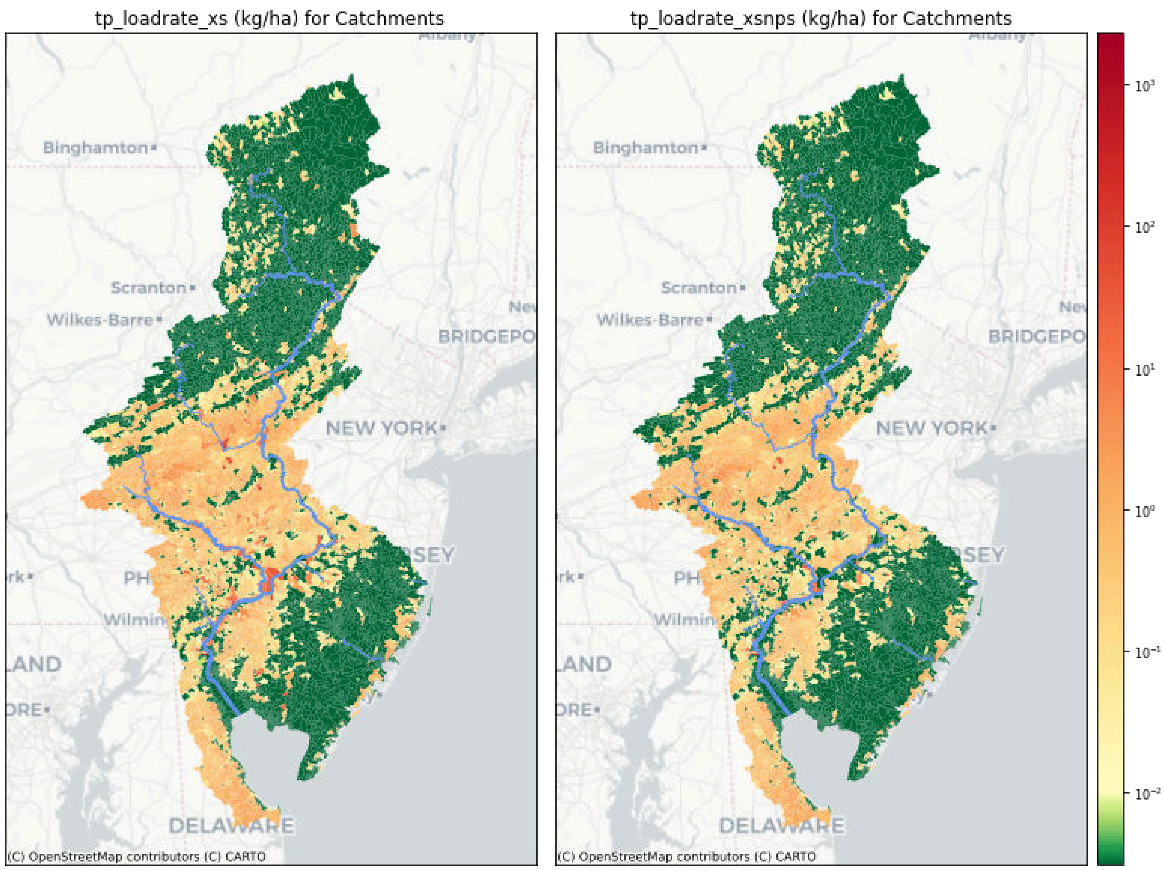


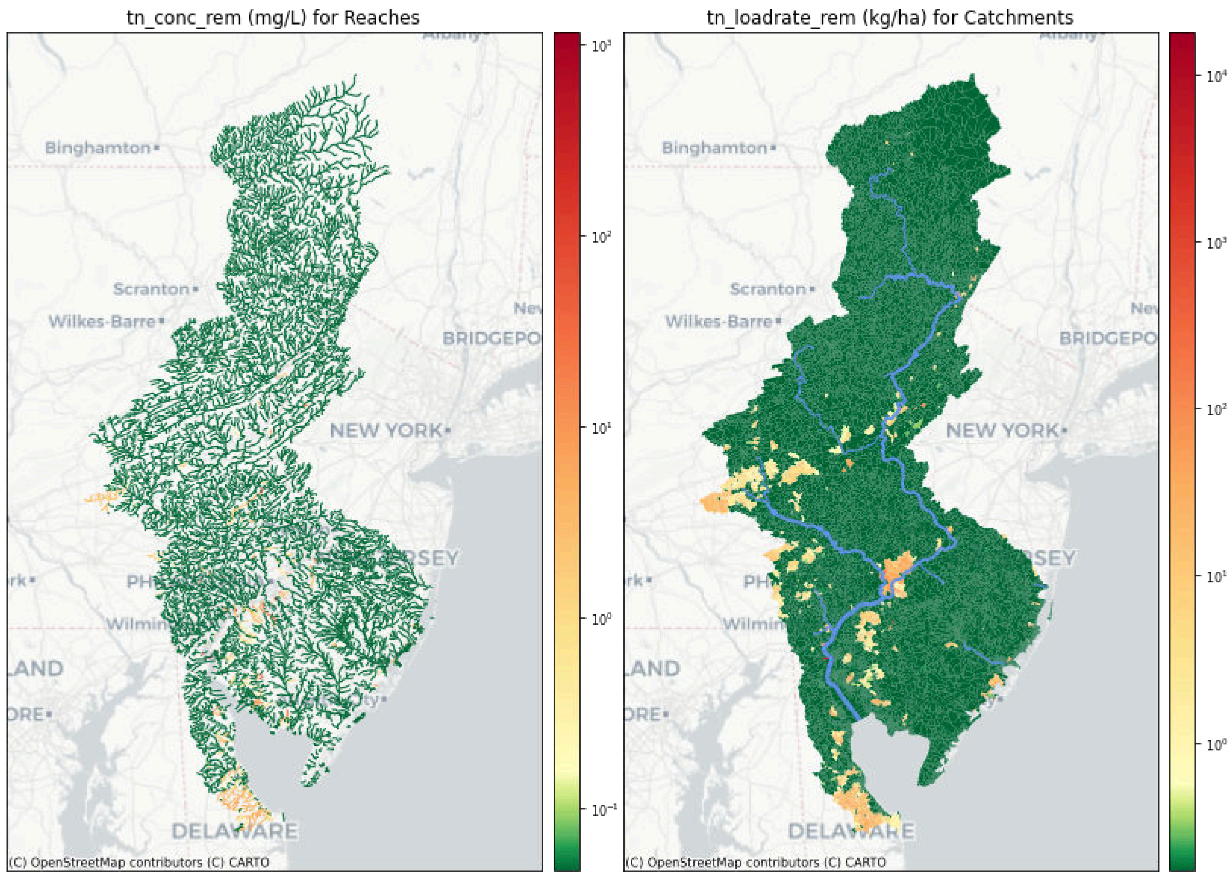
Figure 5. Hotspot maps for the entire DRWI area for excess (XS) catchment load rates (left, identical to Figure 4) compared to *excess nonpoint source* (XSNPS) catchment load rates (right), for (A) total nitrogen, and (B) total phosphorus. Suspended sediments do not have point sources. Excess nonpoint source stream reach concentrations could not be calculated for the Stage 1 assessment but will be included with model improvements in Stage 2. Color bars for maps of excess pollution (i.e., baseline minus target values) are set on a log scale (i.e., 10^1=10, 10^2=100, 10^3=1000) with green set to values at or below the XSNPS target, bright yellow set to 30% above the target, and red set to the maximum value.

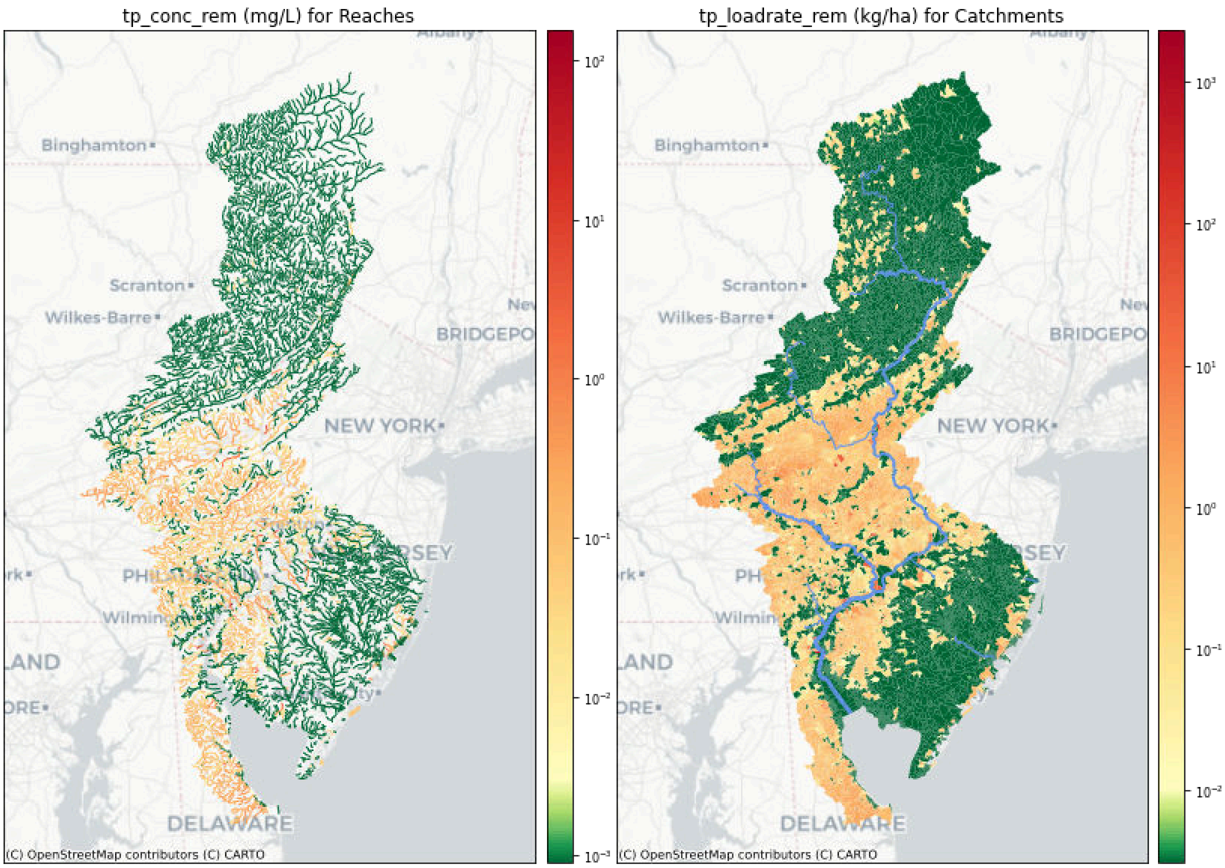
3C. Proportion of Excess Non Point Source Pollution Addressed by DRWI-Style Conservation

Task 3C: In order to address the question "What proportion of the NPS within the cluster boundaries could be addressed by DRWI land protection and ag restoration tactics", the remaining load (non-point source load) that is in excess of the "healthy WQ" criteria will be compared to the cumulative load reductions from all DRWI BMP investments that have been tracked to date (reported to FieldDocs).

Remaining XSNPS Pollution after Reductions from DRWI Restoration

A comparison of excess pollution with excess nonpoint source pollution (Figure 5) shows that most of the "hottest" pollution loads are catchments with large point sources. This can be clearly seen by the elimination of most of the catchments colored red or dark orange in the plots on the right compared to the left (Figure 5). This comparison of hotspot maps for catchments is the first map view of the relative contributions of point sources versus nonpoint sources to catchments of the DRWI area. This XSNPS analysis is incomplete and inaccurate until we implement in Stage 2 the tracking of pollution sources through the routing and attenuation algorithms of SRAT.

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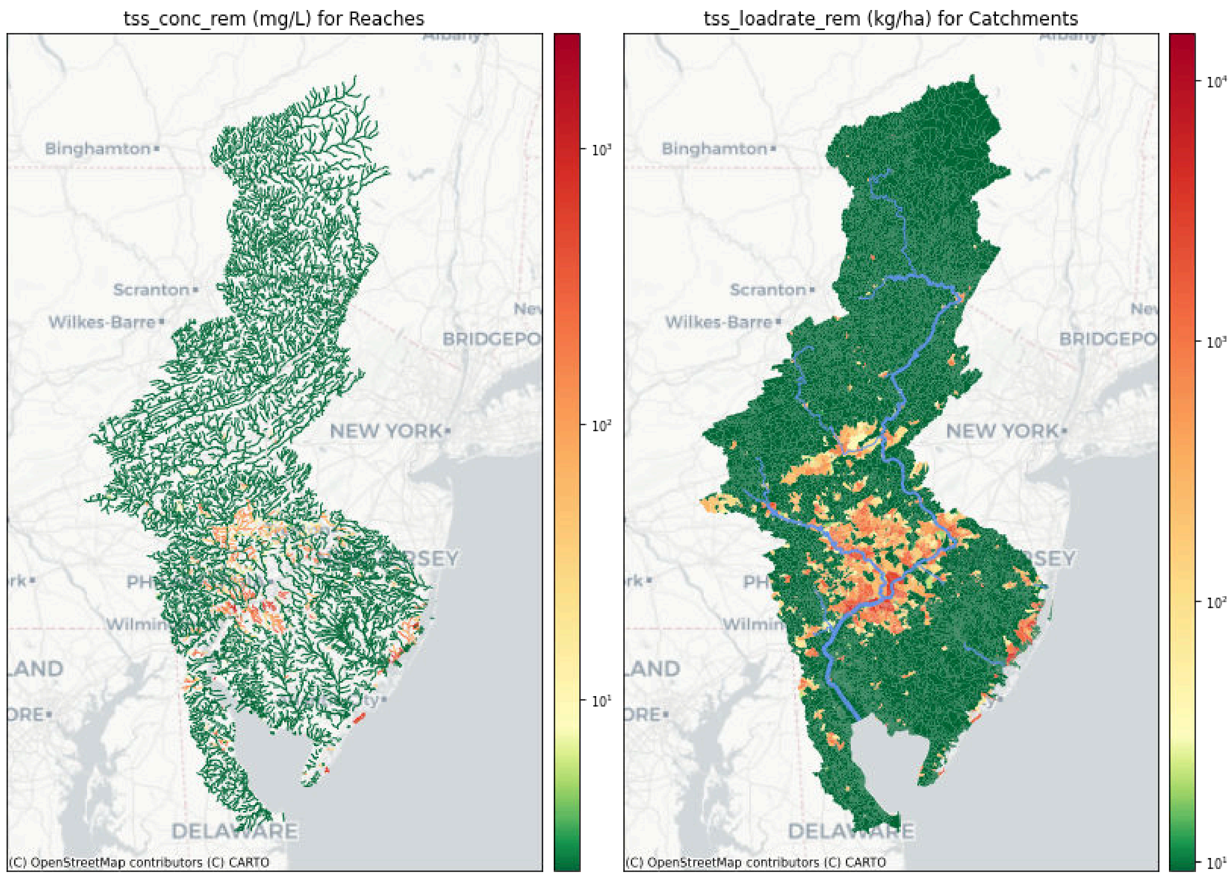


Figure 6. Hotspot maps for the entire DRWI area for *excess remaining* (rem) stream concentrations (left) and *excess remaining nonpoint source* (rem) catchment load rates (right), after accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. (A) total nitrogen, (B) total phosphorus, and (C) total suspended sediments are shown. Color bars for maps of remaining pollution are set on a log scale (i.e., 10^1=10, 10^2=100, 10^3=1000) with green set to 1% of the threshold target, yellow set to 30% of the target, and red set to the maximum value. Color maps are identical to XSNPS heatmaps for comparison and change detection.

Avoided Pollution by Land Protection

Land protection activities, such as those funded via DRWI, essentially maintain "natural" land cover conditions in protected areas for a variety of water quality-related reasons, including the prevention of future development in unique and sensitive areas. While such activities do not necessarily reduce pollutant loads in a given area, land protection can result in smaller future loads in areas that might otherwise be developed. In this study, these are referred to as "avoided" loads.

For Task 3C, we calculated the cumulative total avoided loads from 54 DRWI land protection projects that were tracked in the FieldDoc web application, covering 9,794 hectares (24,201 acres) of natural lands (Table 3), primarily within three clusters (Kirkwood - Cohansey Aquifer, Poconos and Kittatinny, and Upper Lehigh).

Based on model simulations run at the entire DRB level, existing DRWI-funded land protection projects resulted in avoided loads of approximately 48,316 kg/yr, 11,942 kg/yr and 32,385,721 kg/yr for TN, TP and TSS, respectively (Table 5). These avoided loads were equivalent to 89%, 74%, and 257% of the reduction in pollution loads from DRWI restoration projects.

Similar to the DRB-wide estimates described above, avoided load estimates were also made for the eight DRWI clusters (Table 5). Land protection projects targeted areas with health watersheds that already meet threshold targets, and in the three DRWI clusters that prioritized land protection, the avoided total phosphorus loads were equivalent to 151% to 277% of the reductions from DRWI restoration projects. This represents a significant impact on preserving water quality for these and downstream areas. Given that land protection projects targeted clean watersheds that typically did not have excess pollution, it is not appropriate to include them in calculations of remaining pollution.

For the Stage 1 Rapid Assessment, the simplified approach to evaluating the potential impact of these activities on water quality within the DRB centered around estimating the differences in potential sediment, nitrogen and phosphorus loads between "pre-" and "post-" development conditions. Initial calculations were made by assuming 100% build-out using medium-density development conditions for each parcel associated with WPF-funded projects, calculating "future" pollutant loads that might occur as a result, and then determining the difference between these loads and loads under "current" conditions. Additionally, for Stage 1 we can not route these benefits downstream; these estimates represent un-attenuated loads delivered to local catchments.

For the proposed Stage 2 Refined assessment, we will use the approach developed by OSI for the Land Protection Impact Assessment (LPIA) that relies on the future land-use projects modeled by Shippensburg University. We will also be able to propagate the benefits to downstream reaches by adding source tracking capabilities to the pollution routing and attenuation algorithms first developed for the Stream Reach Assessment Tool (SRAT) that have been integrated into the subbasin modeling capabilities of Model My Watershed.

Results from avoided loads were not displayed in hotspot maps, as they were focused in areas that did not have any excess pollution load. In other words, land protection projects were designed to keep areas on the maps that are shown as green to stay green forever.

Avoided pollution loads can be quantified for each catchment, aggregated by geography, and compared to reduced pollution loads from restoration. These aggregated results are presented with Task 3D, below.

Table 5. Avoided Loads by Cluster Due to Land Protection Funded by DRWI.

DRWI Cluster	TN Load (kg/y)	TP Load (kg/y)	TSS Load (kg/y)
Brandywine and Christina	0	0	0
Kirkwood - Cohansey Aquifer	12,330	2,020	8,321,023
Middle Schuylkill	0	0	0
New Jersey Highlands	4,920	1,275	3,472,097
Poconos and Kittatinny	20,229	5,781	14,406,768
Schuylkill Highlands	975	237	593,288
Upper Lehigh	7,737	2,163	4,620,667
Upstream Suburban Philadelphia	0	0	0
other inside DRB	2,126	467	971,879
other outside DRB	0	0	0
DRWI Total	**48,316**	**11,942**	**32,385,721**

3D. Aggregate Pollution Loads by Geography

Task 3D: Aggregate pollution estimates from all hotspots to produce subbasin (HUC 12) and DRWI cluster-specific estimates of 1) total NPS average annual loads, 2) non-point NPS average annual loads and 3) point-source NPS average annual loads. (In this case, N is nitrogen, P is phosphorus, and S is sediment).

For Task 3D, we aggregated results by simple summation over the entire DRWI (Tables 6, 7, 8) and by Cluster and Focus Area (Task 3 Results by Cluster and Focus Area).

It is critical to note that our Stage 1 Rapid Assessment findings do not account for downstream routing and natural attenuation when aggregating results, because our calculations of excess pollution and excess nonpoint source pollution were run outside the modeling system, as described previously.

For Stage 1, we developed a simplified approach, where we converted catchment loading rates (pollution mass per land area), which were used for hotspot maps and for calculating excess pollution, to catchment loads (pollution mass), which can be summed over each geographic area of interest. This provides a very rough approximation of how benefits from upstream catchments can propagate to downstream reaches. This simplification, however, does not actually consider the position of DRWI conservation projects relative to impairments; it will apply the benefits even to reaches that are not downstream of a project. As a result, our simplifications for the Stage 1 assessment may underestimate excess pollution and overestimate DRWI benefits for many catchments, and these biases increase with increasing size of our considered geography.

For the proposed Stage 2 Refined Assessment, the modeling system will be improved so that aggregation of results will take into account routing and attenuation. For this reason, Stage 2 estimates will much better reflect downstream benefits in some locations, and the lack of benefits to other locations.

For both Stage 1 and Stage 2 Pollution Assessment, we aggregate all Pollution Loads to areas that are strictly based on USGS National Hydrography Dataset v2 catchment boundaries, which have been considered the definitive source for water boundary information for nearly two decades. All DRWI analysis and modeling tools follow NHDplus v2 geographies, in order to properly accumulate and route water and pollution through the natural system. The original DRWI Cluster and Focus Area boundaries, however, were not drawn around USGS NHDplus v2 catchment boundaries, and it is rare that the two sets of boundaries line up exactly. For the Pollution Assessment, we needed to adjust Cluster and Focus Area boundaries to line up exactly with NHDplus v2 catchment boundaries in order to correctly calculate pollution loads. As a result, the DRWI areas calculated for the Pollution Assessment are usually a few percent different than the originally drawn boundaries.

Note that excess pollution and excess nonpoint source (XSNPS) pollution can be negative numbers where baseline values are better (i.e., less than) target values for any catchment.

As shown in Table 6, non-point source TN did not have excess amounts (i.e., XSNPS values were negative) when summed over any of the DRWI clusters or the DRWI area as a whole. As mentioned above, this result is due to the simplifications taken for the Stage 1 Rapid Assessment. Figure 5 shows that this is not true for smaller geographies. DWRI-funded restoration work did result in TN reductions throughout the DRWI area on the order of 54,280 kg/yr, which did produce notable benefits within the catchments and watersheds local to those projects.

As shown in Table 7, non-point source TP did have excess amounts within all of the DRWI clusters except for the Kirkwood-Cohansey, Poconos-Kittatinny and Upper Lehigh clusters. In the remaining clusters, excess non-point TP was reduced by 16,107 kg/yr, an amount equivalent to 6.2% of the DWRI excess non-point source TP. Within three clusters DRWI restoration projects reduced 6% to 14% of excess nonpoint source pollution (Table 7). The benefits are further amplified within Focus Areas, where restoration reductions summed to more than 100% of excess nonpoint source TP pollution within three Focus Areas, and more than 20% for an additional ten Focus Areas. The proportion of excess nonpoint source pollution remaining is the balance of the proportion reduced, as presented in the percentages above and in Table 7 and in Task 3 Results by Cluster and Focus Area.

As shown in Table 8, excess TSS only occurred within the Upstream Suburban Philadelphia cluster. Of the simulated 6,526,249 kg/yr of excess non-point source TSS load occurring in this cluster, about 789,081 kg/yr (12.1%) were estimated to be reduced by DWRI-funded restoration activities. In total, about 12,595,000 kg/yr were estimated to be reduced by DWRI-funded restoration activities.

Table 6. Total Nitrogen (TN) loads from catchments within the DRWI program area, by Cluster and other areas of interest. These loads have not been attenuated through the stream network.

DRWI Cluster *or other areas*	*Area (ha)*	**TN Load (kg/y)** *Target*	*Baseline Assessment* tn_load	*Point Sources* tn_load_ps	*Excess NPS* tn_load_xsnps	*Reduced by Restoration*	*Remaining NPS Load* tn_load_rem	*Avoided by Protection* tn_load_avoid	**Proportion Restored** *% of Excess NPS Reduced* only if excess is positive	*% of Excess NPS Remaining*
Brandywine and Christina	145,739	2,487,766	2,032,147	373,899	-829,518	9,646	-839,164	0	--	--
Kirkwood - Cohansey Aquifer	550,180	9,391,566	2,849,539	1,112,279	-7,654,306	8,973	-7,663,279	12,330	--	--
Middle Schuylkill	202,959	3,464,503	3,441,219	1,614,086	-1,637,369	15,668	-1,653,036	0	--	--
New Jersey Highlands	178,647	3,049,507	1,640,035	437,297	-1,846,769	17,933	-1,864,702	4,920	--	--
Poconos and Kittatinny	342,462	5,845,829	876,611	88,157	-5,057,374	0	-5,057,374	20,229	--	--
Schuylkill Highlands	44,855	765,677	669,055	173,033	-269,655	229	-269,884	975	--	--
Upper Lehigh	198,030	3,380,368	534,462	90,585	-2,936,491	0	-2,936,491	7,737	--	--
Upstream Suburban Philadelphia	37,411	638,607	372,054	64,410	-330,964	1,243	-332,206	0	--	--
other inside DRB	1,945,876	33,216,096	34,825,029	21,901,800	-20,292,867	594	-20,293,461	2,126	--	--
other outside DRB	140,399	2,396,606	767,772	0	-1,628,834	0	-1,628,834	0	--	--
Clusters Total	1,700,282	29,023,822	12,415,122	3,953,746	-20,562,445	53,692	-20,616,137	46,190	--	--
DRB Total	3,368,532	57,500,837	46,520,034	25,855,546	-36,836,349	54,285	-36,890,634	43,618	--	--
DRWI Total	**3,786,557**	**64,636,523**	**48,007,923**	**25,855,546**	**-42,484,146**	**54,285**	**-42,538,432**	**48,316**	--	--

Table 7. Total Phosphorus (TP) loads from catchments within the DRWI program area, by Cluster and other areas of interest. These loads have not been attenuated through the stream network.

DRWI Cluster		TP Load (kg/y)							Proportion Restored	
	Area (ha)	*Target*	*Baseline Assessment*	*Point Sources*	*Excess NPS*	*Reduced by Restoration*	*Remaining NPS Load*	*Avoided by Protection*	*% of Excess NPS Reduced*	*% of Excess NPS Remaining*
			tp_load	tp_load_ps	tp_load_xsnps		tp_load_rem	tp_load_avoid	only if excess is positive	
Brandywine and Christina	145,739	45,179	117,940	34,274	38,486	3,581	34,905	0	9%	91%
Kirkwood - Cohansey Aquifer	550,180	170,556	160,820	104,215	-113,950	1,338	-115,288	2,020	--	--
Middle Schuylkill	202,959	62,917	300,007	146,362	90,728	5,046	85,682	0	6%	94%
New Jersey Highlands	178,647	55,381	162,557	67,809	39,368	5,403	33,965	1,275	14%	86%
Poconos and Kittatinny	342,462	106,163	68,983	14,893	-52,073	0	-52,073	5,781	--	--
Schuylkill Highlands	44,855	13,905	54,380	22,943	17,532	86	17,447	237	0%	100%
Upper Lehigh	198,030	61,389	59,960	16,246	-17,676	0	-17,676	2,163	--	--
Upstream Suburban Philadelphia	37,411	11,597	59,372	42,784	4,990	385	4,605	0	8%	92%
other inside DRB	1,945,876	603,221	2,891,731	2,048,578	239,931	267	239,664	467	0%	100%
other outside DRB	140,399	43,524	52,874	0	9,351	0	9,351	0	0%	100%
Clusters Total	1,700,282	527,088	984,020	449,526	7,406	15,839	-8,433	11,475	not calculated in Stage 1	not calculated in Stage 1
DRB Total	3,368,532	1,044,245	3,842,764	2,498,105	300,414	16,106	284,308	11,087	**5%**	**95%**
DRWI Total	**3,786,557**	**1,173,833**	**3,928,625**	**2,498,105**	**256,687**	**16,106**	**240,581**	**11,942**	**6%**	**94%**

Table 8. Total Suspended Sediment (TSS) loads from catchments within the DRWI program area, by Cluster and other areas of interest. These loads have not been attenuated through the stream network.

DRWI Cluster	Area (ha)	TSS Load (kg/y)							Proportion Restored	
		Target	Baseline Assessment	Point Sources	Excess NPS	Reduced by Restoration	Remaining NPS Load	Avoided by Protection	% of Excess NPS Reduced	% of Excess NPS Remaining
			tss_load		tss_load_xsnps		tss_load_rem	tss_load_avoid	only if excess is positive	
Brandywine and Christina	145,739	134,633,735	103,533,502	0	-31,100,233	5,105,763	-36,205,996	0	--	--
Kirkwood - Cohansey Aquifer	550,180	508,255,927	182,163,755	0	-326,092,172	1,835,192	-327,927,364	8,321,023	--	--
Middle Schuylkill	202,959	187,493,117	140,924,762	0	-46,568,355	1,237,969	-47,806,323	0	--	--
New Jersey Highlands	178,647	165,034,233	87,748,771	0	-77,285,462	3,458,640	-80,744,102	3,472,097	--	--
Poconos and Kittatinny	342,462	316,366,519	71,151,330	0	-245,215,189	0	-245,215,189	14,406,768	--	--
Schuylkill Highlands	44,855	41,437,154	28,019,762	0	-13,417,392	24,013	-13,441,406	593,288	--	--
Upper Lehigh	198,030	182,939,900	54,479,311	0	-128,460,589	0	-128,460,589	4,620,667	--	--
Upstream Suburban Philadelphia	37,411	34,560,369	41,086,618	0	6,526,249	789,081	5,737,168	0	12%	88%
other inside DRB	1,945,876	1,797,599,846	1,058,436,715	0	-739,163,131	143,594	-739,306,725	971,879	--	--
other outside DRB	140,399	129,700,313	113,758,317	0	-15,941,995	0	-15,941,995	0	--	--
Clusters Total	1,700,282	1,570,720,954	709,107,811	0	-861,613,143	12,450,658	-874,063,801	31,413,842	not calculated in Stage 1	not calculated in Stage 1
DRB Total	3,368,532	3,111,849,656	1,699,502,256	0	-1,412,347,400	12,594,244	-1,424,941,644	28,465,067	--	--
DRWI Total	**3,786,557**	**3,498,021,112**	**1,881,302,843**	**0**	**-1,616,718,269**	**12,594,252**	**-1,629,312,521**	**32,385,721**	--	--

Task 3 Results by Cluster and Focus Area

Overview of DRWI Clusters and Focus Areas

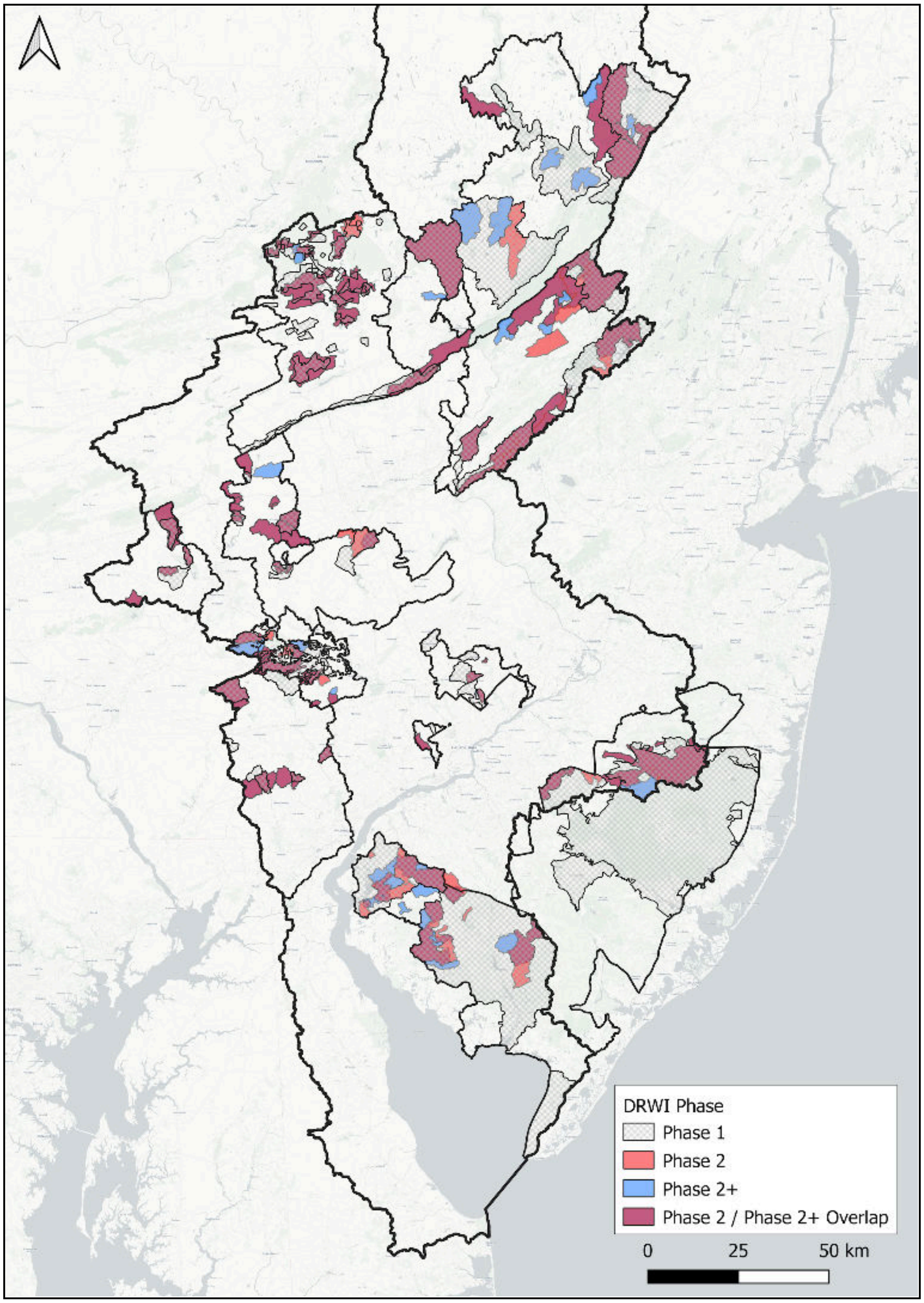


Figure 7. A map of DRWI Focus Areas by Phase, where the bold boundary represents the hydrologically defined Delaware River Watershed (DRW).

Brandywine and Christina

Characterized by:

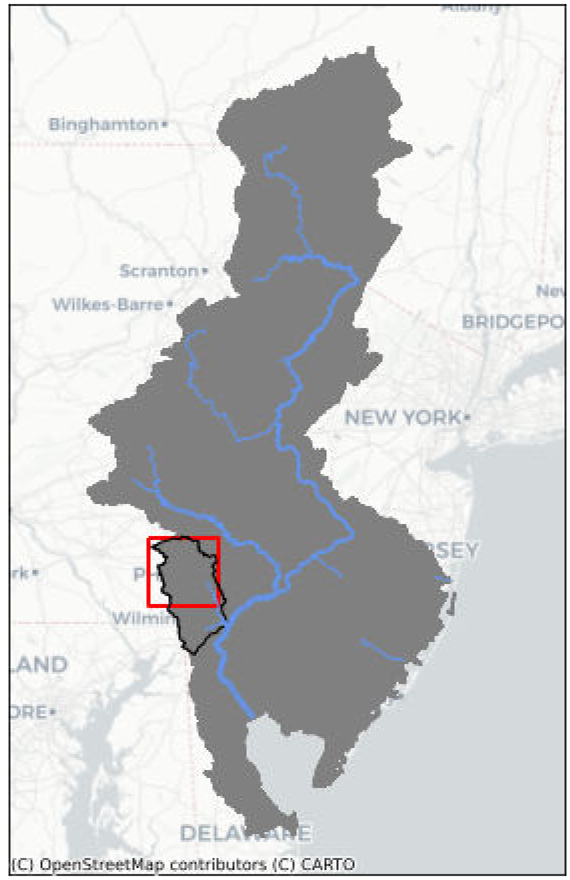
145,739 ha (360,128 acres):

- 36% urban,
- 32% forest,
- 27% agricultural,
- 5% wetlands and water,
- 51% impaired streams,
- 7% protected lands

Stressors/threats:

- Agricultural activity
- Development: impervious surfaces and large volumes of runoff

Extent Map:
Brandywine and Christina Cluster



Total Phosphorus

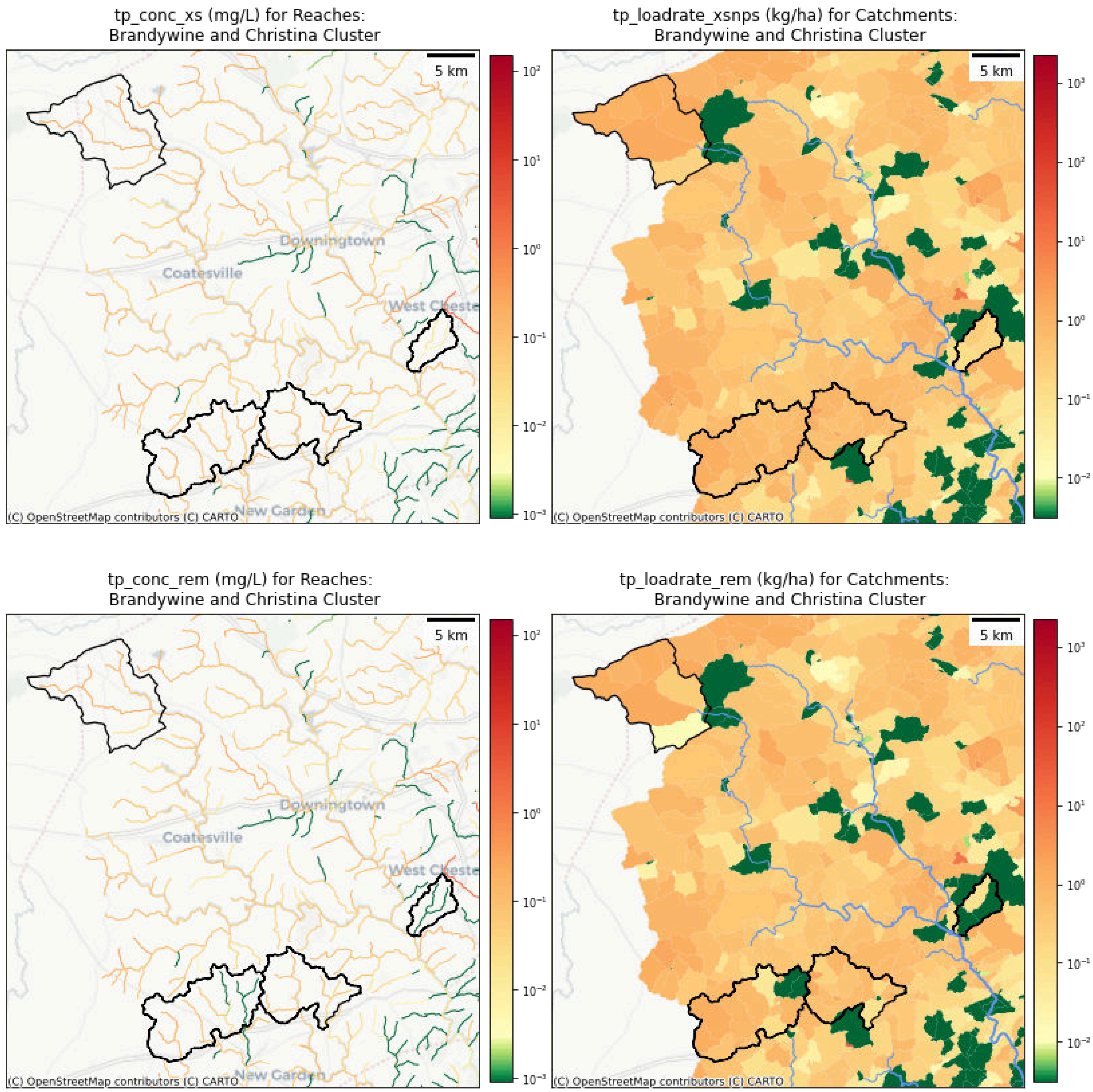


Figure B-1. Total phosphorus hotspot maps for the Brandywine and Christina Cluster of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Phase 2 Focus Areas are outlined to highlight locations with most concentrated restoration activities and improvements.

Table B-1. Total Phosphorus (TP) loads for Focus Areas in the Brandywine and Christina Cluster

Focus Areas in			**TP Load (kg/y)**							**Proportion Restored**	
Brandywine and Christina Cluster	*DRWI Phase*	*Area (ha)*	*Target*	*Baseline Assessment*	*Point Sources*	*Excess NPS*	*Reduced by Restoration*	*Remaining NPS Load*	*Avoided by Protection*	*% of Excess Reduced*	*% of Excess Remaining*
				tp_load	tp_load_ps	tp_load_xsnps		tp_load_rem	tp_load_avoid	only if excess is positive	
Brandywine Creek Headwaters	Phase 2	4,724	1,464	7,002	249	5,289	1,190	4,099	0	23%	77%
Plum Run	Phase 2	982	304	521	29	188	486	-299	0	259%	–
Red Clay Creek	Phase 2	2,795	866	2,700	0	1,834	327	1,507	0	18%	82%
White Clay Creek	Phase 2	4,603	1,427	5,106	107	3,572	941	2,631	0	26%	74%
Little Buck Run	Phase 1 only	951	295	1,097	0	802	56	746	0	7%	93%
Sharitz Run	Phase 1 only	968	300	717	0	417	0	417	0	0%	100%
Upper East Branch/Marsh Creek	Phase 1 only	3,852	1,194	3,478	419	1,865	0	1,865	0	0%	100%
Other Areas		126,864	39,328	97,318	33,470	24,520	580	23,940	0	2%	98%
Total for Cluster		**145,739**	**45,179**	**117,940**	**34,274**	**38,486**	**3,581**	**34,905**	**0**	**9%**	**91%**

Kirkwood - Cohansey Aquifer

Characterized by:

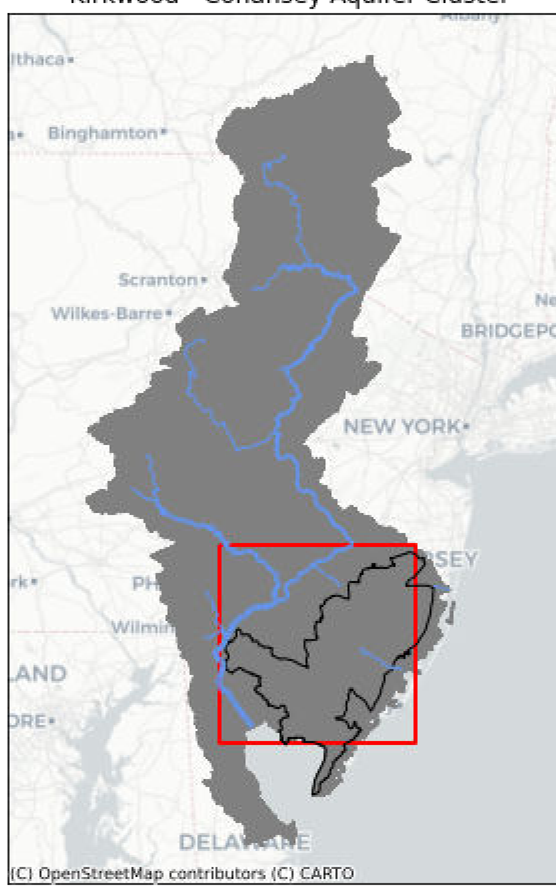
550,180 ha (1,359,518 acres):

- 38% forested,
- 36% wetland and water,
- 14% urban,
- 14% agricultural,
- 14% impaired streams,
- 47% protected land

Stressors/threats:

- Management of protected areas (recreation use, especially all-terrain vehicles and riparian forest damage)
- Farming practices
- Urban development
- Groundwater depletion and contamination

Extent Map:
Kirkwood - Cohansey Aquifer Cluster



Total Phosphorus

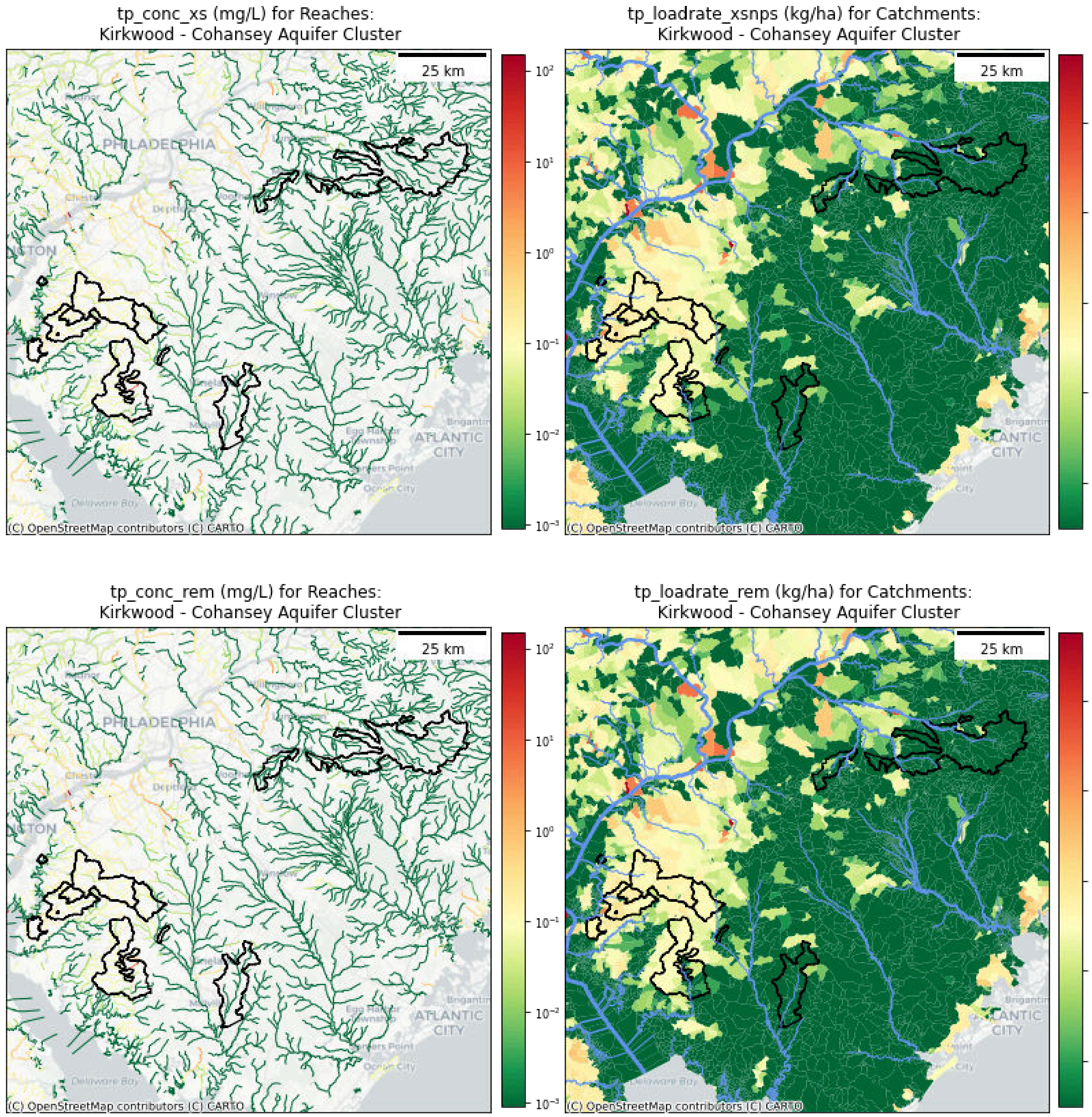


Figure B-2. Total phosphorus hotspot maps for the Kirkwood - Cohansey Aquifer Cluster of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-2. Total Phosphorus (TP) loads for Focus Areas in the Kirkwood - Cohansey Aquifer Cluster

Focus Areas in			TP Load (kg/y)							Proportion Restored	
Kirkwood - Cohansey Aquifer Cluster	*DRWI Phase*	*Area (ha)*	*Target*	*Baseline Assessment*	*Point Sources*	*Excess NPS*	*Reduced by Restoration*	*Remaining NPS Load*	*Avoided by Protection*	*% of Excess NPS Reduced*	*% of Excess NPS Remaining*
				tp_load	tp_load_ps	tp_load_xsnps		tp_load_rem	tp_load_avoid	only if excess is positive	
Cohansey River	Phase 2	10,229	3,171	25,032	19,880	1,982	1,042	940	0	53%	47%
Lower Salem River	Phase 2	5,513	1,709	4,916	0	3,207	16	3,191	0	0%	100%
Menantico	Phase 2	7,822	2,425	1,321	0	-1,104	12	-1,116	119	--	--
Muddy Run	Phase 2	3,663	1,135	2,315	70	1,110	4	1,106	0	0%	100%
Muddy Run	Phase 2	3,663	1,135	2,315	70	1,110	4	1,106	0	0%	100%
Rancocas	Phase 2	24,933	7,729	2,531	1,688	-6,886	0	-6,886	640	--	--
Upper Salem River	Phase 2	8,402	2,605	6,666	99	3,963	124	3,839	0	3%	97%
Cohansey-Maurice	Phase 1 only	79,845	24,752	34,984	43,386	-33,155	44	-33,199	0	--	--
Core Pine Barrens	Phase 1 only	131,695	40,825	12,435	427	-28,817	0	-28,817	1,033	--	--
Greater Hammonton	Phase 1 only	13,335	4,134	4,076	0	-58	0	-58	0	--	--
Rancocas Creek	Phase 1 only	8,971	2,781	1,569	1,446	-2,657	0	-2,657	146	--	--
Salem River	Phase 1 only	16,061	4,979	12,977	3,894	4,103	101	4,002	0	2%	98%
Western Cape May	Phase 1 only	11,868	3,679	1,659	13,187	-15,207	0	-15,207	0	--	--
Other Areas		229,361	71,102	51,249	20,148	-40,001	0	-40,001	82	--	--
Total for Cluster		**555,362**	**172,162**	**164,044**	**104,294**	**-112,412**	**1,346**	**-113,758**	**2,020**	**--**	**--**

Note that totals in this table are ~1% greater than those in Tables 6-8 because some Phase 1 focus areas include NHDplus catchments outside of the final cluster boundary.

Middle Schuylkill

Characterized by:

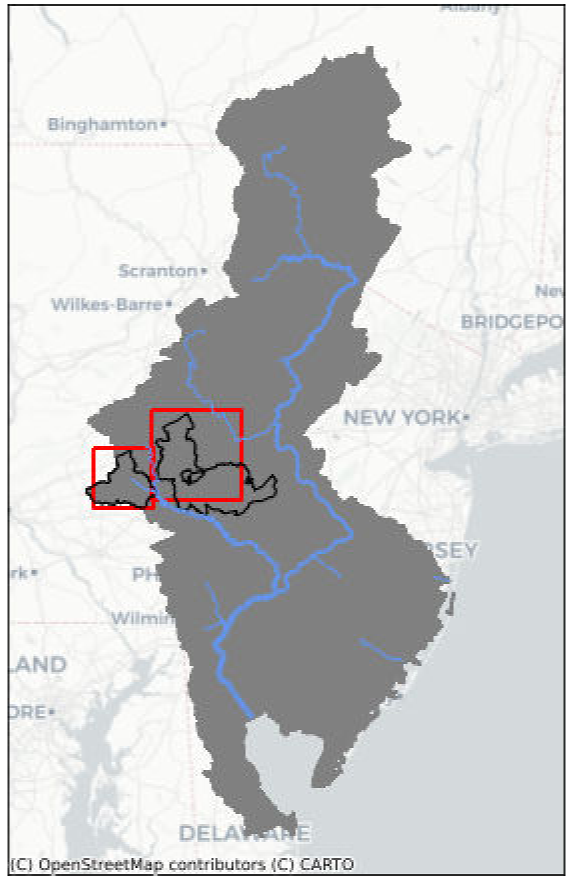
202,959 ha (501,520 acres):

- 44% agricultural,
- 35% forested land,
- 18% urban,
- 3% wetland and water,
- 29% impaired streams,
- 5% protected

Stressors/threats:

- Urban runoff from small towns
- Farms without Best Management Practices: nutrients, sediment and other substances in runof

Extent Map:
Middle Schuylkill Cluster



Total Phosphorus

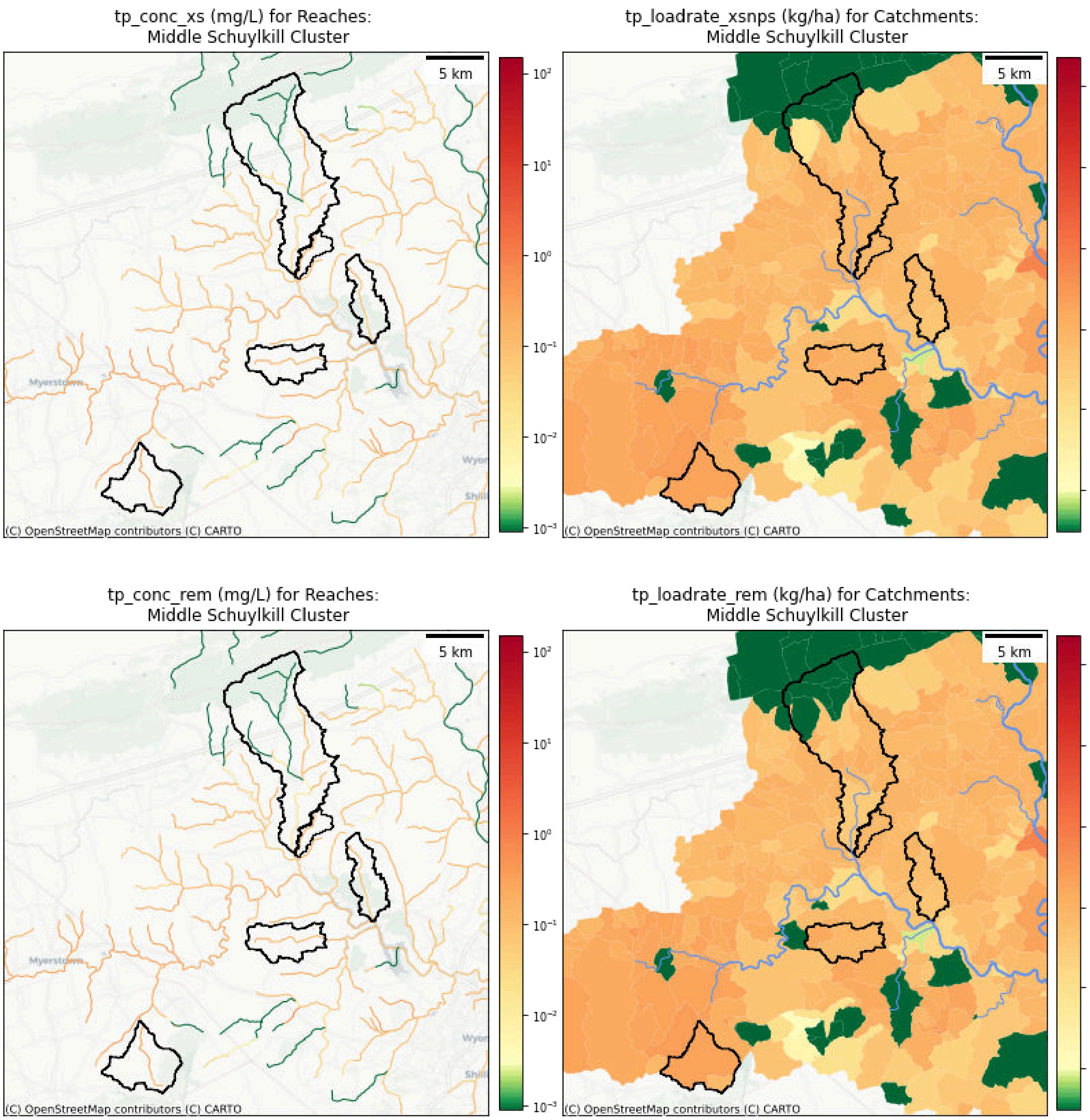


Figure B-3A. Total phosphorus hotspot maps for the western group of Focus Areas in the Middle Schuylkill of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

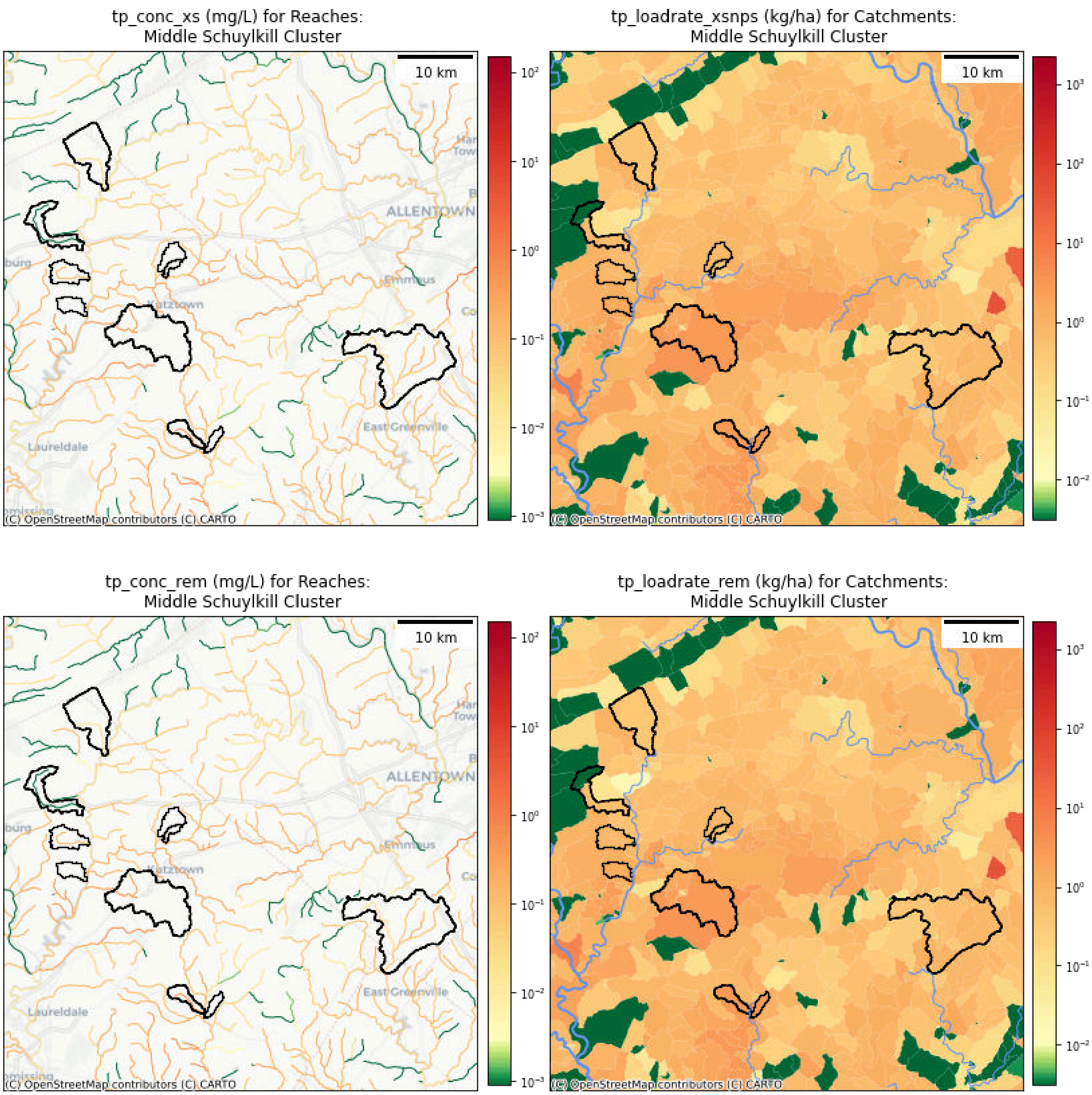


Figure B-3B. Total phosphorus hotspot maps for the eastern group of Focus Areas in the Middle Schuylkill of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-3. Total Phosphorus (TP) loads for Focus Areas in the Middle Schuylkill Cluster

Focus Areas in Middle Schuylkill Cluster	DRWI Phase	Area (ha)	TP Load (kg/y) Target	Baseline Assessment	Point Sources	Excess NPS	Reduced by Restoration	Remaining NPS Load	Avoided by Protection	Proportion Restored % of Excess Reduced	% of Excess Remaining
				tp_load	tp_load_ps	tp_load_xsnps		tp_load_rem	tp_load_avoid	only if excess is positive	
Furnace Cr	Phase 2	949	294	547	3	250	59	191	0	24%	76%
Hosensack Cr	Phase 2	3,656	1,133	3,863	2	2,728	0	2,728	0	0%	100%
Licking Cr	Phase 2	862	267	752	0	484	1	483	0	0%	100%
Little Manatawny Trib 4	Phase 2	291	90	863	0	772	1	771	0	0%	100%
Lower Maiden Cr Trib 1	Phase 2	657	204	689	22	463	0	463	0	0%	100%
Lower Maiden Cr Trib 2	Phase 2	489	152	765	0	613	0	613	0	0%	100%
Lower Maiden Cr Trib 3	Phase 2	648	201	1,162	0	960	107	854	0	11%	89%
Manatawny Trib 2	Phase 2	236	73	729	0	656	77	578	0	12%	88%
Manatawny Trib 3	Phase 2	395	123	1,285	0	1,163	0	1,163	0	0%	100%
Manor Cr	Phase 2	1,761	546	1,265	0	719	73	646	0	10%	90%
Mill Cr Trib 2	Phase 2	1,286	399	2,669	0	2,270	0	2,270	0	0%	100%
Moselem Cr	Phase 2	3,102	962	8,769	0	7,807	404	7,403	0	5%	95%
Northkill	Phase 2	4,451	1,380	3,519	18	2,121	589	1,532	0	28%	72%
Saucony Cr Trib 1	Phase 2	2,966	920	8,394	1,652	5,823	1,784	4,038	0	31%	69%
Saucony Cr Trib 2	Phase 2	3,068	951	5,910	845	4,114	9	4,104	0	0%	100%
Tulpehocken Trib 2	Phase 2	990	307	1,292	0	985	40	945	0	4%	96%
Tulpehocken Trib 3	Phase 2	307	95	333	0	238	0	238	0	0%	100%
Manatawny Creek	Phase 1 only	282	88	723	0	636	0	636	0	0%	100%
Spring Creek	Phase 1 only	1,845	572	2,528	0	1,956	0	1,956	0	0%	100%
Tributary to Maiden Creek	Phase 1 only	493	153	502	0	349	135	213	0	39%	61%
Upper Perkiomen Creek	Phase 1 only	2,038	632	2,624	0	1,992	0	1,992	0	0%	100%
Other Areas		172,185	53,377	250,825	143,819	53,629	1,765	51,864	0	3%	97%
Total for Cluster		202,959	62,917	300,007	146,362	90,728	5,046	85,682	0	6%	94%

New Jersey Highlands

Characterized by:

178,647 ha (441,445 acres):

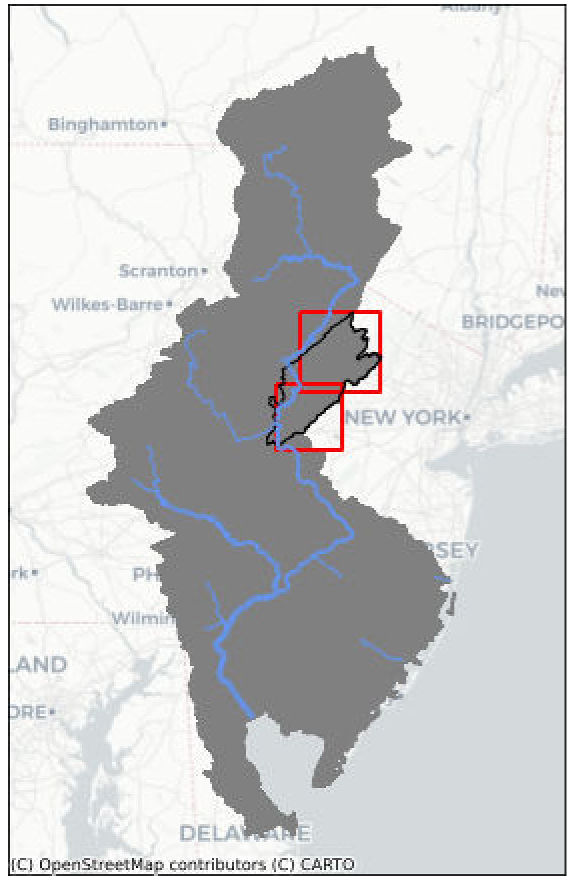
- 46% forested,
- 26% agricultural,
- 15% urban,
- 13% wetland and water,
- 22% impaired streams,
- 41% protected

Stressors/threats:

Development:

- Approximately 3,000 acres/yr converted to urban land
- Suburban point and non-point source pollution from sewage overflow
- Fertilizer from lawns and agriculture

Extent Map:
New Jersey Highlands Cluster



Total Phosphorus

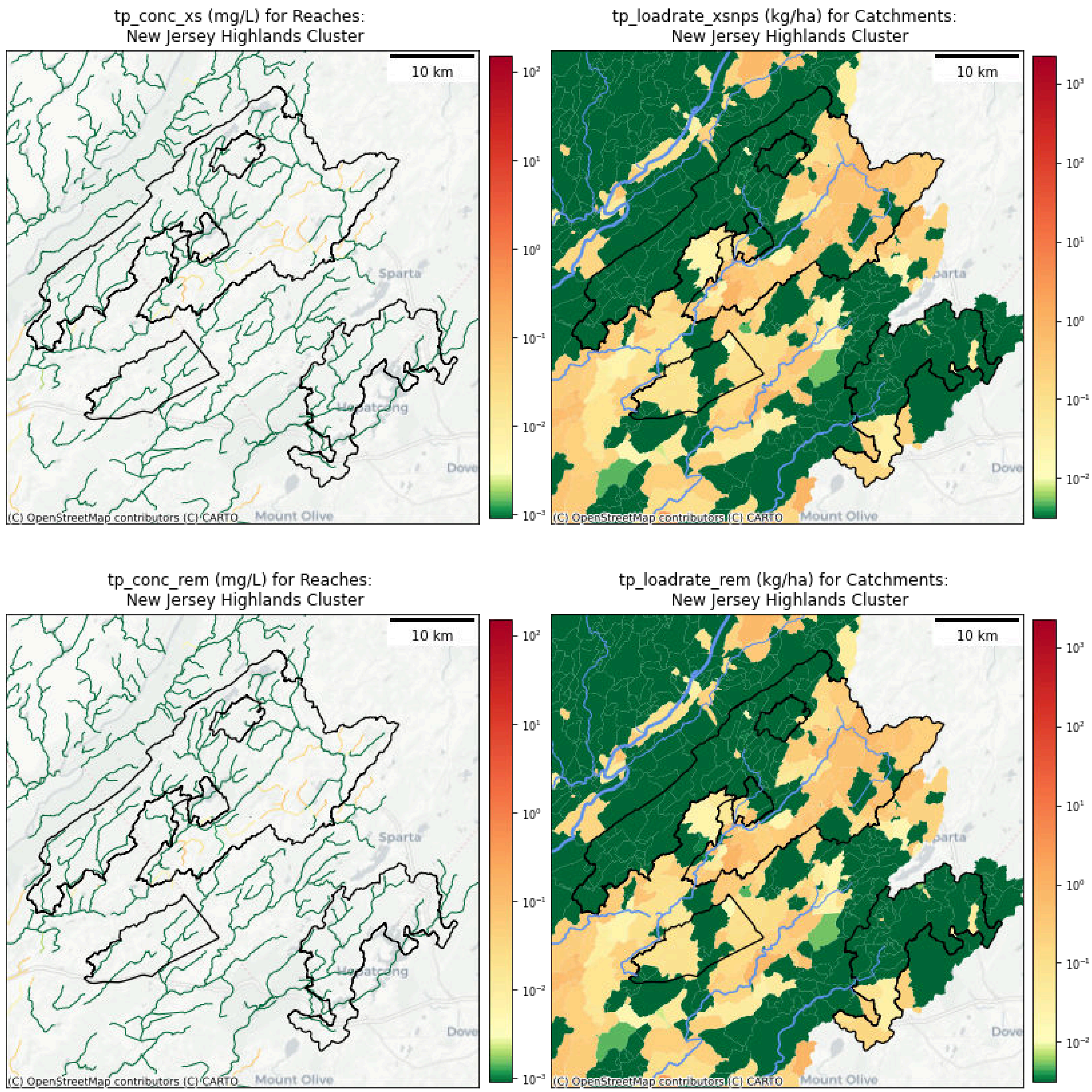


Figure B-4A. Total phosphorus hotspot maps for the northern group of Focus Areas in the New Jersey Highlands Cluster of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

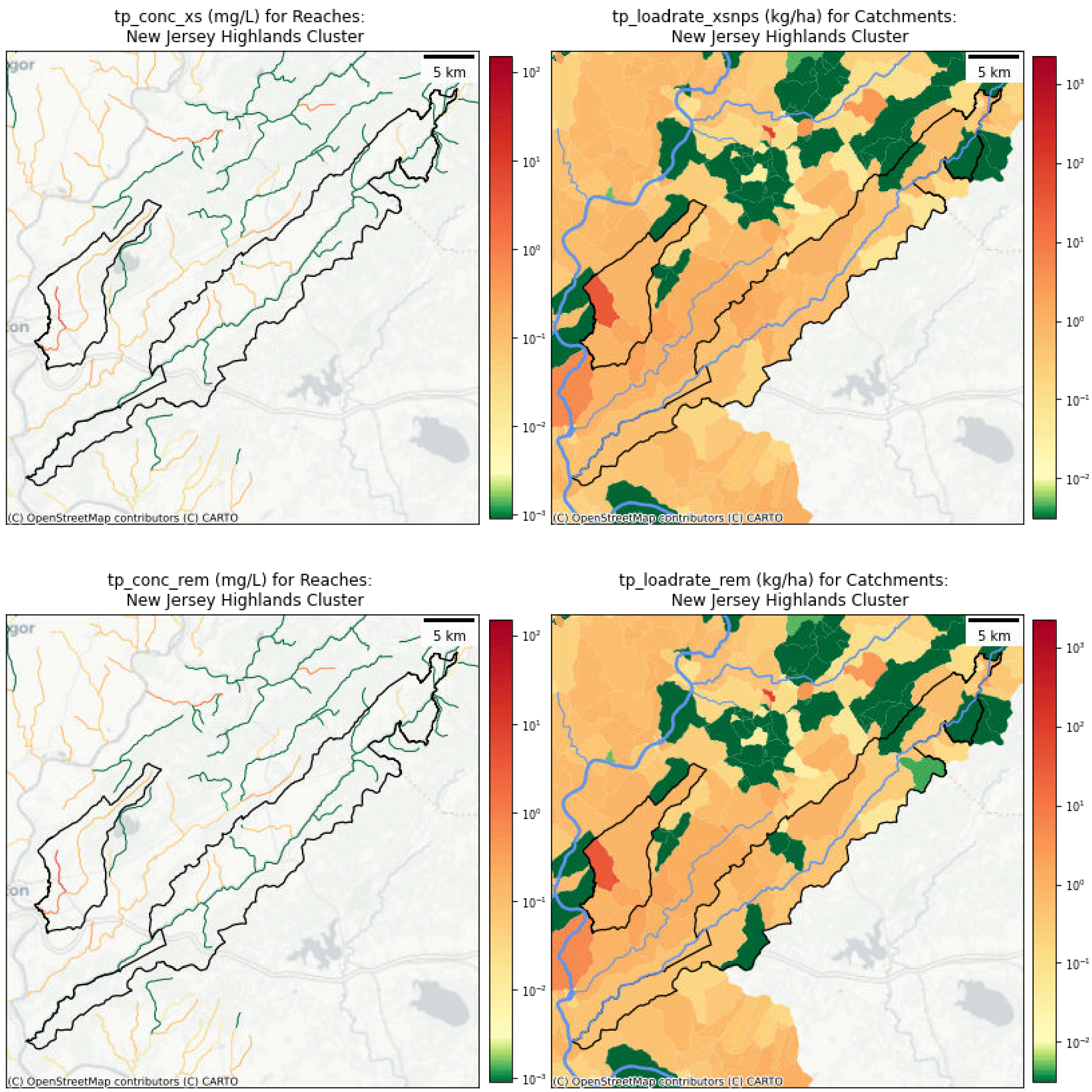


Figure B-4B. Total phosphorus hotspot maps for the southern group of Focus Areas in the New Jersey Highlands Cluster of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-4. Total Phosphorus (TP) loads for Focus Areas in the New Jersey Highlands Cluster

Focus Areas in New Jersey Highlands Cluster	*DRWI Phase*	*Area (ha)*	TP Load (kg/y) *Target*	*Baseline Assessment* tp_load	*Point Sources* tp_load_ps	*Excess NPS* tp_load_xsnps	*Reduced by Restoration*	*Remaining NPS Load* tp_load_rem	*Avoided by Protection* tp_load_avoid	**Proportion Restored** *% of Excess Reduced* only if excess is positive	*% of Excess Remaining*
Beaver Brook	Phase 2	3,860	1,197	1,339	0	142	0	142	0	0%	100%
Lopatcong Creek	Phase 2	3,877	1,202	24,528	844	22,483	137	22,346	0	1%	99%
Lower Middle Musconetcong	Phase 2	11,986	3,716	10,503	1,207	5,580	2,160	3,420	0	39%	61%
Paulinskill	Phase 2	27,100	8,401	10,835	596	1,838	2,502	-664	102	136%	--
Upper Musconetcong	Phase 2	9,169	2,842	1,979	0	-863	0	-863	1,066	--	--
Lopatcong Creek	Phase 1 only	2,906	901	32,878	49,200	-17,223	49	-17,271	0	--	--
Lower Musconetcong	Phase 1 only	4,612	1,430	3,702	19	2,253	201	2,052	0	9%	91%
Upper Musconetcong	Phase 1 only	11,882	3,683	3,552	1,053	-1,185	1	-1,186	85	--	--
Upper Paulins Kill	Phase 1 only	5,302	1,644	2,039	0	395	0	395	0	0%	100%
Other Areas		97,954	30,366	71,202	14,890	25,946	353	25,593	21	1%	99%
Total for Cluster		178,647	55,381	162,557	67,809	39,368	5,403	33,965	1,275	14%	86%

Poconos and Kittatinny

Characterized by:

342,462 ha (846,239 acres),

- 79% forested,
- 9% urban,
- 9%wetland and water,
- 3% agriculture,
- 15% impaired streams,
- 29% protected lands

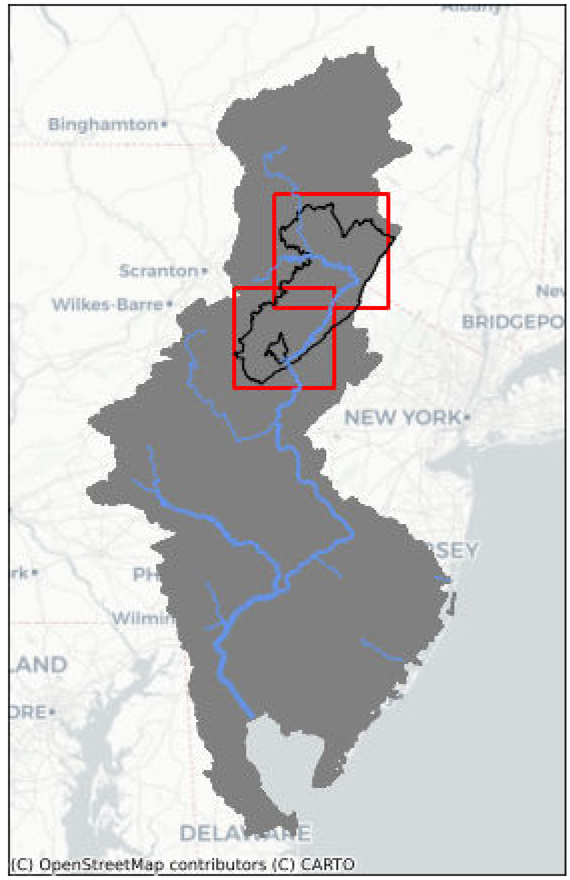
Stressors/threats:

Development:

- Year-round as well as seasonal homes: Pike and Monroe counties (PA) have the fastest-growing populations within the Delaware Basin

  • Energy infrastructure (if legislation changes)

Extent Map:
Poconos and Kittatinny Cluster



Total Phosphorus

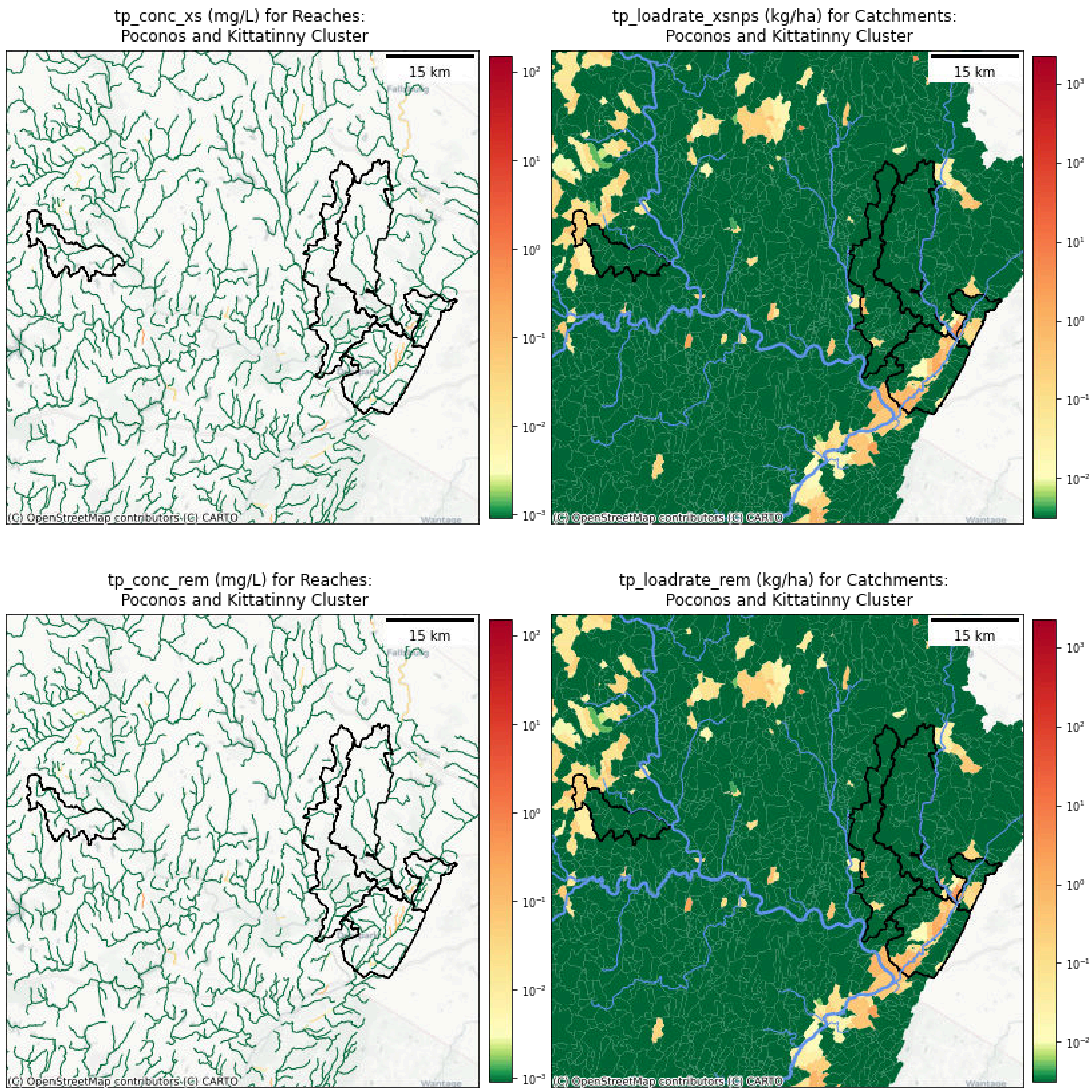


Figure B-5A. Total phosphorus hotspot maps for the northern group of Focus Areas in the Poconos and Kittatinny Cluster (upper focus areas) of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

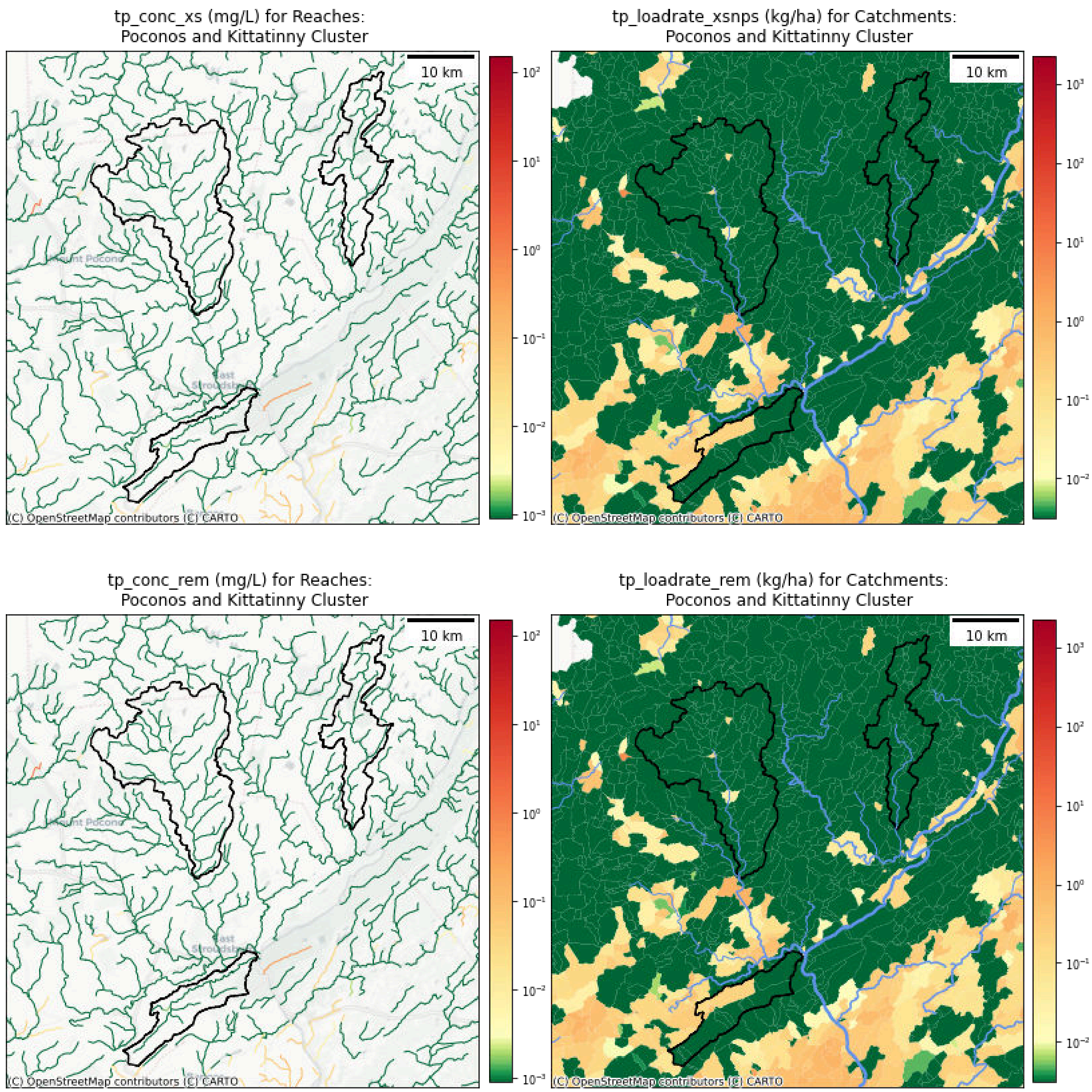


Figure B-5B. Total phosphorus hotspot maps for the southern group of Focus Areas in the Poconos and Kittatinny Cluster (upper focus areas) of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-5. Total Phosphorus (TP) loads for Focus Areas in the Poconos and Kittatinny Cluster

Focus Areas in			**TP Load (kg/y)**							**Proportion Restored**	
Poconos and Kittatinny Cluster	*DRWI Phase*	*Area (ha)*	*Target*	*Baseline Assessment*	*Point Sources*	*Excess NPS*	*Reduced by Restoration*	*Remaining NPS Load*	*Avoided by Protection*	*% of Excess Reduced*	*% of Excess Remaining*
				tp_load	tp_load_ps	tp_load_xsnps		tp_load_rem	tp_load_avoid	only if excess is positive	
Lower Neversink V2	Phase 2	18,263	5,662	2,144	275	-3,792	0	-3,792	1,054	--	--
Upper Neversink V2	Phase 2	5,411	1,677	2,055	730	-353	0	-353	790	--	--
Upper Neversink River up	Phase 2	9,146	2,835	1,003	0	-1,833	0	-1,833	0	--	--
Upper Neversink River down	Phase 2	7,330	2,272	417	2	-1,858	0	-1,858	1,695	--	--
Upper Basha Kill V2	Phase 2	2,203	683	597	0	-86	0	-86	0	--	--
Twin Lakes	Phase 2	7,687	2,383	2,917	0	534	0	534	0	0%	100%
Brights Kill	Phase 2	4,347	1,347	440	0	-907	0	-907	0	--	--
Broadhead Creek	Phase 2	8,650	2,681	873	69	-1,878	0	-1,878	0	--	--
Shimers Brook	Phase 1 only	44,485	13,790	7,339	2,271	-8,722	0	-8,722	1,104	--	--
Broadhead V2	Phase 1 only	21,653	6,712	4,211	0	-2,501	0	-2,501	0	--	--
Lower Neversink River	Phase 1 only	30,653	9,502	3,903	168	-5,768	0	-5,768	19	--	--
Other Areas		182,634	56,617	43,086	11,378	-24,909	0	-24,909	1,119	--	--
Total for Cluster		**342,462**	**106,163**	**68,983**	**14,893**	**-52,073**	**0**	**-52,073**	**5,781**	**--**	**--**

Schuylkill Highlands

Characterized by:

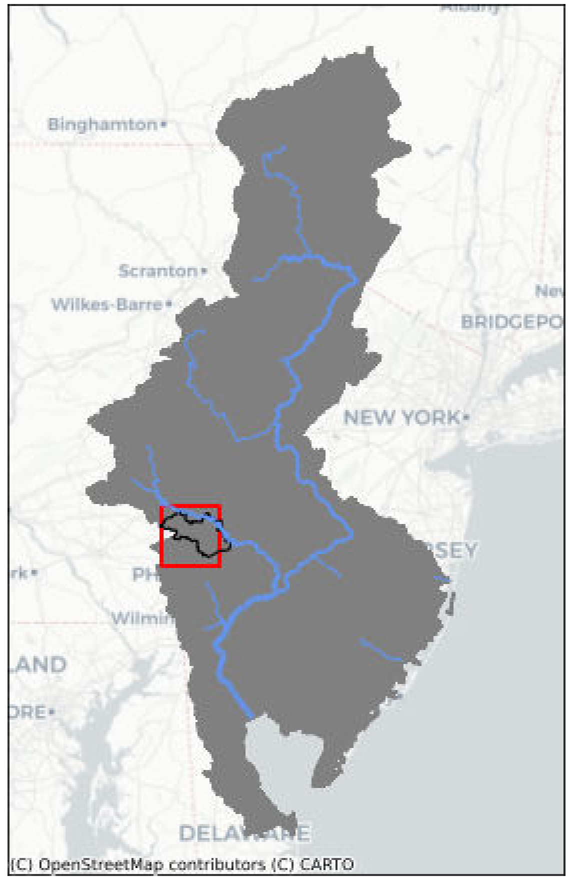
44,855 ha (110,839 acres),

- 49% forested,
- 25% agricultural,
- 22% urban,
- 4% wetland and water,
- 16% impaired streams,
- 11% protected lands

Stressors/threats:

- Residential Development and associated sewer construction and maintenance.
- Agriculture

Extent Map:
Schuylkill Highlands Cluster



Total Phosphorus

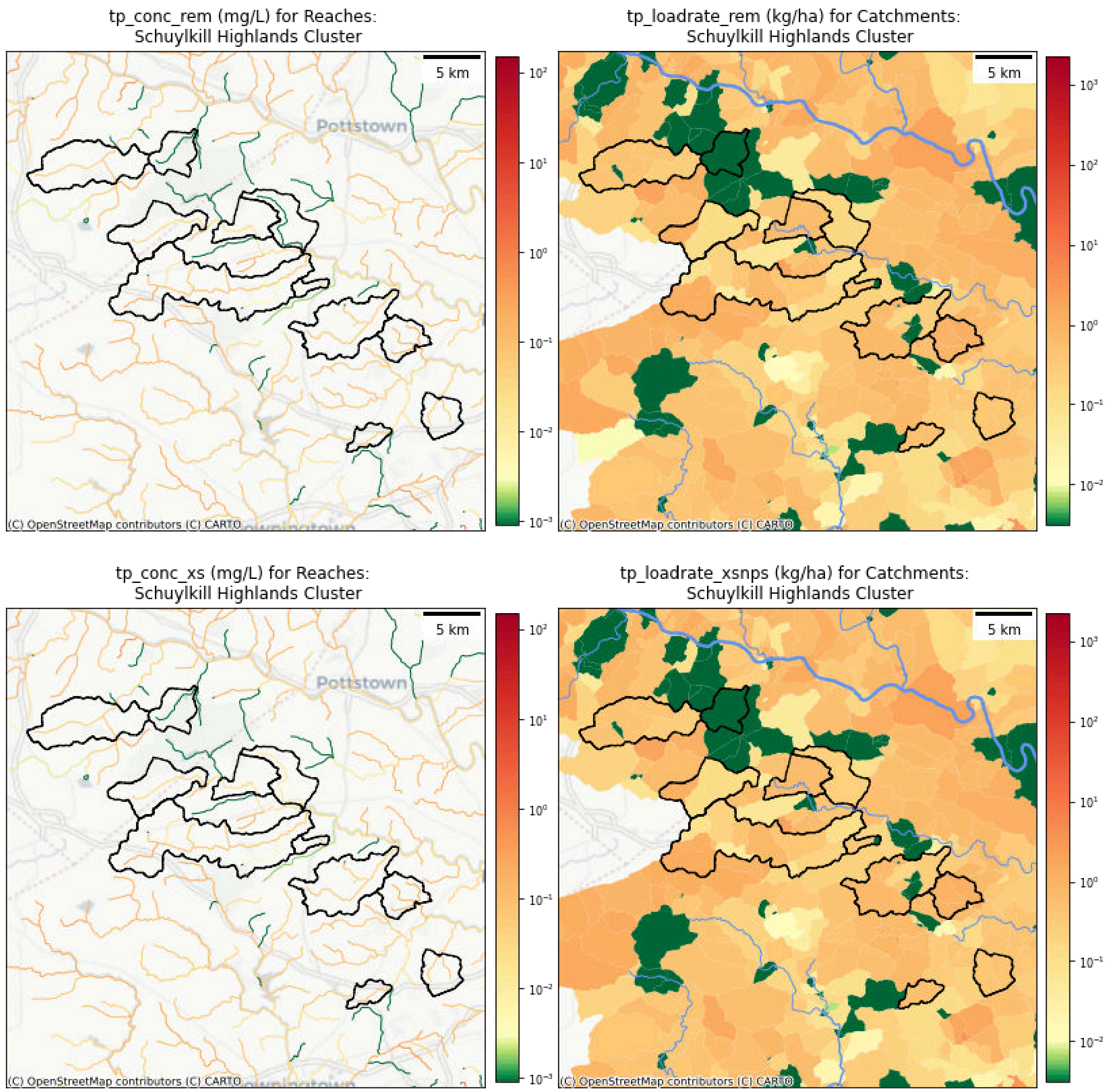


Figure B-6. Total phosphorus hotspot maps for the Schuylkill Highlands Cluster of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-6. Total Phosphorus (TP) loads for Focus Areas in the Schuylkill Highlands Cluster

Focus Areas in Schuylkill Highlands Cluster	DRWI Phase	Area (ha)	TP Load (kg/y) Target	Baseline Assessment tp_load	Point Sources tp_load_ps	Excess NPS tp_load_xsnps	Reduced by Restoration	Remaining NPS Load tp_load_rem	Avoided by Protection tp_load_avoid	Proportion Restored % of Excess Reduced (only if excess is positive)	% of Excess Remaining
Beaver Run/Hay Creek	Phase 2	1,759	545	1,186	0	641	0	641	87	0%	100%
Bryn Coed	Phase 2	653	203	866	0	663	0	663	4	0%	100%
Pigeon Run	Phase 2	592	184	417	0	233	11	222	0	5%	95%
Pine Creek/French Creek	Phase 2	1,187	368	763	0	395	0	395	0	0%	100%
Pine Creek/Pickering Creek	Phase 2	317	98	254	0	156	2	154	0	1%	99%
Rock Run	Phase 2	874	271	473	0	202	64	138	0	32%	68%
Sixpenny	Phase 2	645	200	73	0	-127	0	-127	0	--	--
South Branch French Creek	Phase 2	3,516	1,090	2,901	0	1,811	8	1,803	57	0%	100%
Upper Birch Run	Phase 2	1,695	526	1,291	0	765	0	765	0	0%	100%
Upper French Creek	Phase 2	767	238	745	14	493	0	493	0	0%	100%
Welkinweir/Beaver Run	Phase 2	166	51	96	0	45	0	45	11	0%	100%
French Creek Headwaters	Phase 1 only	4,600	1,426	3,124	38	1,660	0	1,660	60	0%	100%
Pigeon Creek	Phase 1 only	2,698	836	1,989	0	1,153	0	1,153	0	0%	100%
Schuylkill River	Phase 1 only	24	8	4	0	-3	0	-3	0	--	--
Sixpenny/Hay Creek	Phase 1 only	3,332	1,033	2,307	27	1,248	0	1,248	0	0%	100%
Stony Creek	Phase 1 only	1,469	455	2,001	0	1,546	0	1,546	0	0%	100%
Other Areas		20,561	6,374	35,891	22,864	6,652	0	6,652	19	0%	100%
Total for Cluster		**44,855**	**13,905**	**54,380**	**22,943**	**17,532**	**86**	**17,447**	**237**	**0%**	**100%**

Upper Lehigh

Characterized by:

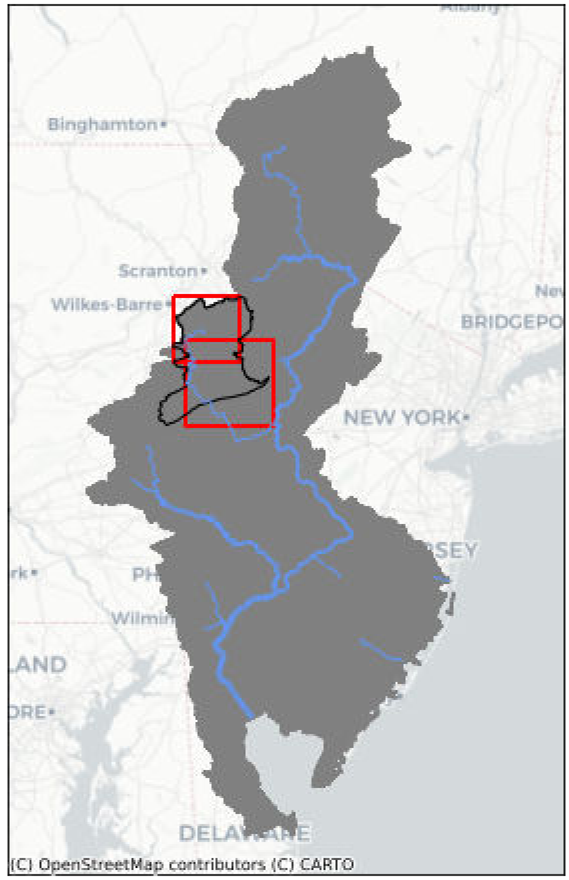
198,030 ha (489,340 acres):

- 72% forested,
- 11% urban,
- 9% agricultural,
- 8% wetland and water,
- 6% impaired streams,
- 24% protected lands

Stressors/threats:

- Small inactive dams
- Development: Disparate development projects with little large-scale planning

Extent Map:
Upper Lehigh Cluster



Total Phosphorus

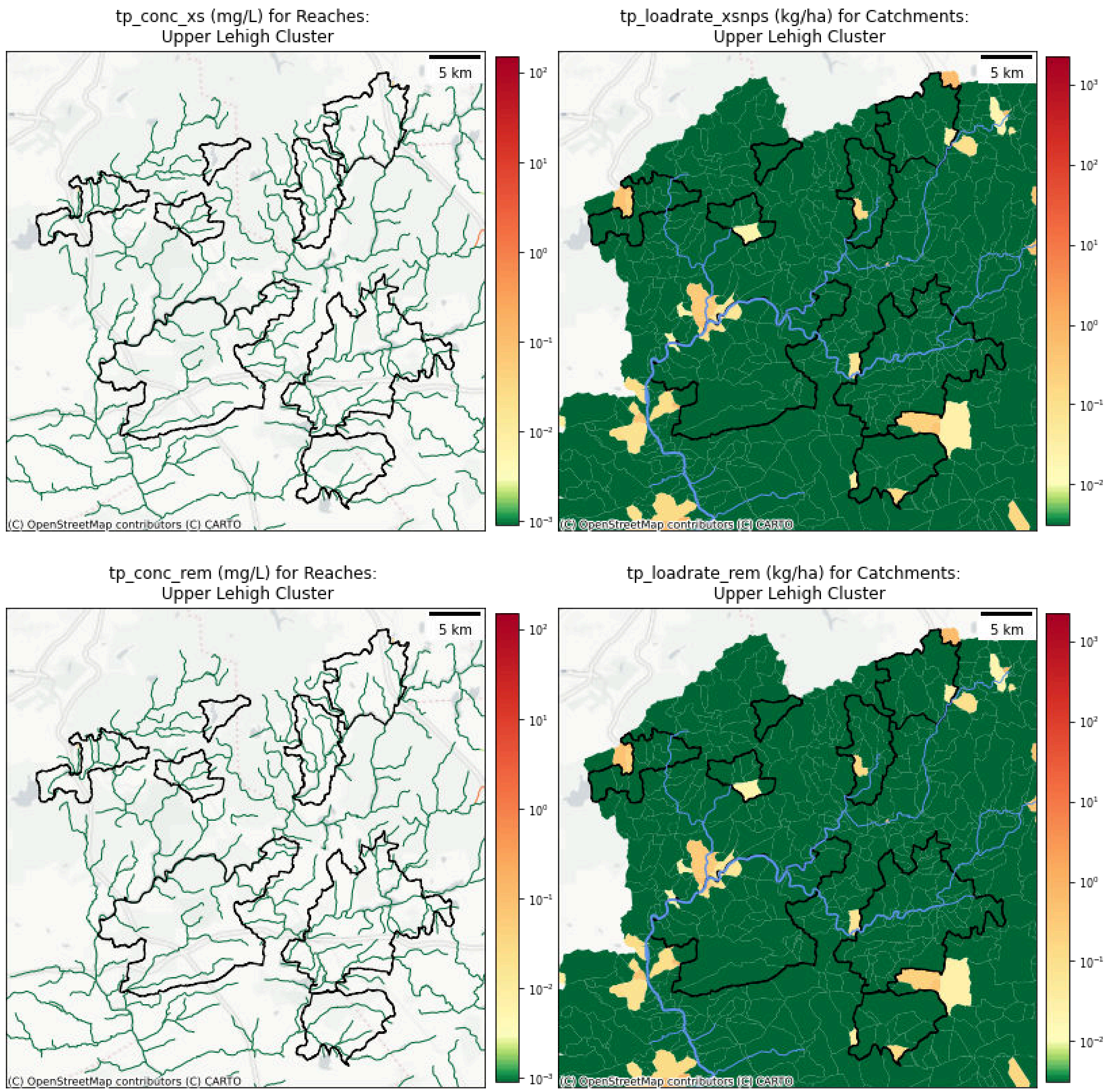


Figure B-7A. Total phosphorus hotspot maps for the northern group of Focus Areas in the Upper Lehigh Cluster (upper focus areas) of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

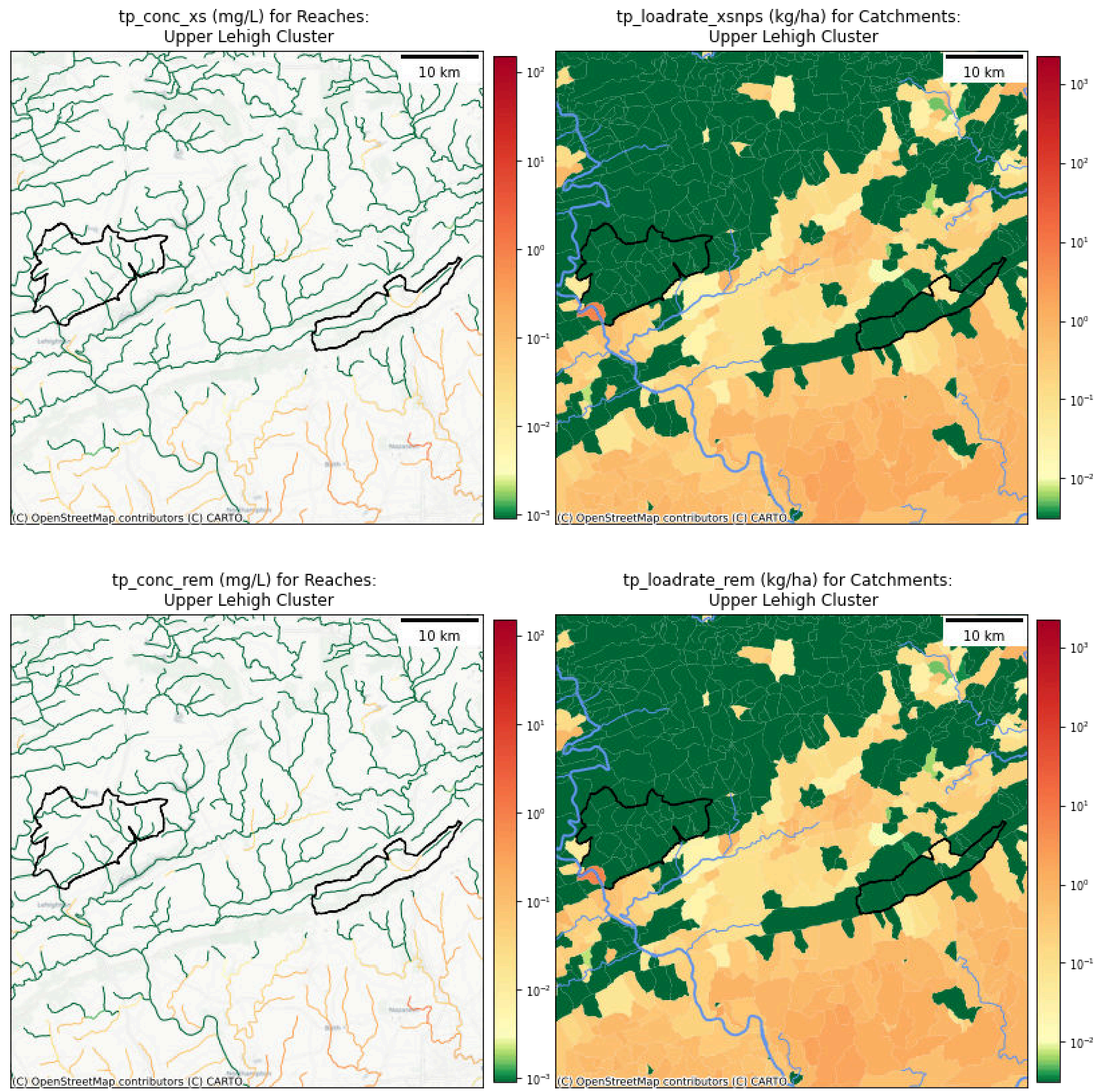


Figure B-7B. Total phosphorus hotspot maps for the southern group of Focus Areas in the Upper Lehigh Cluster (upper focus areas) of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-7. Total Phosphorus (TP) loads for Focus Areas in the Upper Lehigh Cluster

Focus Areas in Upper Lehigh Cluster	*DRWI Phase*	*Area (ha)*	**TP Load (kg/y)** *Target*	*Baseline Assessment* tp_load	*Point Sources* tp_load_ps	*Excess NPS* tp_load_xsnps	*Reduced by Restoration*	*Remaining NPS Load* tp_load_rem	*Avoided by Protection* tp_load_avoid	**Proportion Restored** *% of Excess Reduced* only if excess is positive	*% of Excess Remaining*
Bear Creek	Phase 2	3,264	1,012	442	0	-569	0	-569	543	--	--
Blue Ridge	Phase 2	8,838	2,740	1,148	1	-1,593	0	-1,593	0	--	--
Clifton	Phase 2	2,541	788	424	0	-364	0	-364	0	--	--
Fogal Smith	Phase 2	2,535	786	346	17	-457	0	-457	0	--	--
Jim Thorpe	Phase 2	7,196	2,231	907	0	-1,324	0	-1,324	0	--	--
Kittatinny Ridge East	Phase 2	3,670	1,138	1,319	804	-622	0	-622	1,072	--	--
Thornhurst	Phase 2	2,003	621	298	0	-323	0	-323	0	--	--
Tobyhanna Tunkhannock	Phase 2	6,814	2,112	846	0	-1,267	0	-1,267	15	--	--
Bear Creek	Phase 1 only	7,167	2,222	1,462	0	-760	0	-760	177	--	--
Kittatinny Ridge	Phase 1 only	5,625	1,744	1,447	124	-421	0	-421	65	--	--
Lehigh River Headwaters	Phase 1 only	1,050	325	97	0	-228	0	-228	131	--	--
Mud Run	Phase 1 only	2,673	829	254	0	-574	0	-574	0	--	--
Tobyhanna/Tunkhannock Creek	Phase 1 only	1,228	381	106	0	-275	0	-275	0	--	--
Wild Creek	Phase 1 only	721	223	41	0	-182	0	-182	0	--	--
Other Areas		142,704	44,238	50,822	15,300	-8,717	0	-8,717	161	--	--
Total for Cluster		**198,030**	**61,389**	**59,960**	**16,246**	**-17,676**	**0**	**-17,676**	**2,163**	**--**	**--**

Upstream Suburban Philadelphia

Characterized by:

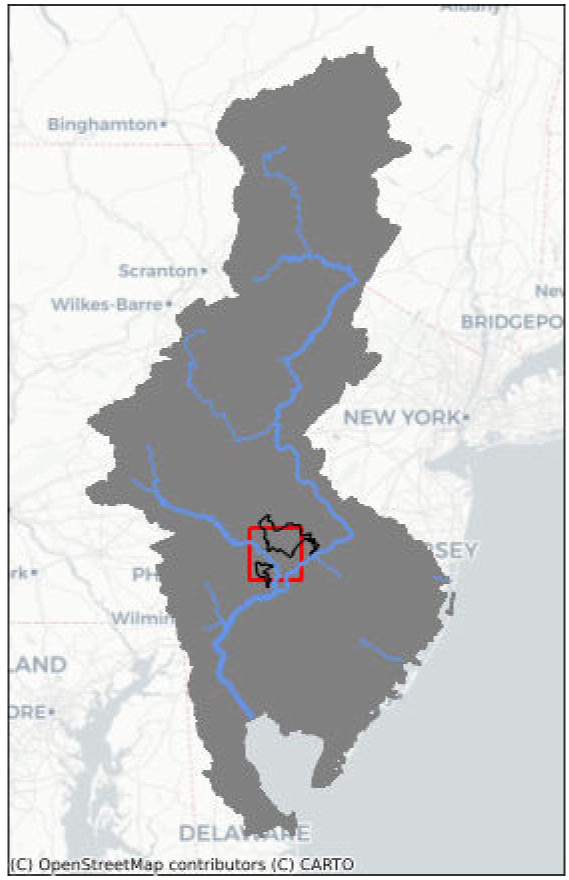
37,411 ha (92,444 acres):

- 77% urban,
- 17% forested,
- 4% agricultural,
- 2% wetlands and water,
- 95% impaired streams,
- 3% protected lands.

Stressors/threats:

- Stormwater runoff carrying pollutants, especially nutrients and sometimes sewage overflow
- High percentage of impervious cover

Extent Map:
Upstream Suburban Philadelphia Cluster



Total Phosphorus

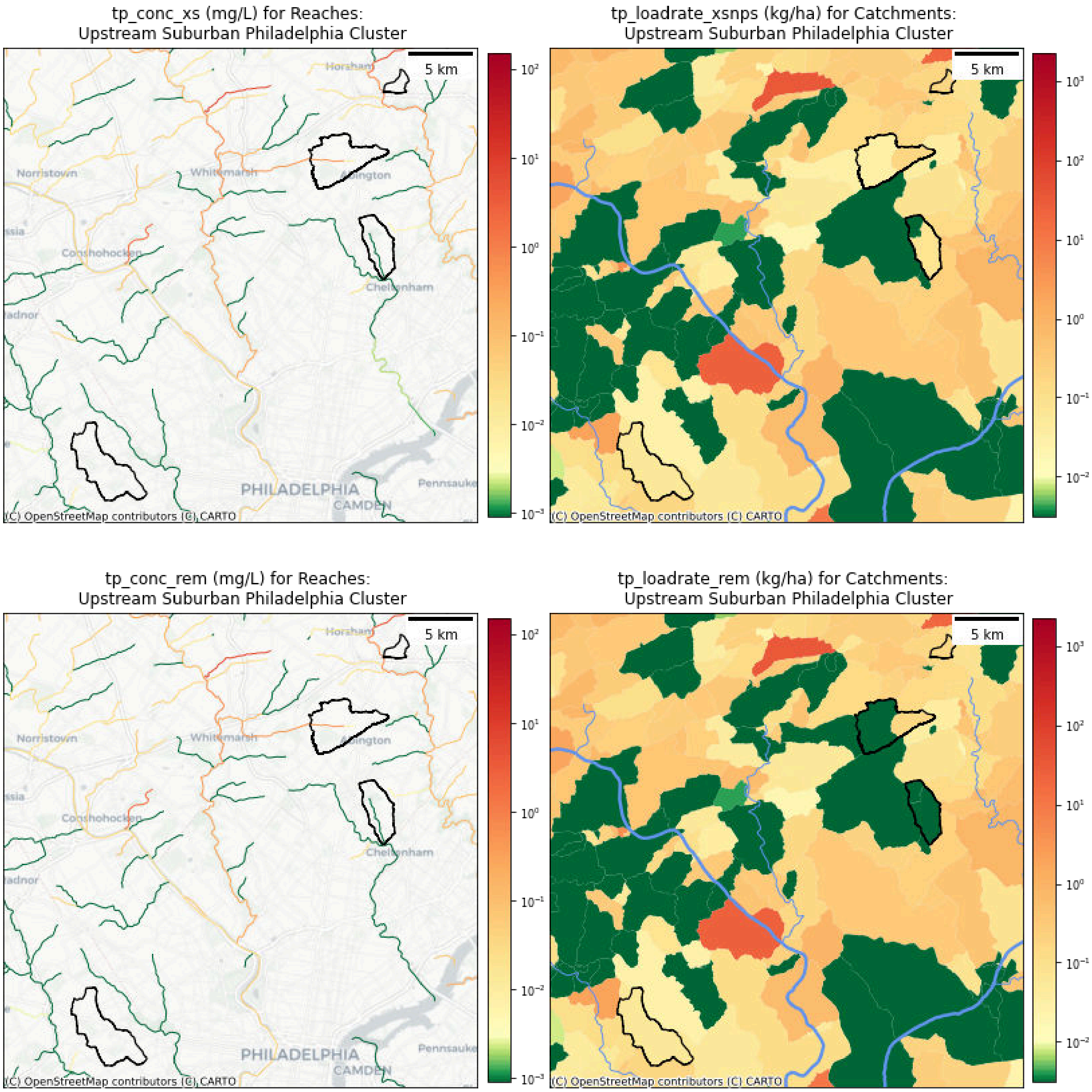


Figure B-23. Total phosphorus hotspot maps for the Upstream Suburban Philadelphia Cluster of stream concentrations (left) and catchment load rates (right), for (A) excess nonpoint source (XSNPS) compared to (B) XSNPS remaining accounting for reductions from DRWI restoration projects completed in Phase 1 & 2. Focus Areas are outlined in medium grey to highlight locations with most concentrated restoration activities and improvements.

Table B-23. Total Phosphorus (TP) loads for Focus Areas in the Upstream Suburban Philadelphia Cluster

Focus Areas in			TP Load (kg/y)							Proportion Restored	
Upstream Suburban Philadelphia Cluster	*DRWI Phase*	*Area (ha)*	*Target*	*Baseline Assessment* tp_load	*Point Sources* tp_load_ps	*Excess NPS* tp_load_xsnps	*Reduced by Restoration*	*Remaining NPS Load* tp_load_rem	*Avoided by Protection* tp_load_avoid	*% of Excess Reduced* only if excess is positive	*% of Excess Remaining*
Jenkintown	Phase 2	479	149	161	0	12	54	-42	0	434%	-334%
Sandy Run	Phase 2	230	71	112	0	40	3	37	0	7%	93%
Indian Creek	Phase 1 only	211	65	71	0	5	0	5	0	0%	100%
Pennypack Creek	Phase 1 only	978	303	576	0	273	29	244	0	10%	90%
Sandy/Rapp Run	Phase 1 only	2,844	882	5,610	4,484	245	168	76	0	69%	31%
Tookany Creek	Phase 1 only	3,940	1,221	1,493	0	272	0	272	0	0%	100%
Wissahickon Creek	Phase 1 only	1,883	584	2,282	40	1,659	99	1,560	0	6%	94%
Other Areas		26,846	8,322	49,067	38,260	2,485	32	2,452	0	1%	99%
Total for Cluster		**37,411**	**11,597**	**59,372**	**42,784**	**4,990**	**385**	**4,605**	**0**	**8%**	**92%**

Task 4: Provide Guidance on Appropriate Use of Pollution Assessment Results

Description of Task 4

Produce an accessible report that clearly presents the estimates and provides guidance on appropriate use of the information. This report should clarify the limitations of the estimates and explain:

A. Why these thresholds are or are not appropriate for DRWI goals;

B. What proportion of the total pollution is attributed as nonpoint source and of this, what is the relative proportion attributed to DRWI clusters compared to the entire basin;

C. What proportion of the NPS within the cluster boundaries could be addressed by DRWI land protection and ag restoration tactics;

   a. Please note there are still significant unresolved questions about methods to derive "pounds of NPS avoided" through land protection

D. What proportion of NPSP could be addressed in the other basin subwatersheds using the DRWI-style approach;

   a. We will need further feedback from WPF regarding what to use to describe the DRWI-style approach...for example, total dollars invested to generate load reductions over 1, 2, 10 years? Total BMPs installed per year or over 10 years? How might land protection fit in this question?

E. What proportion cannot be addressed using DRWI-style approach (and why) across the clusters and full basin; and

F. Rough estimates of the cost and time needed to protect and/or restore sufficient land, both basinwide and DRWI clusterwide, to eliminate the differential between the thresholds and current nonpoint source conditions.

   a. We will make progress on this in Stage 1, but expect that our results may be "provisional" so that we can further refine our approaches in Stage 2

   b. We will attempt to utilize at least three approaches as stated in 3.c.i. (above): 1) total dollars invested by WPF for DRWI to achieve the currently estimated load reductions; 2) total cost of BMP implementation reported in FieldDoc by partners (data may be incomplete); or 3) a derived average cost per pound reduced for a suite of BMPs that are estimated by the Chesapeake Bay Foundation's Cast database

4A. Appropriateness of Thresholds for DRWI Goals

Task 4A: Why these thresholds are or are not appropriate for DRWI goals?

The pollution thresholds set for the DRWI Pollution Assessment describe the 95% confidence below which stream reaches and catchments are no longer impaired based on independent assessments by states using various metrics. These confidence limits were calculated using similar methods to those used for the DRWI Pollution Assessment. These thresholds therefore are appropriate targets to meet the DRWI goals for healthy streams.

For more details, see the Pollution Threshold Targets section under Task 1, above.

4B. Proportion of Nonpoint Source Pollution

Task 4B: What proportion of the total pollution is attributed as nonpoint source and of this, what is the relative proportion attributed to DRWI clusters compared to the entire basin?

Point sources of TP accounted for approximately 64% of the total un-attenuated load delivered to local streams DRWI-wide (or about 56% of the attenuated TP load delivered to Delaware Bay), and accounted for 22% to 72% of the source load within clusters (Table 7).

Properly accounting for the downstream routing and attenuation of point sources in Stage 2 will be critical for mapping where it is not possible to improve water quality by reducing or avoiding nonpoint sources of pollution (a goal of this Pollution Assessment). Point sources are geographically concentrated, which appear only as small red dots in hotspot maps of catchments, yet their impacts extend far downstream, which do not appear on our Stage 1 hotspot maps of stream reaches.

4C. Proportion Addressable by DRWI Conservation within Clusters

Task 4C: What proportion of the NPS within the cluster boundaries could be addressed by DRWI land protection and ag restoration tactics?

The 918 DRWI-funded restoration projects reduced about 6.2% of the TP pollution load over the entire DRWI-area, and accounted for 6% to 14% within clusters focused on restoration activities (Table 7). This equates to a total TP reduction of about 16,107 kg/yr (or 35,500 lb/yr). Within Focus Areas, the benefits of restoration were much more dramatic (Task 3 Results by Cluster and Focus Area). Three Focus Areas reduced more than 100% of excess nonpoint source TP pollution, and ten additional Focus Areas reduced more than 20%. The proportion of excess nonpoint source pollution remaining is the balance of the proportion reduced, as presented in the percentages above and in Table 7.

Note that other DRWI-style restoration reductions are at least 7-10 times larger than from restoration projects funded by DRWI. This implies that all implemented restoration activities may have already reduced excess nonpoint source TP pollution by 40% to 60%. The proposed Stage 2 Refined Assessment will incorporate restoration data from a number of other BMP databases to fully assess remaining excess nonpoint source pollution.

The 54 DRWI-funded land protection projects avoided TP pollution equivalent to 74% of the reductions from restoration (Table 7), and equivalent to 151% to 277% of the reductions from DRWI restoration projects in the three clusters that prioritized land protection activities (Kirkwood - Cohansey Aquifer, Poconos and Kittatinny, and Upper Lehigh). This represents a significant impact on preserving water quality for these and downstream areas.

Land protection activities as funded by WPF essentially involve the acquisition of land at various locations throughout the Delaware River Basin (DRB) for the express purpose of maintaining these areas in a "natural" state so that they are not subject to being developed in the future. Land protection activities do not actually reduce current pollutant loads. However, we can estimate potential future load reductions based on assumptions about future land development. These avoided loads that could potentially occur as a result of such activities can therefore be compared to past and current load reductions due to restoration. However, given that land protection projects targeted clean watersheds that typically did not have excess pollution, it is not appropriate to include them in calculations of remaining pollution.

Note that other DRWI-style land protection also likely exceeds land protection projects directly funded by DRWI. We are not able to provide a ballpark estimate with the Stage 1 Rapid Assessment, but have proposed for Stage 2 that we fully incorporate the detailed Delaware River Watershed Conserved Lands database actively maintained by We Conserve PA.

4D. Proportion Addressable by DRWI Conservation outside Clusters

Task 4D: What proportion of NPSP could be addressed in the other basin subwatersheds using the DRWI-style approach?

The 918 DRWI-funded restoration projects reduced approximately 6.2% of the excess nonpoint source TP pollution load over the entire DRWI-area. Zooming into the geographies prioritized by DRWI, TP load reductions amounted to about 6% to 14% of XSNPS TP within clusters that prioritized restoration (Table 7), and from 20% to 259% of XSNPS TP within the Focus Areas where restoration projects were more intensely applied.

Similarly, the 54 DRWI-land project projects avoided TP loads in at nearly equivalent levels as loads reduced by restoration. These avoided loads were concentrated in three clusters with predominantly natural lands, ensuring that these source waters remain clean.

Our analysis show that these DRWI-style conservation practices also provide benefits for nitrogen and suspended sediment, and that once TP is addressed, the other pollutants will also no longer be in excess of thresholds.

These successes suggest that all remaining excess nonpoint source pollution in the DRB is likely addressable by DRWI-style conservation approaches, whether in a cluster or not. However, DRWI-style conservation approaches can not address or compensate for point source pollution, as described in under Task 4E, below.

4E. Proportion Not Addressable by DRWI Conservation

Point source pollution in the DRB totals about 66% of the total phosphorus load entering stream reaches across the DRWI area (Table 7; Task 4B). Point source loads are six to ten times higher than excess nonpoint source loads, depending on how we approximate downstream routing of pollution (note that in Stage 2 we will be able to explicitly route pollution sources downstream through the stream network).

Fortunately, the largest point source loads are located in the downstream reaches of each of the major tributaries to the Delaware river mainstem (Figure 4 compared to Figure 5), so their impacts are limited in the geographic extent. These point sources are much more of an issue for water quality within Delaware Bay than they are for streams and rivers within the Delaware River Basin. As such, most of these point sources are actively and effectively being addressed by municipalities, states, and the US Environmental Protection Agency under the Clean Water Act, with a focus on protecting the Bay.

With our Stage 1 Rapid Assessment, we conclude that a small fraction of catchments with excess pollution are not addressable by DRWI conservation projects, due to upstream point source pollution. With the proposed Stage 2 Refined Assessment, we will be able to map these catchments and calculate this percentage explicitly.

4F. Projected Costs to Address Remaining Pollution

Projected Restoration Costs

There are a wide range of less expensive field-based mitigation strategies that can be utilized to reduce nonpoint source nutrient and sediment loads which are conventionally referred to as “Best Management Practices” or BMPs. Some of these practices include those that are implemented on an annual basis such as the use of cover crops, conservation tillage and nutrient management in agricultural areas. Others, such as riparian buffers, involve the implementation of “structural” components that are designed to last for multiple years and are primarily used to filter pollutant loads from agricultural lands. Similarly, structural BMPs are often used in more developed areas to address problems associated with urban stormwater runoff. For the current assessment, focus was put on the simulation of the water quality benefits of structural BMPs under the assumption that WPF would be more inclined to fund “one-time” BMP implementation rather than provide long-term annual funding for BMPs. To reduce nutrient loads discharged from point sources, many advanced, expensive control technologies are typically used, but mitigation of point sources is not addressed in this assessment.

As part of this Stage 1 Pollution Assessment, simulations were done to determine potential reductions of remaining excess nonpoint source loads identified previously in Table 4, Task 3D, and Table 7 using the BMPs described in Appendix B for the entire DRB. Additional work was also conducted to determine the total costs that might be required to fund the implementation of these or similar BMPs in order to reduce pollutant loads to an “acceptable” level within the DRB. In this case, model-estimated pollutant loads for each NHD catchment within the DWRI area (over 19,000 in all) were compared against the target “threshold” values discussed in Task 1 and provided in Table 1. Estimates of the degree to which pollutant loads need to be reduced in order to meet the target values were calculated for each catchment. In turn, these estimated load reductions for each pollutant were accumulated across the entire DRB for the purpose of determining total load reductions needed basin-wide.

To clarify, these remaining or “required” load reductions are actually nonpoint source load reductions. In this case, it is assumed that if these nonpoint source load reductions are made where identified by this pollution assessment, they would be sufficient to allow local water quality impairments to be mitigated as long as any point source discharges in these areas are also similarly addressed and reduced via regulatory mandates.

Table 9 below shows the nonpoint pollutant reductions estimated to be needed as a result of the analyses described in the previous paragraphs. Note that these values are higher than those shown for the entire DRWI in Table 7 due to our recognition that we must distribute future restoration projects to where they are needed most, and for this Stage 1 Rapid Assessment we have not fully accounted for downstream routing of pollution as we will for the Stage 2 Refined Assessment.

Table 9. Summary of existing pollutant loads and potential load reductions.

Pollutant	Remaining Load Reductions Needed (kg/yr)[1]
Total Nitrogen	0
Total Phosphorus	416,267
Sediment	5,737,168

[1] Loads estimated to remain after accounting for DRWI-funded restoration projects

As illustrated by the basin-wide modeling exercise described earlier in Task 3 (and as illustrated in Table 9), annual basin-wide load reductions of 416,267 kg/yr Total Phosphorus and 5,737,168 kg/yr Total Suspended Sediment is remaining in order to achieve "acceptable" levels of water quality across the DRB. Based on the comparative analysis between "threshold" and "existing" loads, it was determined that similar reductions were not needed for nitrogen. To estimate how the remaining reductions might be achieved via the implementation of the representative BMPs described in Appendix B, 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. The results of this particular exercise are shown in Table 10 and Table 11.

Again, the reductions simulated in these tables are for nonpoint source loads only. It is assumed that if point source reductions are also made as needed, then acceptable water quality conditions will be met across the DRB based on the threshold values used. In areas where point source discharges don't currently exist, these nonpoint load reductions should achieve acceptable water quality conditions by themselves.

Table 10. Summary of simulated load reductions for the entire DRB.

Source	Initial Load (kg/yr)	% of Total DRB Load Reduced	% of Non-Point Source Load Reduced
Total Nitrogen	42,947,189	5.0	9.8
Total Phosphorus	2,977,846	14.1	31.8
Sediment	1,442,144,197	15.9	15.9

As described above, the BMPs in Table A-2 in Appendix A were "applied" to the remaining loads shown in Table 9 to simulate additional reductions that might be achieved with these BMPs, and these simulated reductions are shown in Tables 10 and 11. In Table 11, the estimated costs associated with implementing these BMPs are also given. In these tables, the "% reduced" and "loads reduced" estimates account for both recently-funded efforts by DRWI as well as future BMP implementation needed to address remaining non-point source loads in the DRB.

Similar to the work described above for the entire DRB, estimated load reductions attributed to recent DRWI-funded restoration projects, as well as reductions that could be achieved for each cluster through the use of future BMP implementation, were also estimated. The results from this exercise for each cluster are provided in a series of tables included in Appendix A which are in the same format used for Table 11 above.

Table 11. BMPs with associated implementation costs and pollutant loads reduced for the entire DRB.

BMP	Total Cost	TN Load (kg) Reduced[1]	TP Load (kg) Reduced[1]	TSS Load (kg) Reduced[1]
Urban Stormwater Management System	$186,912,626	45,159 (0.11%)	14,131 (0.5%)	69,118,853 (4.8%)
Animal Waste Management Systems	$54,827,002	934,151 (2.2%)	186,026 (6.3%)	0
Riparian Forest Buffers in Cropland Areas	$164,908,480	1,154,923 (2.7%)	217,225 (7.3%)	159,753,187 (11.1%)
Streambank Restoration/Protection	$27,010,767	4,172 (0.01)	1,140 (0.04%)	900,359 (0.06%)
TOTAL DRB COSTS AND LOADS REDUCED	**$433,658,875**	**2,138,404 (5.0%)**	**418,522 (14.1%)**	**229,772,399 (15.9%)**

[1] Percent of initial source load reduced indicated in parentheses ( )

DRWI-style restoration – such as $165M for riparian forest buffers in croplands and $55M for animal waste management systems – could together reduce 96% of the excess nonpoint source phosphorus. Urban stormwater practices and streambank restoration could together reduce all remaining pollutants for $214M. These costs are presently being borne by developers, cities, and state governments. The total estimated cost of $434 million also does not take into consideration load reductions that have already been achieved through the implementation of BMPs funded by other entities such as state and federal agencies (e.g., PADEP, USEPA, NRCS, etc.), municipalities (as required by existing or updated NPDES permits or state requirements), and various other private groups and foundations.

As described elsewhere, much BMP implementation work has already been accomplished by others through assorted funding programs (e.g., by various state and federal agencies and other organizations) and as a result of various regulatory requirements (e.g., NPDES permits and TMDL mandates). While it is our intent to more accurately establish such implementation levels as a part of Stage 2, some initial work was done to establish rough estimates of these implementation levels during Stage 1. Based on this initial analysis, it was estimated that a wide range of mitigation measures have already been implemented to address such pollutant sources such as urban stormwater runoff, croplands, farm animal wastes, streambank erosion, and nutrient build-up in groundwater underlying agricultural areas. Such measures were estimated to result in pollutant load reductions of approximately 356,765 kg/yr of TN, 199,652 kg/yr of TP, and 80,491,032 kg/yr of TSS. For context, these can be compared with the estimated reductions of 54,285 kg/yr of TN, 14,768 kg/yr of TP, and 789,081 kg/yr achieved as a result of DWRI-funded restoration activities as shown in Table 9.

If the assumed implementation levels used for this initial analysis are accurate, such reductions would equate to about half of the "needed" TP reductions given in Table 9 above and would address all of the needed TSS reductions shown in the same table. This would therefore result in a significant decrease in the cost estimate for future BMP implementation given in Table 11. However, additional work will need to be undertaken in Stage 2 to establish more accurate BMP implementation levels, specifically regarding both quantity and geographic location. This latter point is important since load reductions not only have to be looked at in aggregate, but also with respect to where they are geographically implemented since "more than enough" reductions might be made in some locations, but "less than enough" reductions may still occur in other areas.

Projected Land Protection Costs

No attempt was made to estimate future land protection costs for addressing "future" loads as part of Stage 1. It was felt that such an exercise would require that modeling be done with more recent land cover data than was used in the current analysis (i.e., 2011 vintage) as well as more detailed analysis of "projected development" datasets produced by Shippensburg University. With respect to the former, more recent land cover data (2019 vintage) is now being incorporated into Model My Watershed, and will be available for simulation purposes before the end of 2021.

References

Sheeder, S.A. and Evans, B.M., 2004. Estimating nutrient and sediment threshold criteria for biological impairment in Pennsylvania watersheds. *Journal of the American Water Resources Association*, 40(4), pp.881-888.

Appendix A: Methods and Supplemental Results

Restoration and Protection Project Information from FieldDoc

For Stage 1 of the Pollution Assessment, we manually downloaded spreadsheets containing restoration and protection project data stored in FieldDoc. For the purposes of setting up a reproducible process that would enable us to "refresh" project information to generate the most up to date analysis, we developed scripts that: 1) format FieldDoc outputs, 2) save updated project data to the ANS DRWI Database, and 3) re-run our analysis that apportions practice reductions in N,P, and S to specific sub-watersheds within the basin. In Stage 2 we proposed to open up the FieldDoc platform with a public access point(API). This will enable us to re-run analysis with a few clicks, as opposed to an extensive manual process.

Modeling Methods for Baseline Pollutant Loads

No additional description of the modeling of baseline loads beyond that provided in Task 3 are needed.

Assessment of Load Reductions Based on DRWI-Funded Restoration Efforts

No additional description of estimating these load reductions beyond that provided in Task 3 are needed.

Modeling Methods for BMP Pollutant Load Reductions

No additional description of estimating these load reductions beyond that provided in Task 3 are needed.

Estimation of Additional Costs for Future BMP Implementation

As described previously, water quality problems throughout the Delaware River Basin (DRB) are caused by pollutant loads delivered to streams, ponds and other water bodies from a number of point and nonpoint sources. Within the DRB, point sources include both municipal and industrial wastewater treatment systems. For the purposes of this assessment, the pollutants of primary concern from these sources are nitrogen and phosphorus. With respect to non-point sources, the pollutants of primary concern are nitrogen, phosphorus and sediment. These pollutants can come from any area on the landscape, but the largest loads typically come from developed land and agricultural land that is cultivated and/or contains large populations of farm animals such as dairy and beef cows, poultry, pigs, etc. Another important non-point source includes eroded streambanks, particularly those downstream of highly-developed areas. Table A-1 below provides the distribution of pollutant loads within the DRB as determined using the results from Model My Watershed (ModelMW).

Table A-1. Distribution of pollutant loads within the DRB.

Source	TN Load (kg/yr)	% of Total DRB TN Load	TP Load (kg/yr)	% of Total DRB TP Load	Sediment Load (kg/yr)	% of Total DRB TSS Load
Hay/Pasture	256,339	0.60	94,478	3.17	24,516,768	1.70
Cropland	1,694,328	3.95	437,709	14.70	288,724,776	20.02
Wooded Areas	177,197	0.41	10,916	0.37	2,669,478	0.19
Wetlands	101823	0.24	3,322	0.11	166,382	0.01
Open Land	14,651	0.03	1,242	0.04	884,440	0.06
Barren Areas	5,218	0.01	148	0.00	7,266	0.00
Low-Density Mixed	62,114	0.14	5,448	0.18	2,086,385	0.14
Medium-Density Mixed	140,175	0.33	12,051	0.40	5,643,191	0.39
High-Density Mixed	65,394	0.15	5,738	0.19	2,565,312	0.18
Low-Density Open Space	116,645	0.27	10,260	0.34	4,067,696	0.28
Farm Animals	1,245,534	2.90	248,034	8.33	0	0.00
Stream Bank Erosion	688,660	1.60	284,649	9.56	1,110,812,503	77.03
Subsurface Flow	17,105,336	39.83	197,284	6.63	0	0.00
Point Source Discharges	20,945,465	48.77	1,666,567	55.97	0	0.00
Septic Systems	328,310	0.76	0	0.00	0	0.00
TOTALS	42,947,189	100.00	2,977,846	100.00	1,442,144,197	100.00

To reduce nutrient loads discharged from point sources, many advanced, expensive control technologies are typically used. Costs associated with reducing such loads, however, are not addressed in this current assessment. Conversely, there is a wide range of field-based mitigation strategies that can be utilized to reduce nonpoint source nutrient and sediment loads which are conventionally referred to as “Best Management Practices” or BMPs. Some of these practices include those that are implemented on an annual basis such as the use of cover crops, conservation tillage and nutrient management in agricultural areas. Others, such as riparian buffers, involve the implementation of “structural” components that are designed to last for multiple years and are primarily used to filter pollutant loads from agricultural lands. For the current assessment, focus was put on the simulation of the water quality benefits of structural BMPs under the assumption that WPF would be more interested in funding “one-time” BMP implementation rather than provide long-term annual funding for BMPs.

As can be seen in Table A-1, the primary sources of nitrogen, phosphorus and sediment pollution within the DRB include agricultural land, urban development of all types, farm animals in agricultural areas, stream bank erosion, subsurface flow, and point source discharges. It should be noted here that although stream bank erosion appears in this table as a separate category (due primarily to the way it is simulated within ModelMW), is it actually a natural occurrence of runoff from all the land cover types shown in the table. It is also true that runoff produced from impervious surfaces in developed areas is by far the most important source in watersheds where development approaches 10% or more of the total area, as is the case in the DRB. Consequently, implementing stormwater BMPs in urban areas decreases surface transport of sediment as well as streambank erosion downstream of these areas.

Similarly, subsurface flow also appears in Table A-1 as a separate category, although nutrients transported via this mechanism (principally nitrogen) primarily originate from surface sources (particularly agricultural land) via soil leaching. Since agricultural land represents about 20% of the land area within the DRB, at least 20% of the subsurface nitrogen and phosphorus loads in the DRB can also be attributed to leaching from these areas.

To estimate the potential reductions and costs associated with implementing non-point source BMPs throughout the DRB, a select number of practices that address the sources mentioned above were used for simulation purposes. These practices, along with representative reduction coefficients and implementation costs, are shown in Table A-2. These costs and reduction coefficients are those currently used in ModelMW and related tools, and come from a number of established literature sources (primarily reports associated with EPA's Chesapeake Bay Watershed model). It should be noted that if "annual" BMP practices such as cover crops, conservation tillage and nutrient management are used in place of the riparian buffer option used in this analysis, the total costs would not change that significantly over the long term. The costs of implementing such BMPs in agricultural areas would be less initially, but they would require continuing annual investments.

Table A-2. BMPs with associated implementation costs and reduction coefficients.

BMP	Implementation Cost	TN Reduction Coefficient	TP Reduction Coefficient	TSS Reduction Coefficient
Urban Stormwater Management System	$2989 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

As part of the Stage 1 Pollution Assessment, simulations were done to determine potential reductions of those nonpoint source loads described above using the BMPs shown in Table A-2 for the entire DRB. Additional work was also conducted to determine the total costs that might be required to fund the implementation of these or similar BMPs in order to reduce pollutant loads to an "acceptable" level within the DRB. In this case, model-estimated pollutant loading rates for each NHD catchment within the DRB (over 15,000 in all) were compared against the target "threshold" values shown in Table 1 in Task 1, and estimates of the degree to which pollutant loads need to be reduced in order to meet the target values were calculated for each catchment. In turn, these estimated load reductions for each pollutant were accumulated across the entire DRB for the purpose of determining total load reductions needed basin-wide.

Table A-3 below shows the initial (baseline) loads estimated to be produced with the DRB on an annual basis. (Note: these initial estimates do not account for any load reductions that might be related to existing BMPs implemented as a result of WPF funding or the activities of other groups such as state and federal agencies). Also shown in this table are the pollutant reductions estimated to be needed as a result of the analyses described in the previous paragraph.

Table A-3. Summary of existing pollutant loads and potential load reductions.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	42,947,189	0	54,285 (0.13%)	0
Total Phosphorus	2,977,846	431,036	14,768 (3.4%)	416,267
Sediment	1,442,144,197	6,526,249	789,081 (12.1)%	5,737,168

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of DRWI-funded restoration projects. The % values shown indicate the percent of the "needed" reductions achieved.
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

As illustrated by the basin-wide modeling exercise described earlier in Task 3 (and as illustrated in Table A-3), annual basin-wide load reductions of 431,036(14.5%), and 6,526,249 (0.9%) were determined to be needed for phosphorus and sediment, respectively, in order to achieve "acceptable" levels of water quality across the DRB. Of these needed reductions, it was determined that some progress has already been made due to various BMPs implemented as a result of DRWI-funded restoration projects, and the load reductions resulting from these efforts are also shown in this table. To estimate how the remaining reductions might be achieved via the implementation of the BMPs shown in Table A-2, 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. The results of this particular exercise are shown in Tables A-4 and A-5 below.

Table A-4. Summary of simulated load reductions for the entire DRB.

Source	Initial Load (kg/yr)	% of Total DRB Load Reduced	% of Non-Point Source Load Reduced
Total Nitrogen	42,947,189	5.0	9.8
Total Phosphorus	2,977,846	14.1	31.8
Sediment	1,442,144,197	15.9	15.9

Table A-5. BMPs with associated implementation costs and pollutant pounds reduced for the entire DRB

BMP	Total Cost	TN Load (kg) Reduced[1]	TP Load (kg) Reduced[1]	TSS Load (kg) Reduced[1]
Urban Stormwater Management System	$186,912,626	45,159 (0.11%)	14,131 (0.5%)	69,118,853 (4.8%)
Animal Waste Management Systems	$54,827,002	934,151 (2.2%)	186,026 (6.3%)	0
Riparian Forest Buffers in Cropland Areas	$164,908,480	1,154,923 (2.7%)	217,225 (7.3%)	159,753,187 (11.1%)
Streambank Restoration/Protection	$27,010,767	4,172 (0.01)	1,140 (0.04%	900,359 (0.06%)
TOTAL DRB COSTS AND LOADS REDUCED	$433,658,875	2,138,404 (5.0%)	418,522 (14.1%)	229,772,399 (15.9%)

[1] Percent of initial source load reduced indicated in parentheses ( )

As described above, the BMPs in Table A-2 were "applied" to the remaining loads shown in Table A-3 to simulate additional reductions that might be achieved with these BMPs, and these simulated reductions are shown in Tables A-4 and A-5. In Table A-5, the estimated costs associated with implementing these BMPs are also given. In these tables, the "% reduced" and "kilograms reduced" estimates account for both recently-funded efforts by DRWI as well as future BMP implementation needed to address remaining non-point source loads in the DRB.

Similar to the work described above for the entire DRB, estimated load reductions attributed to recent DRWI-funded restoration projects in the eight different DRWI clusters, as well as reductions that could be achieved for each cluster through the use of future BMP implementation, were also estimated. The results from this exercise for each cluster are provided in the following tables which are in the same format used for Table A-5 above.

Brandywine Christina Cluster

Table A-6. Summary of existing pollutant loads and potential load reductions Brandywine-Christina Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	2,032,147	0	0	0
Total Phosphorus	117,940	38,486	3,581	34,905
Sediment	103,533,502	0	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A-7. BMP implementation costs and pollutant pounds reduced for the Brandywine Christina Cluster.

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$4,386,160	74,732 (3.7%)	14,882 (12.6%)	0
Riparian Forest Buffers in Cropland Areas	$922,213	108,563 (5.3%)	20,419 (17.3%)	15,016,800 (14.2%)
Streambank Restoration/Protection	$0	0	0	0
Total Cluster Costs and Loads Reduced	$5,308,371	183,295 (9.0%)	35,301 (29.9%)	15,016,800 (14.2%)

[1] Percent of initial source load reduced indicated in parentheses ( )

Kirkwood-Cohansey Aquifer

Table A8. Summary of existing pollutant loads and potential load reductions Kirkwood-Cohansey Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	2,849,539	Not needed	0	0
Total Phosphorus	160,820	Not needed	0	0
Sediment	182,163,755	Not needed	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A9. BMP implementation costs and pollutant pounds reduced for the Kirkwood-Cohansey Cluster.

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$0	0	0	0
Riparian Forest Buffers in Cropland Areas	$0	0	0	0
Streambank Restoration/Protection	$0	0	0	0
Total Cluster Costs and Loads Reduced	$0	0	0	0

[1] Percent of initial source load reduced indicated in parentheses ( )

Middle Schuylkill

Table A10. Summary of existing pollutant loads and potential load reductions Middle Schuylkill Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	3,441,219	Not needed	0	0
Total Phosphorus	300,007	90,728	5,046	85,682
Sediment	140,924,762	Not needed	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A11. BMP implementation costs and pollutant pounds reduced for the Middle-Schuylkill Cluster

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$12,061,941	205,513 (6.0%)	40,926 (13.6%)	0
Riparian Forest Buffers in Cropland Areas	$4,699,742	242,534(7.0%)	45,617 (15.2%)	33,548,169 (23.8%)
Streambank Restoration/Protection	0	0	0	0
Total Cluster Costs and Loads Reduced	$16,761,683	448,047 (13.0%)	86,543 (28.8%)	33,548,169 (23.8%)

[1] Percent of initial source load reduced indicated in parentheses ( )

New Jersey Highlands

Table A12. Summary of existing pollutant loads and potential load reductions for the NJ Highlands Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	1,640,035	Not needed	0	0
Total Phosphorus	162,557	39,368	5,403	33,965
Sediment	87,748,771	Not needed	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A13. BMP implementation costs and pollutant pounds reduced for the New Jersey Highlands Cluster

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$4,386,160	74,732 (4.6%)	14,882 (9.2%)	0
Riparian Forest Buffers in Cropland Areas	$1,063,999	103,943 (6.3%)	19,550 (12.0%)	14,377,787 (16.4%)
Streambank Restoration/Protection	$0	0	0	0
Total Cluster Costs and Loads Reduced	$5,450,159	178,675 (10.9%)	34,432 (21.2%)	14,377,787 (16.4%)

[1] Percent of initial source load reduced indicated in parentheses ( )

Table A14. Summary of existing pollutant loads and potential load reductions Poconos-Kittatinny Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	876,611	Not needed	0	0
Total Phosphorus	68,983	Not needed	0	0
Sediment	71,151,330	Not needed	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A14. BMP implementation costs and pollutant pounds reduced for the Poconos-Kittatinny Cluster

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$0	0	0	0
Riparian Forest Buffers in Cropland Areas	$0	0	0	0
Streambank Restoration/Protection	$0	0	0	0
Total Cluster Costs and Loads Reduced	$0	0	0	0

[1] Percent of initial source load reduced indicated in parentheses ( )

Table A15. Summary of existing pollutant loads and potential load reductions Schuylkill Highlands Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	669,055	Not needed	0	0
Total Phosphorus	54,380	17,532	85	17,447
Sediment	28,019,762	Not needed	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A16. BMP implementation costs and pollutant pounds reduced for the Schuylkill Highlands Cluster

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$2,741,350	46,708 (7.0%)	9,301 (17.1%)	0
Riparian Forest Buffers in Cropland Areas	$105,862	43,887 (6.6%)	8,255 (15.2%)	6,070,621 (21.7%)
Streambank Restoration/Protection	$0	0	0	0
Total Cluster Costs and Loads Reduced	$2,847,212	90,595 (13.6%)	17,556 (32.3%)	6,070,621 (21.7%)

[1] Percent of initial source load reduced indicated in parentheses ( )

Table A17. Summary of existing pollutant loads and potential load reductions Upper Lehigh Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	534,462	Not needed	0	0
Total Phosphorus	59,960	Not needed	0	0
Sediment	54,479,311	Not needed	0	0

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A18. BMP implementation costs and pollutant pounds reduced for the Upper Lehigh Cluster

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$0	0	0	0
Animal Waste Management Systems	$0	0	0	0
Riparian Forest Buffers in Cropland Areas	$0	0	0	0
Streambank Restoration/Protection	$0	0	0	0
Total Cluster Costs and Loads Reduced	$0	0	0	0

[1] Percent of initial source load reduced indicated in parentheses ( )

Table A19. Summary of existing pollutant loads and potential load reductions Upstream Sub Phila Cluster.

Pollutant	Initial Load (kg/yr)[1]	Total DRB Reduction Needed (kg/yr)[2]	Estimated DRWI-Funded Reductions (kg/yr)[3]	Remaining Load Reductions Needed (kg/yr)[4]
Total Nitrogen	372,054	Not needed	0	0
Total Phosphorus	59,372	4,990	385	4,605
Sediment	41,086,618	6,526,249	789,081	5,737,168

[1] Estimates based on simulations with Model My Watershed
[2] Estimates based on comparison of existing loads with threshold loading values
[3] Based on simulation of future BMP implementation
[4] Loads estimated to remain after accounting for DRWI-funded restoration projects

Table A20. BMP implementation costs and pollutant pounds reduced for the Upstream Sub Phila Cluster

BMP	Total Cost	TN Load (kg/yr) Reduced[1]	TP Load (kg/yr) Reduced[1]	TSS Load (kg/yr) Reduced[1]
Urban Stormwater Management System	$95,350,923	16,102 (4.3%)	4,126 (6.9%)	18,891,159 (46.0%)
Animal Waste Management Systems	$0	0	0	0
Riparian Forest Buffers in Cropland Areas	$0	0	0	0
Streambank Restoration/Protection	$13,505,383	2,086 (0.6%)	570 (1.0%)	450,179 (1.1%)
Total Cluster Costs and Loads Reduced	$108,856,307	18,188 (4.9%)	4,605 (7.9%)	19,341,338 (47.1%)

[1] Percent of initial source load reduced indicated in parentheses ( )

Evaluation of Land Protection Benefits

Land protection activities as funded by WPF essentially involve the acquisition of land at various locations throughout the Delaware River Basin (DRB) for the express purpose of keeping these areas in a "natural" state so that they are not subject to being developed in the future. For the purposes of Stage 1 of the Pollution Assessment, the basic approach to evaluating the potential impact of these activities on water quality within the DRB centered around estimating the differences in potential sediment, nitrogen and phosphorus loads between "pre-" and "post-" development conditions. Initial calculations were made by assuming 100% build-out using medium-density development conditions for each parcel associated with WPF-funded projects, calculating "future" pollutant loads that might occur as a result, and then determining the difference between these loads and loads under "current" conditions. These initial estimates were then modified by using "growth" projections for each parcel based on development patterns modeled by Shippensburg University and development projections made by the Open Space Institute. The results for all of these calculations were put into a spreadsheet (osilpia_projects_lbsavoided.xlsx) to facilitate further calculations, and the data/results associated with various tabs in the spreadsheet are described below.

Tab: **osi_projects_lbsavoided**

This tab contains the initial calculations made by Mike Campagna at Drexel/ANS as well as some that were added later. Column A (proj_name) contains a separate line for each parcel associated with a given land protection project. Column C (comid) gives the NHD catchment that each parcel is in, and Column G (area_acres) gives the area for each parcel. Columns D-F gives the HUC12, HUC10 and HUC8 watersheds that each parcel is located in. Columns H through M provide the loading rates (lb/ac) for medium-density developed and forest land for each parcel based on the HUC12 that it is located in, and columns N and O, Q and R, and T and U provide the total TSS, TN and TP loads for fully developed and forested parcels, respectively. Using these loads, the "pollutant loads avoided" (i.e., the difference between fully developed and forest loads) were calculated, and are shown in columns P (parcel_tssload_lbyr_avoided), S (parcel_tnload_lbyr_avoided), and V (parcel_tpload_lbyr_avoided).

Tabs: **Aggregated and Aggregated2**

This tab is basically the preliminary tab to the "Aggregated2" tab which shows how acres and loads for each parcel were summed into the larger project areas. This tab is similar to the previous tab, except that the watershed columns (comid, HUC12, HUC10, and HUC8) have been eliminated and newer columns that show how the parcel values have been summed for each project (Total Acres, ProjectDevTSS, ProjectForTSSload, ProjectTSSavoided, etc.) have been added. The "Aggregated2" tab is a simplified version of the "Aggregated" tab where only the project-level loads for 'pre-" and "post-" development conditions are given.

Tab: **DevAmtRecalc**

As mentioned previously, the initial "pollutant loads avoided" values shown in the first tab were calculated assuming 100% build-out with medium-density development in each project parcel. In this additional tab, these initial load estimates were reduced using estimates of future development provided by Shippensburg's projected growth modeling results for 2100 (Corridor scenario) and by OSI based on their best estimates of what might occur in different project areas based on local knowledge. In this tab, columns B and C contain the "percent development" estimates for each aggregated project from Shippensburg and OSI, respectively. For each pollutant, these values were multiplied by the initial "full development" development estimates in columns D, G and J to calculate the "reduced" load estimates for each pollutant shown in columns E, F, H, I, K and L. (Note here that the records highlighted in peach indicate projects that were later abandoned for various reasons).

Tab: **Reduction Summary**

In this tab, the "initial" and "reduced" loads in the previous tab are summed and compared against estimates of basin-wide loads for the DRB as estimated by the SPARROW model developed by USGS. In this case, the estimated loads for abandoned projects have been eliminated from the results.

Appendix B: Best Management Practice Descriptions

Table B1. Modeled BMP descriptions. This list represents 55 BMP types that fit within 7 classes (or archetypes).

Class	Best Management Practice (BMP)	BMP Description
Agricultural Animal	Animal Waste Management Systems (All Types) Waste Storage Facility Waste Storage Pond Waste Storage Structure	Systems designed to collect runoff and/or wastes from confined animal operations for the purpose of breaking down wastes via aerobic or anaerobic processes. Typical examples include waste lagoons or holding tanks that collect the wastes and prevent their discharge to nearby streams. *
Stream Restoration	Watering Facility	Watering structures (e.g., troughs) located off-stream.
	Fence	Fencing constructed to keep livestock out of the stream.
	Non Urban Stream Restoration	Use of "natural channel design" or "regenerative stream channel" principles to maintain a state of dynamic equilibrium between water, sediment and vegetation in order to create a stable channel in non-urban areas.
	Stream Channel Stabilization	The use of rip-rap, gabion walls, or a "bio-engineering" solution of some type along the edges of a stream to protect the banks during periods of heavy stream flow, thereby reducing direct stream bank erosion. These methods are generally less effective than the "stream restoration" BMP.
	Streambank and Shoreline Protection	Use of "natural channel design" or "regenerative stream channel" principles to maintain a state of dynamic equilibrium between water, sediment and vegetation in order to create a stable channel in non-urban areas.
	Urban Stream Restoration	Use of "natural channel design" or "regenerative stream channel" principles to maintain a state of dynamic equilibrium between water, sediment and vegetation in order to create a stable channel in non-urban areas.
Land Use Change	Tree and Shrub Establishment	Refers to the planting of trees on agricultural land, except those used to establish riparian forest buffers, targeting lands that are highly erodible or identified as critical resource areas.
	Tree Planting	Refers to the planting of trees on agricultural land, except those used to establish riparian forest buffers,

Class	Best Management Practice (BMP)	BMP Description
		targeting lands that are highly erodible or identified as critical resource areas.
	Barnyard Runoff Controls	Includes the installation of practices such as roof runoff control, diversion of clean water from entering the barnyard, and control of runoff from barnyard areas.
	Conservation Easement (allow cropland to be retired)	An easement is implemented under which future development is prevented, but existing cultivation is discontinued.
	Conservation Easement (allow cropland to remain)	An easement is implemented under which future development is prevented, but existing cultivation is allowed to continue.
	Conservation Easement (allow natural land to remain)	An easement is implemented under which future development is prevented, and existing natural land remains.
	Heavy Use Area Protection	This involves the stabilization of areas frequently and intensively used by people, animals or vehicles by establishing vegetative cover, surfacing with suitable materials, and/or installing needed structures. (Note: this is no longer a BMP recognized by the Chesapeake Bay Program).
	Roof Runoff Management	This is similar to "Barnyard Runoff Controls", but less inclusive of other practices.
	Roof Runoff Structure	This is similar to "Barnyard Runoff Controls", but less inclusive of other practices.
	Roofs and Covers	This is similar to "Barnyard Runoff Controls", but less inclusive of other practices.
Agricultural Land	Conservation Tillage	Practice of leaving crop residue on the ground after harvesting in order to reduce soil erosion.
	Soil Conservation and Water Quality Plans	Farm conservation plans that involve a combination of agronomic, management and engineered practices that protect and improve soil productivity and water quality, and prevent deterioration on all or part of a farm. Generally, these plans are assumed to meet applicable NRCS technical standards.
	Comprehensive Nutrient Management Plan	Same as "Nutrient Management"; however, plan must be implemented in order to get nutrient reduction credit.
	Nutrient Management	Planned use of limited amounts of organic and/or inorganic nutrients sufficient to sustain optimum crop production while at the same time protecting the quality of nearby water resources.
	Conservation Cover	Establishing and maintaining permanent vegetative cover. Usually considered to be part of a "soil conservation plan".

Class	Best Management Practice (BMP)	BMP Description
	Cover Crop	Use of annual or perennial plant cover to protect soil from erosion during time period between harvesting and planting of primary crop.
	Grazing Land Protection	This practice utilizes a range of pasture management and grazing techniques to improve the quality and quantity of the forages grown on pastures and reduce the impact of animal travel lanes, animal concentration areas or other degraded areas.
	Prescribed Grazing	This practice utilizes a range of pasture management and grazing techniques to improve the quality and quantity of the forages grown on pastures and reduce the impact of animal travel lanes, animal concentration areas or other degraded areas.
Urban Stormwater Management	Constructed Wetland Dry Extended Detention Ponds Wet Pond Wet Ponds & Wetlands Bioretention Bioretention/raingarden C/D soils no underdrain Bioretention/raingardens - A/B soils no underdrain Bioretention/raingardens - C/D soils underdrain Bioswale Dry Well/Seepage Pit Impervious Surface Reduction Infiltration Practices w/o Sand Veg. - A/B soils no underdrain Permeable Pavement w/o Sand Veg. - A/B soils no underdrain Stormwater Performance Standard-Runoff Reduction Urban Infiltration Practices	A BMP used in urban areas to capture runoff from pervious surfaces in order to slow down water, nutrient and sediment transport to nearby streams.*

Class	Best Management Practice (BMP)	BMP Description
	Stormwater Performance Standard-Stormwater Treatment	
Polygon Drainage	Forest Buffer	Linear strips of wooded areas maintained on agricultural land between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutants from runoff. These buffers are usually between 35-100 feet in width.
	Forest Buffer - Narrow	Linear strips of wooded areas maintained on agricultural land between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutants from runoff. These buffers are usually between 10-35 feet in width.
	Riparian Forest Buffer	Linear strips of wooded areas maintained on agricultural land between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutants from runoff. These buffers are usually between 35-100 feet in width.
	Riparian Herbaceous Buffer	Linear strips of grass or other non-woody vegetation maintained on agricultural land between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutants from runoff. These buffers are usually between 35-100 feet in width.
	Grass Buffer - Narrow	Linear strips of grass or other non-woody vegetation maintained on agricultural land between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutants from runoff. These buffers are usually between 10-35 feet in width.
	Grass Buffers	Linear strips of grass or other non-woody vegetation maintained on agricultural land between the edge of fields and streams, rivers or tidal waters that help filter nutrients, sediment and other pollutants from runoff. These buffers are usually between 35-100 feet in width.
	Grassed Waterway	These are similar to "Grass Buffers", except that these are buffers that treat "internal drainageways" in cropped areas that are typically dry most of the time.
	Wetland Creation - Floodplain	A wetland created to treat runoff from the surrounding area.
	Wetland Restoration	An existing wetland which has had its' ability to treat runoff from the surrounding area restored.

Class	Best Management Practice (BMP)	BMP Description
	Wetland Restoration - Floodplain	An existing wetland which has had its' ability to treat runoff from the surrounding area restored.
Exclusion Buffer	Forest Buffer-Streamside with Exclusion Fencing	Similar to a "Forest Buffer" except that fencing is also installed to prevent animals from trampling the buffer or streambank, or entering the stream.
	Forest Buffer-Narrow with Exclusion Fencing	Similar to a "Forest Buffer - Narrow" except that fencing is also installed to prevent animals from trampling the buffer or streambank, or entering the stream.
	Grass Buffer-Narrow with Exclusion Fencing	Similar to a "Grass Buffer - Narrow" except that fencing is also installed to prevent animals from trampling the buffer or streambank, or entering the stream.
	Grass Buffer-Streamside with Exclusion Fencing	Similar to a "Grass Buffer" except that fencing is also installed to prevent animals from trampling the buffer or streambank, or entering the stream.

* This description fits all BMPs within this class.