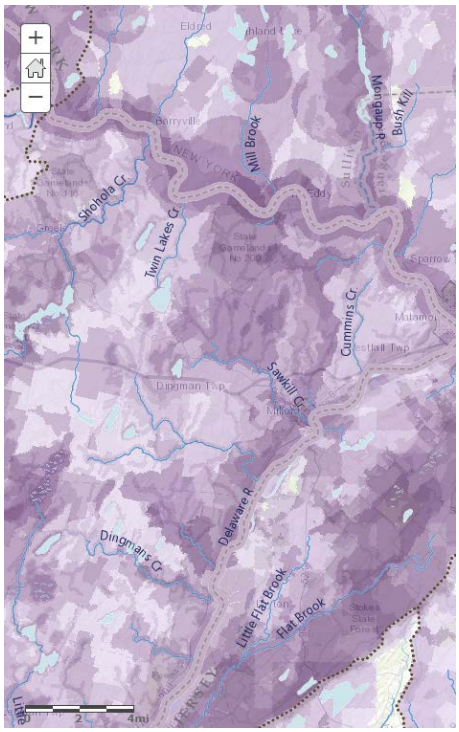
# Conservation Planning for Natural Gas Pipeline Routing: Protecting High-Value Natural Resources in the Delaware Basin

May 2018

TROUT UNLIMITED





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## Introduction

Construction of natural gas pipelines is associated with a variety of impacts to natural resources. With the build-out of transmission lines underway in the Marcellus shale region, Trout Unlimited (TU) has conducted a landscape-scale analysis to identify and map high-value natural resources that should be taken into account during the planning and review of major pipeline proposals in the Delaware River Basin. Working with a focus group representing industry, state and federal government agencies, and the nonprofit conservation community, we identified publicly available datasets across four themes—coldwater fisheries, water quality, biodiversity, and intact lands. We then created a scoring scheme that highlighted attributes of importance to stakeholders, and performed a GIS analysis to produce a map identifying priority ecological areas.

This analysis focuses on areas of ecological significance. Numerous other factors play a significant role in the siting of major pipeline infrastructure, including:

- Local community impacts
- Private landowner concerns
- Presence of existing infrastructure
- Location of historical places
- Occurrence of archeological sites

This product is best viewed as a first-cut analysis of ecological considerations. We encourage industry, agency and conservation professionals to use this analysis and map in concert with other resources that document potential impacts of major pipeline infrastructure in the Delaware River Basin. Please see the Discussion section for more.

### Using TU's Pipeline Siting Map

Our web map is a user-friendly tool for those who want to assess the ecological impacts of major pipeline proposals in the Delaware River Basin states.

**Pipeline industry**: to inform and guide route selection during the planning phases of major interstate pipelines, and to understand the potential natural resource impacts that must be addressed or mitigated;

**Regulatory agencies**: to evaluate routes, set permit conditions, and assess mitigation needs;

**Conservation professionals**: to support science-based discussions about major pipeline proposals with industry and agencies.

## Pipeline Construction Impacts: Why We Care

Natural gas pipeline development can have a variety of impacts on natural resources during both the construction and operational phases. Erosion and sedimentation can degrade water quality and fisheries during construction as a result of the earth-moving and trenching required to place the pipeline. This is especially true at stream crossings. Storms may cause erosion controls to fail before a site has been revegetated, sending plumes of sediment into streams. Water quality can be degraded by runoff from access roads, and by contamination from gas leaks and other chemicals, such as herbicides required to maintain pipeline rights-of-way. Fisheries can also be harmed by changes in stream temperatures associated with the removal of riparian vegetation at crossing locations. Entrekin and others provide a

synthesis of water quality concerns associated with natural gas pipeline construction and Weltman-Fahs and Taylor summarize potential impacts to fisheries.

Pipeline construction generally requires clearing areas 100 to 150 feet wide to accommodate construction equipment and excavated materials. The permanent 50-foot pipeline right-of-way requires mowing or herbicide treatments over the life of a project. Impacts from habitat conversion associated with these activities are most pronounced when pipelines pass through forested habitats. Direct impacts include habitat loss within the right-of-way and fragmentation of the large contiguous patches of core forest that are required by many rare and protected wildlife species. Edge habitats created by pipelines are also associated with secondary effects, such as increased spread of invasive species, increased predation, decreased nest success for birds, and altered dispersal patterns. Abrahams and others describe the effects of pipelines on forested habitats in greater detail.

## Methods

Our conservation planning objective was to identify areas with high-priority natural resources that could be affected by major natural gas pipeline infrastructure in the Delaware River Basin. We identified four categories of natural resources known to face impacts from pipeline development: cold water fisheries, water quality, biodiversity, and intact landscapes. For each theme, we created a preliminary list of publicly available spatial data sources. We categorized those datasets within a two-tiered hierarchy of ecological importance: high concern areas and concern areas. We presented these ideas and preliminary mapped results to a focus group of interested stakeholders, then refined our data sources and methods.

For each theme, high concern areas are scored “2,” concern areas “1,” and areas with low concern “0.” Table 1 outlines data sources and categorization of ecological importance; a Technical Appendix below provides additional details. For each location, we add up the four individual theme scores to determine a cumulative score. The final combined score has a minimum value of 0 (not identified as concern in any theme) and a maximum value of 8 (identified as high concern in all four themes).

When identifying data sources, we sought to balance the detail that was available with the extent of spatial coverage it could provide. Where datasets only covered a portion of the study area, we attempted to identify complementary datasets for the complete study area. We also focused on datasets related to any regulatory restrictions associated with pipeline development. Because of these requirements, we relied heavily on state-based datasets.

Our objective in creating a scoring scheme was to develop relatively simple, transparent rules based on source data attributes with some balance in the numerical and spatial distribution of scores. Balance is an important criterion, because our larger objective is to characterize a continuum of ecologically important areas. By creating a scoring scheme with a degree of scarcity of areas with the highest scores, our product will identify that subset of areas that are the highest priority natural resources.

| Theme | Level | Source Examples |
|---|---|---|
| **Cold Water Fisheries** | High Concern (Score = 2) | Highest tier state fisheries designations (e.g., PFBC Class A & Wilderness Trout streams) & TU Conservation Portfolio (resilient & redundant populations)) |
| | Concern (Score = 1) | Other state fisheries or water quality designations (e.g., NJ DEP water quality standards trout maintenance and trout production waters) |
| **Water Quality** | High Concern (Score = 2) | Highest tier state water quality designations (e.g., DE DNREC water quality standards Waters of Exceptional Recreational or Ecological Significance) |
| | Concern (Score = 1) | Other state water quality designations (e.g., NY DEC water quality standards 'protected waters' designation B - primary and secondary contact recreation and fishing) |
| **Biodiversity** | High Concern (Score = 2) | State natural heritage program database observations (e.g., NJ Natural Heritage Program Priority Sites) |
| | Concern (Score = 1) | State natural heritage communities (PA Natural Heritage Program Supporting Landscapes) |
| **Intact Landscapes** | High Concern (Score = 2) | Protected areas (e.g., state, federal, and conservation easement lands in USGS protected areas database) |
| | Concern (Score = 1) | Resilient terrestrial and aquatic sites (e.g., The Nature Conservancy terrestrial and freshwater resiliency analyses) |

**Table 1: Example data sources by theme for High Concern and Concern Factors. Additional details on data sources are provided in the Technical Appendix.**

## Results

Table 2 and Figures 1 – 5 provide a summary of our mapped results for the four themes and combined score across the Delaware River Basin. Results for individual states are provided for reference.

Cold water fisheries priority areas cover 35% of the Delaware River Basin and between 18 to 48% of the individual states with significant cold water resources (i.e., excluding Delaware). Areas of high concern are concentrated in the headwaters of the Delaware River in New York, the Lehigh and Schuylkill River headwaters in Pennsylvania, and isolated systems such as Flat Brook in New Jersey. Outside the basin, high concern areas occur in the Allegheny and Pocono Mountains of Pennsylvania, and the Adirondack and Catskill Mountains of New York (Figure 1).

Water quality priority areas in the high concern and concern categories cover 36% of Pennsylvania and 52% of the Delaware River Basin. Within the Delaware River Basin, there is nearly complete coverage of high concern areas in northern half of the Pennsylvania portion of the basin. High concern areas are concentrated in headwaters of the Lehigh and Lackawaxen rivers in Pennsylvania, the East and West Branches of Delaware River in New York, the Highlands and Pinelands regions of New Jersey, and scattered watersheds. Beyond the Delaware River Basin, high concern areas occur in the Finger Lakes of New York, the Allegheny Mountains of Pennsylvania, and Nanticoke River in Delaware (Figure 2).

| Theme | Score | Delaware Basin | Pennsylvania | New York | New Jersey | Delaware |
|---|---|---|---|---|---|---|
| **Cold Water Fisheries** | 2 | 8.7% | 18.9% | 18.7% | 0.3% | 0.0% |
| | 1 | 26.1% | 14.6% | 28.7% | 17.7% | 1.0% |
| | 0 | 65.3% | 66.5% | 52.6% | 82.0% | 99.0% |
| **Water Quality** | 2 | 38.6% | 35.4% | 11.5% | 46.5% | 19.6% |
| | 1 | 13.2% | 0.0% | 18.1% | 9.5% | 7.4% |
| | 0 | 48.2% | 64.5% | 70.4% | 44.1% | 73.1% |
| **Biodiversity** | 2 | 11.3% | 7.9% | 25.8% | 7.0% | 0.0% |
| | 1 | 26.4% | 21.0% | 2.3% | 35.7% | 1.5% |
| | 0 | 62.3% | 71.0% | 71.9% | 57.3% | 98.4% |
| **Intact Landscapes** | 2 | 23.2% | 18.5% | 19.3% | 35.8% | 22.4% |
| | 1 | 23.7% | 26.3% | 23.8% | 9.8% | 12.5% |
| | 0 | 53.1% | 55.2% | 56.9% | 54.3% | 65.1% |
| **Final Combined** | 8 | 0.5% | 1.2% | 0.3% | 0.0% | 0.0% |
| | 7 | 1.6% | 1.9% | 1.0% | 0.8% | 0.0% |
| | 6 | 4.3% | 6.7% | 3.7% | 6.5% | 0.1% |
| | 5 | 8.8% | 6.9% | 6.3% | 11.0% | 0.4% |
| | 4 | 14.2% | 10.1% | 13.3% | 12.8% | 3.3% |
| | 3 | 18.4% | 11.0% | 15.6% | 15.8% | 7.5% |
| | 2 | 21.0% | 15.8% | 22.8% | 19.6% | 29.5% |
| | 1 | 14.2% | 21.1% | 14.4% | 14.4% | 8.8% |
| | 0 | 17.1% | 25.3% | 22.5% | 19.1% | 50.4% |

**Table 2: Percent of total area encompassed by high concern and concern scores by theme and combined scores**

Biodiversity scores cover the largest area in New Jersey (43%) and the Delaware River Basin (38%). Areas of high concern in the Delaware River Basin are concentrated along the main stems of the East and West Branches in the headwaters and on mountaintops in the Valley and Ridge province, and scattered in individual watersheds such as Basher Kill, NY and Cooks Creek, PA. At the statewide scale, areas of high concern occur along the mainstem Susquehanna River, in the headwaters of the West Branch Susquehanna, in the Catskill and Adirondack Mountains, and in the New Jersey Pine Barrens (Figure 3).

Intact landscapes scores are very evenly distributed across geographies – high concern areas cover between 19 to 36% of all areas. Concern areas cover 10 – 26%. Protected areas considered high concern areas in the Delaware River Basin include the Delaware Water Gap National Recreation Area, multiple Wild Forests or Wildlife Management Areas in New York, Pennsylvania State Game Lands or State Forests, and New Jersey State Forests. Major high concern areas outside of the basin include large blocks of National and State Forest in Pennsylvania, the Pine Barrens in New Jersey, and Adirondack Park in New York (Figure 4).

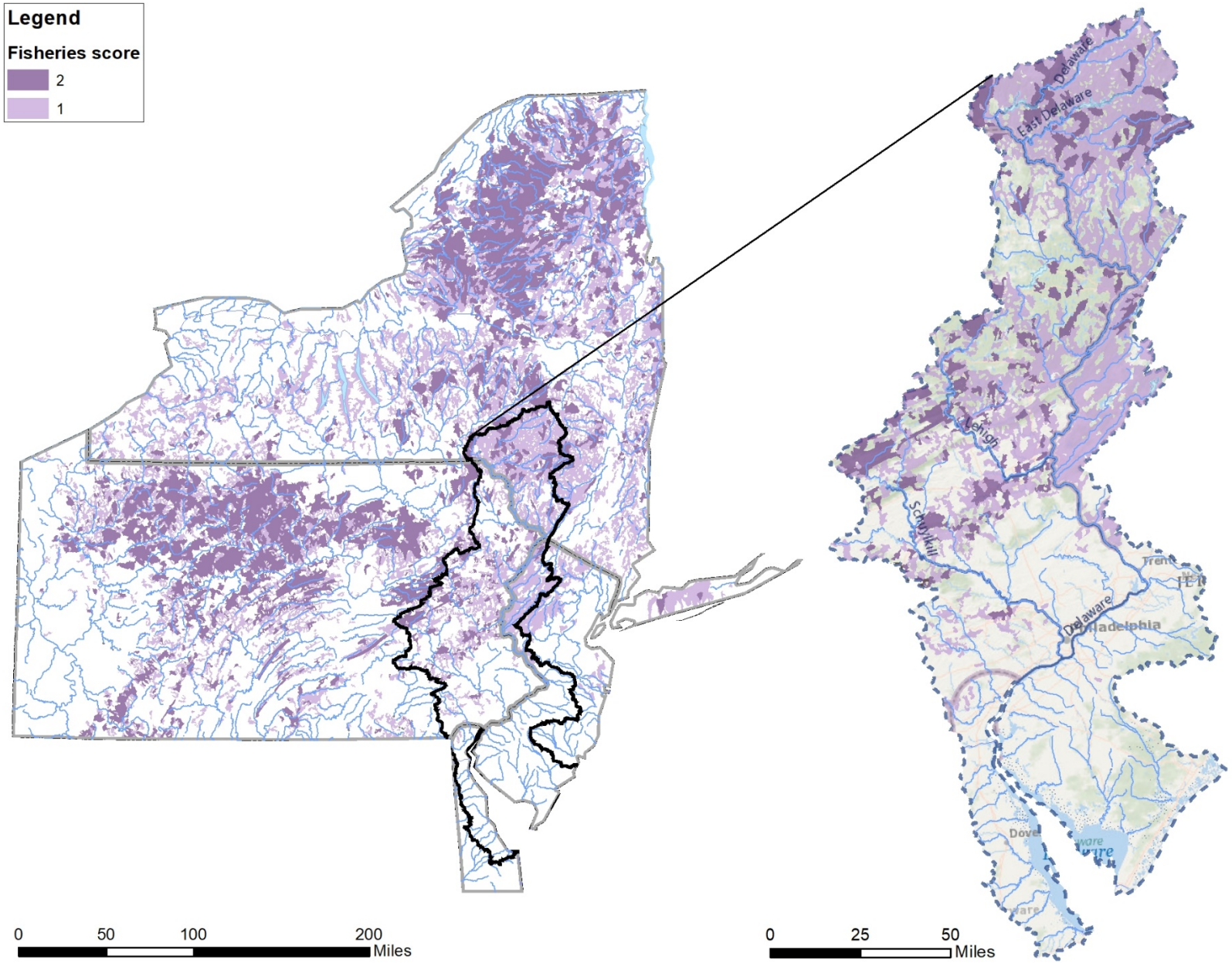


Figure 1: High concern and concern area scores for cold water fisheries

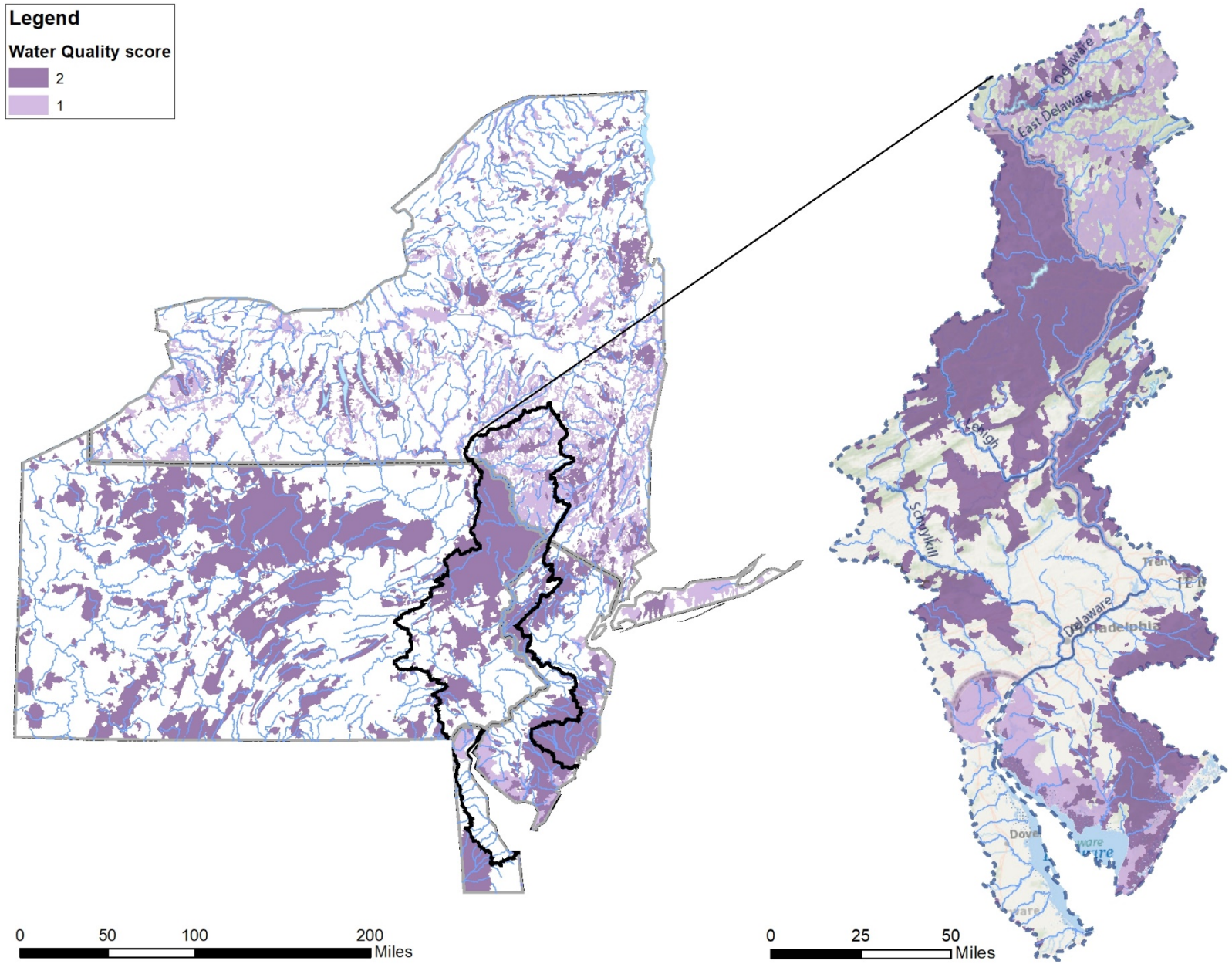


Figure 2: High concern and concern area scores for water quality

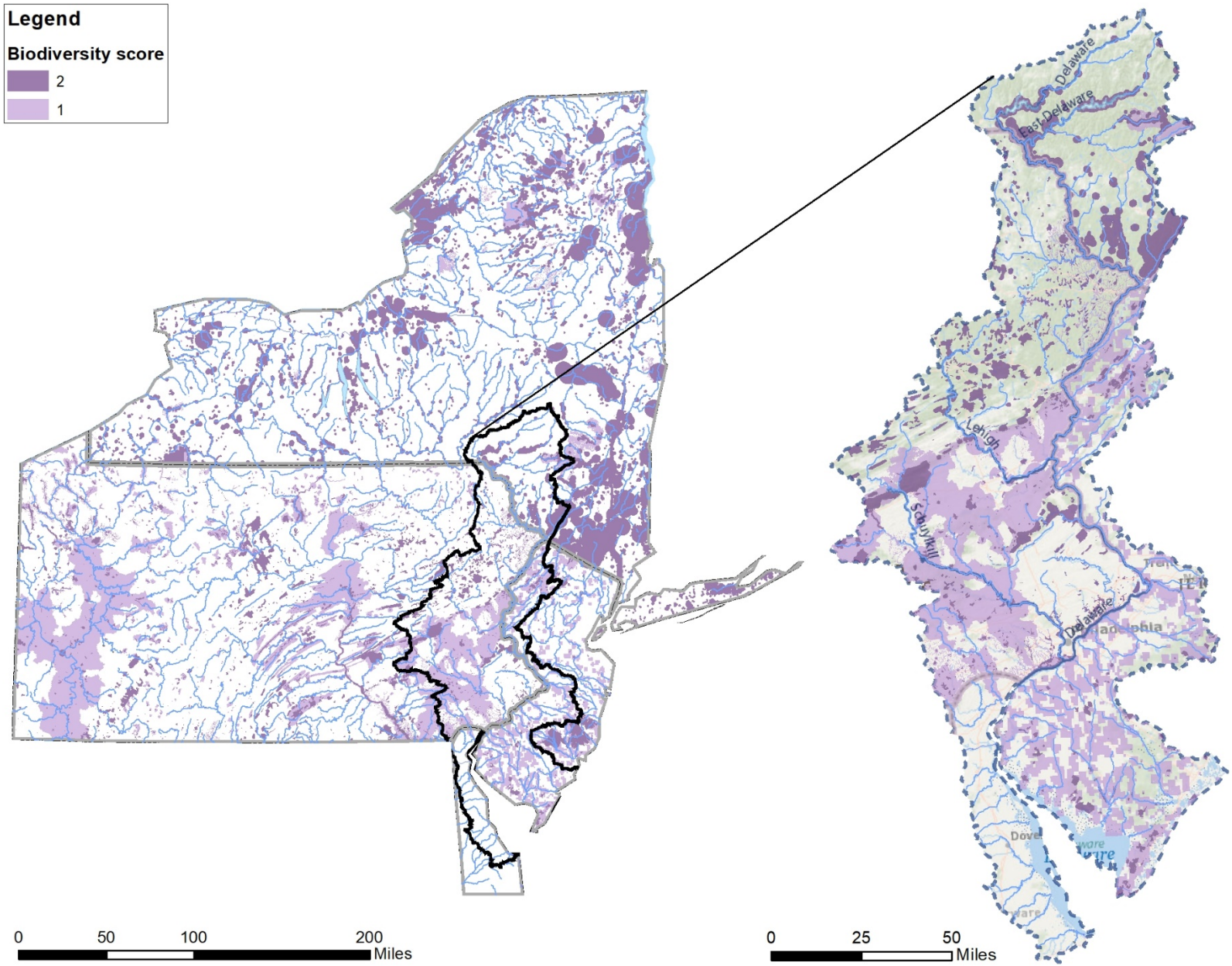


Figure 3: High concern and concern area scores for biodiversity

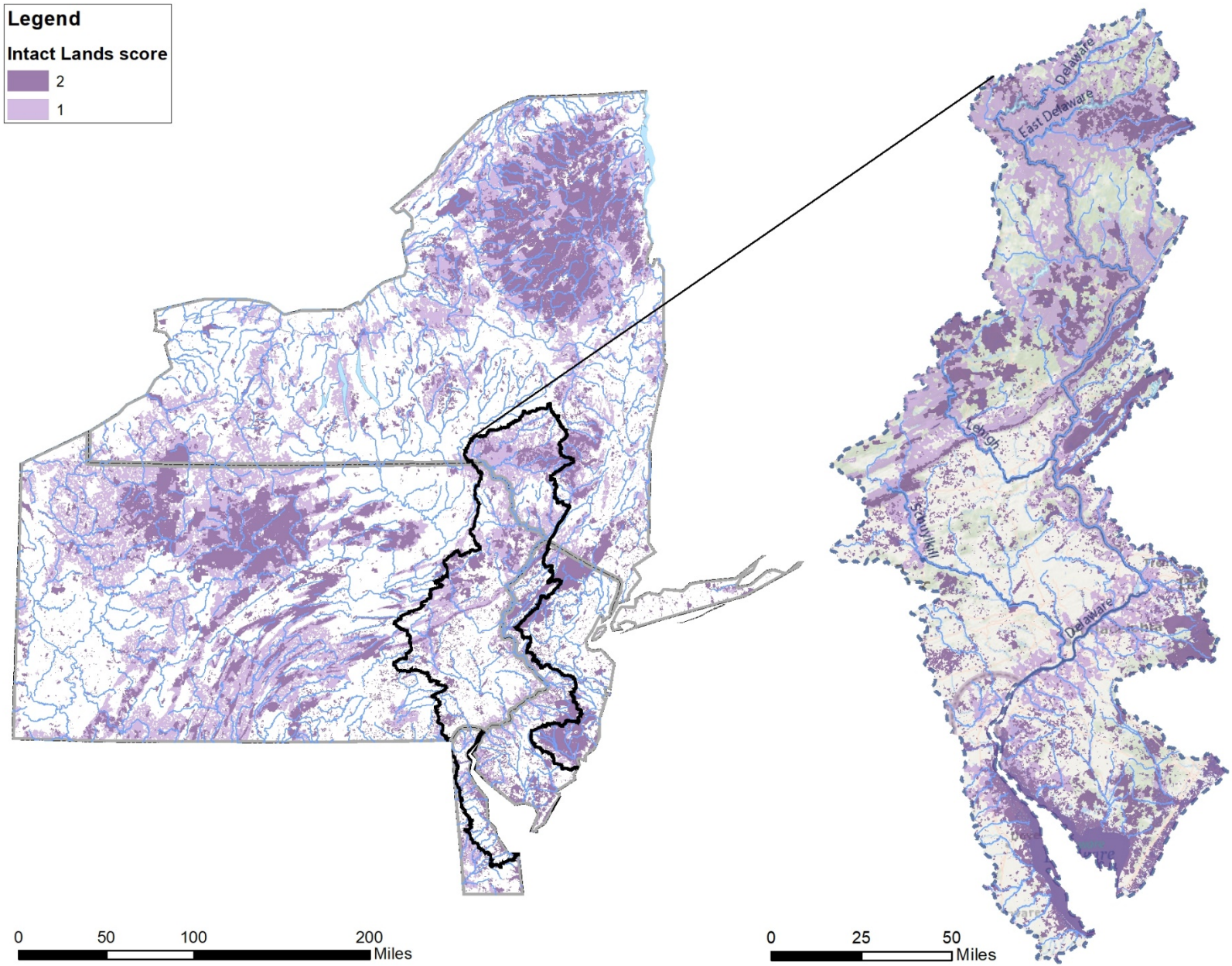


Figure 4: High concern and concern area scores for intact landscapes

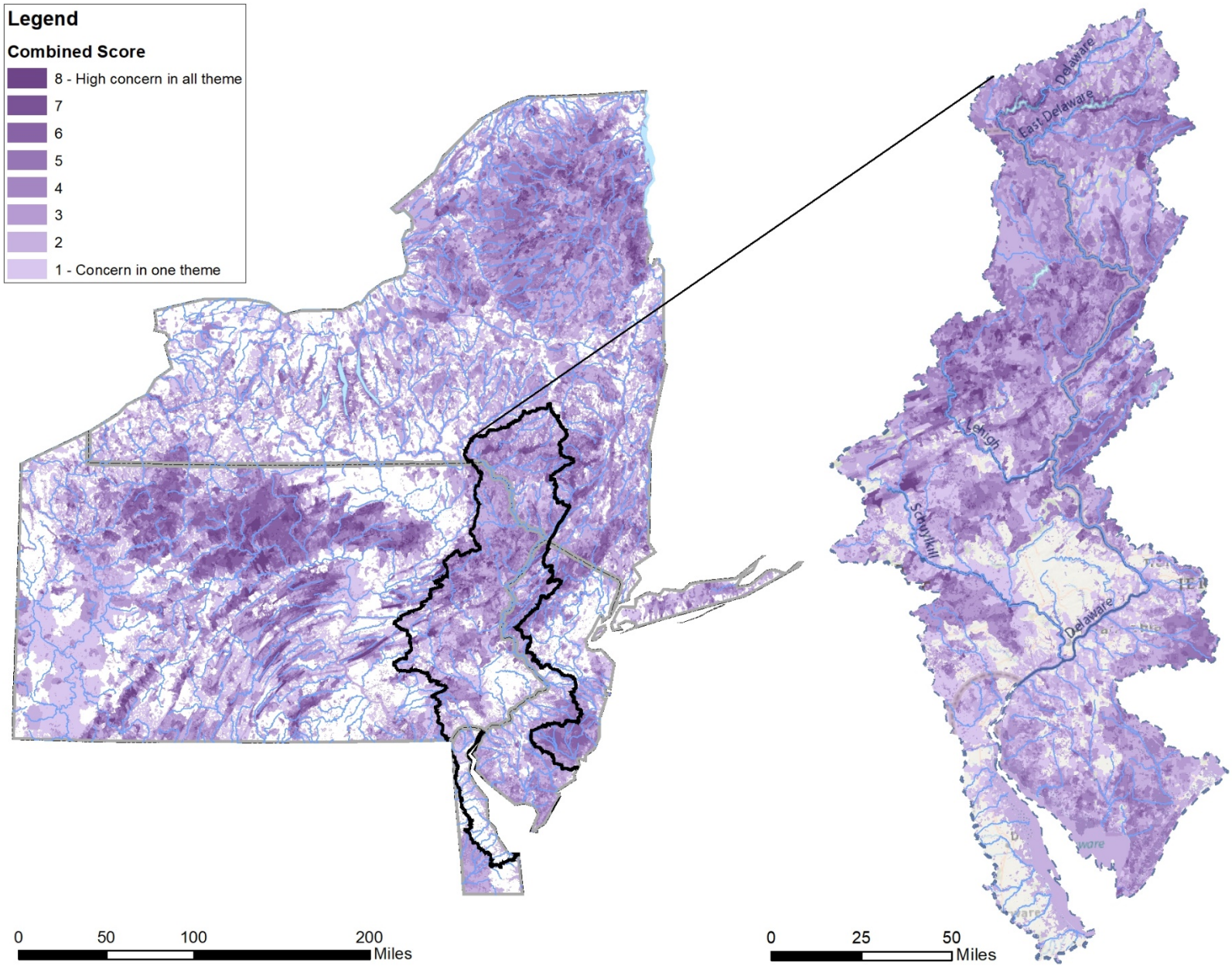


Figure 5: Final combined scores

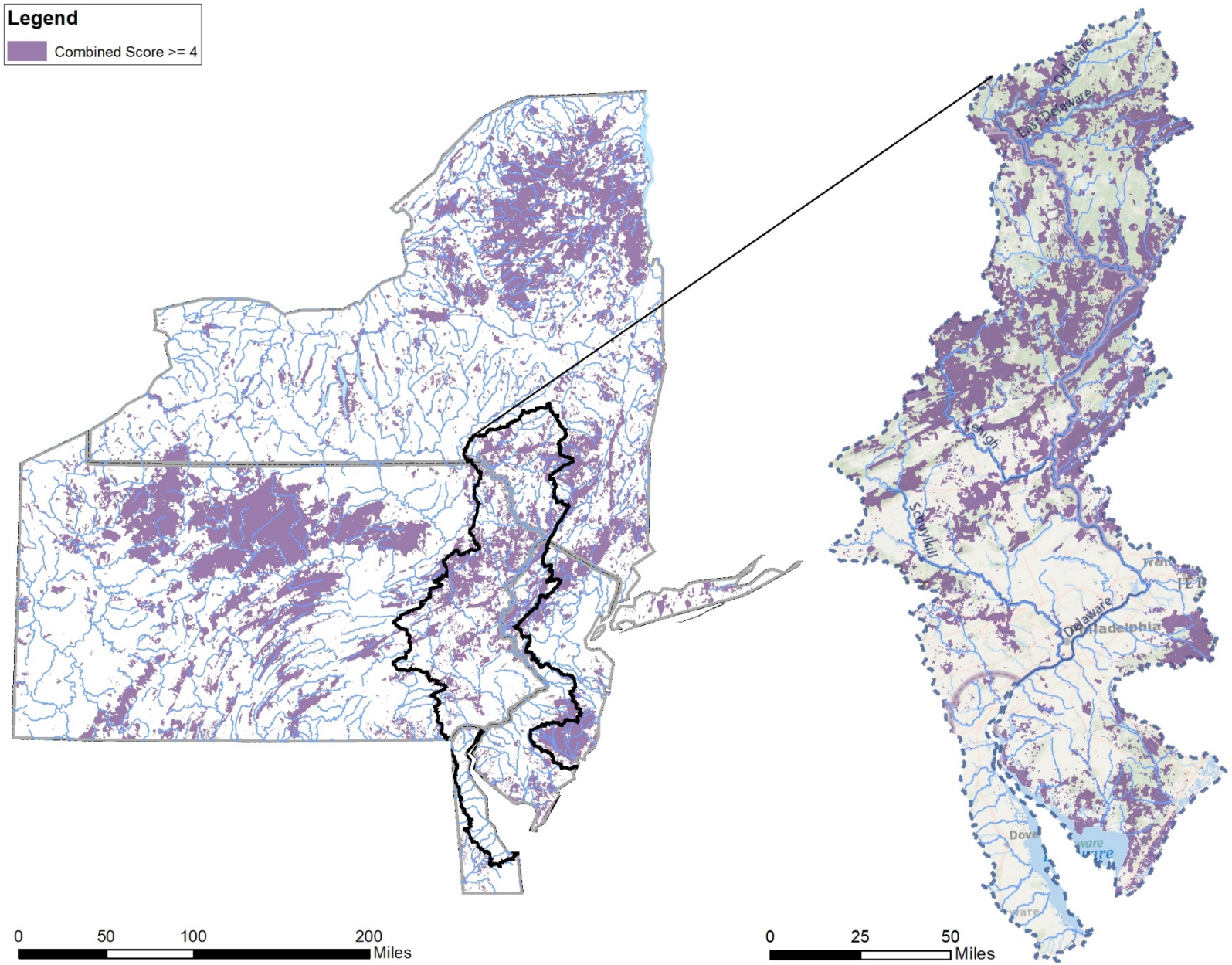


Figure 6: Final combined areas with scores greater than or equal to 4.

Less than 3% of the Delaware River Basin has a combined score of 7 or higher; 30% of the Delaware basin has score 4 or higher. Areas scoring at least 4 in the Delaware River Basin include the river corridor of the East Branch, West Branch, and mainstem Delaware River above the Delaware Water Gap; portions of the Beaver Kill, Mongaup River, and Neversink River drainages in New York; the Kittatinny Ridge and Pinelands in New Jersey; and Pennsylvania State Game Lands in the Pocono Mountains and ranges in the Valley and Ridge. Fifty-five percent of areas with scores of four or higher in the Delaware Basin fall within an existing protected area. These include federal, state, local, and private conservation lands in public ownership or protected through designation or conservation easement.

Outside the Delaware River Basin, priority areas are concentrated in north-central Pennsylvania, the Adirondack and Catskill Mountains of New York, and Highlands and Pinelands regions of New Jersey (Figures 5 and 6).

## Discussion

We refined and developed a simple set of transparent scoring rules using publicly available spatial data for identifying high-value natural resource areas that could be affected by major pipeline infrastructure in the Delaware River Basin and adjacent portions of Pennsylvania, New York, New Jersey, and Delaware. The participation of a focus group consisting of representatives of the conservation community, state and federal agencies, and industry greatly improved our methods. Consistent with the objectives of our analysis, we identified those areas of greatest concern and provided a spectrum of high concern areas. These areas represent conservation priorities across multiple themes.

In terms of application, industry representatives on our focus group told us they could use this analysis as a first-cut informational layer during the pipeline routing process. If a potential route crosses areas with high scores in the combined final map layer, conflicts with high-value natural resources likely exist. Agencies and conservation partners, meanwhile, will find the final map a useful overlay for rapidly evaluating the potential natural resource impacts of proposed routes, which will help them develop data-driven rationales for addressing these impacts.

For both purposes, we developed a companion web-based map viewer for the combined results (Figure 7), and a downloadable GIS dataset for desktop analysis in GIS software – both are available on Trout Unlimited's Delaware River Basin Pipeline Siting webpage, https://www.tu.org/delaware-pipeline-impacts.

Those conducting more detailed analyses of pipeline routes and their impacts on important natural resources should consider these results an initial evaluation of potential areas of natural resource concern. Due to the dynamic nature of some source datasets, which are frequently updated to reflect new water quality designations, rare species observations, or public land acquisitions, we recommend that users assess the source datasets individually when evaluating on-the-ground impacts to natural resources at the site scale, especially in areas with the highest scores in our final results. We provide web addresses for our source datasets in the References section. We do not separate the source layers

in our map viewer due to data use agreement restrictions for some of the data sets used in our analysis, and limit the visibility of the results in the map viewer to scales coarser than 1:50,000.

Other tools, such as Pennsylvania's Conservation Explorer, New York's Environmental Resource Mapper, and U.S. Fish and Wildlife Service's Information for Planning and Consultation system are important resources for additional evaluation of source datasets interpreted by our results. For example, these tools can clarify whether federally threatened or endangered species are present, a distinction we are not able to make within the biodiversity theme due to data redistribution restrictions. Our analysis is distinct from these tools in that it is providing an interpretation of source datasets, rather than access to those data.

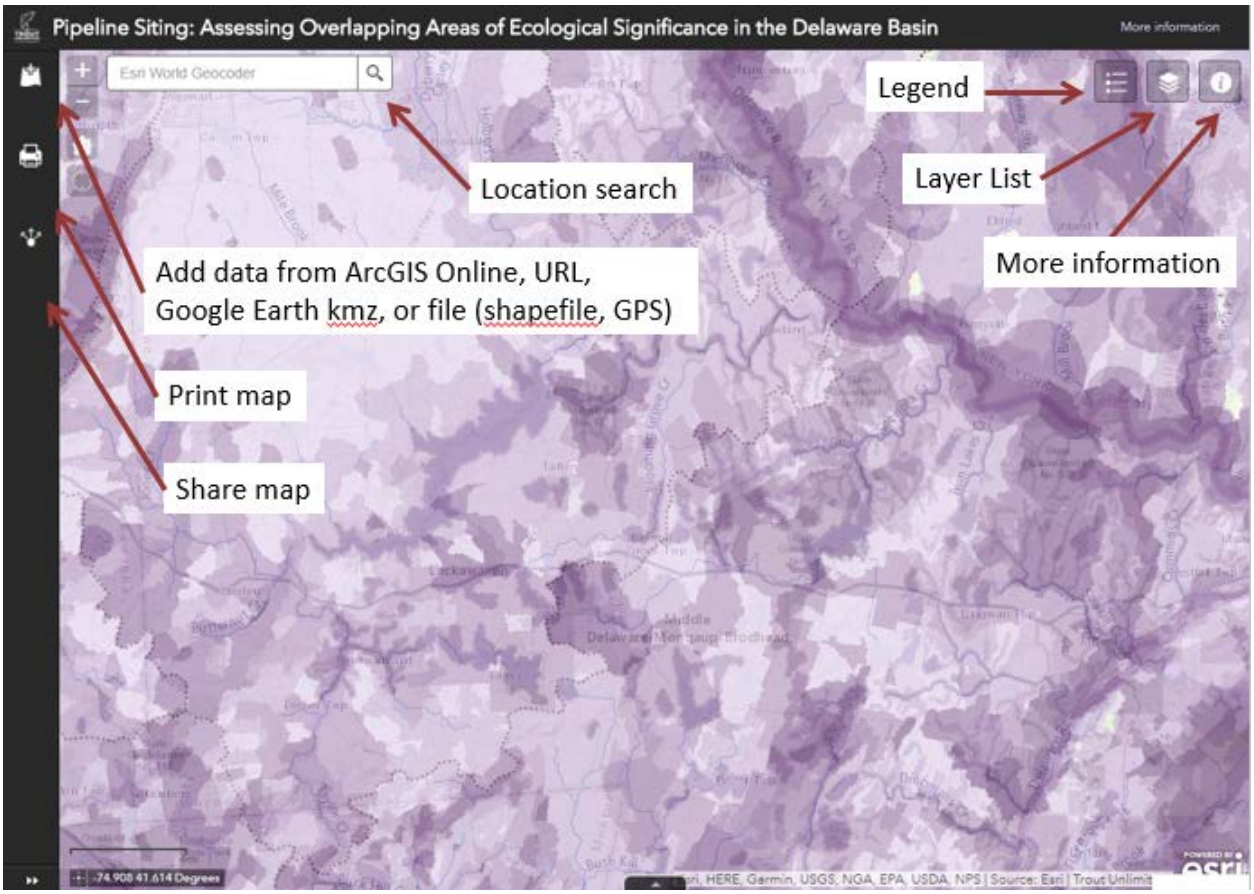


**Figure 7: Web mapping application providing access to final combined results**

Other products are available which interpret the relative value or importance of certain areas for natural resources, such as New Jersey's Conservation Blueprint. Many of these products are complementary to our analysis, but only available for a limited portion of our project area. They may be useful for evaluating ecological impacts from pipeline development within individual states or watersheds.

Still other products are available for identifying specific sources of impairment to natural resources and corresponding restoration opportunity. For example, The Academy of Natural Sciences of Drexel University's Stream Reach Assessment Tool is designed to identify and evaluate pollutant loads and

supporting natural resources affecting water quality, and the Open Space Institute's watershed land protection screening tool can identify areas for water quality protection.

As noted in our introduction, ecological considerations are not the only factors at play when industry, agency, and conservation stakeholders weigh pipeline routes. A wealth of GIS resources are available for assessing other impacts. Those interested in environmental justice (EJ) implications of pipeline proposals can look to resources that map EJ areas—census tracts with higher minority populations and more individuals living in poverty—in Pennsylvania and New York. The EPA's EJSCREEN Environmental Justice Screening and Mapping Tool offers a similar capability. Historic and archaeological sites can be pinpointed via New Jersey's NJ-GeoWeb, which includes maps showing historic districts; state archaeological sites; and the boundaries of Critical and Environmental Historic Sites identified for protection under the State Development and Redevelopment Plan. New York also offers datasets delineating historic sites and heritage areas.

The methods presented here can be modified and adapted to apply to other geographies with proposed pipeline development, such as the Central Appalachian region of Virginia and West Virginia.

## Acknowledgements

Funding for this project was provided by the William Penn Foundation; the opinions expressed in this report are those of the authors and do not necessarily reflect the views of the foundation. Additional financial assistance for this project was provided by the Pennsylvania Department of Conservation and Natural Resources, Bureau of Recreation and Conservation, via a Community Conservation Partnerships Program grant to the National Audubon Society's Kittatinny Ridge Coalition for the Kittatinny Ridge and Appalachian Trail Conservation Project.

We are grateful for the valuable comments and discussion provided during the development of this analysis by our focus group members, including: Tamara Gagnolet and Sarah Johnson (The Nature Conservancy), Ephraim Zimmerman (Western Pennsylvania Conservancy), Jeanne Barrett Ortiz (Kittatinny Ridge Coalition), Carol Collier (Academy of Natural Sciences at Drexel University), Kyle Shenk (The Conservation Fund), Barry Evans (Stroud Water Research Center), Rich Watson (Rex Energy), Brett Barrus (American Petroleum Institute), Will Ratcliffe and Kristy Grigas (Williams), Megan Neylon (EQT), Daniel Bitz (Consol Energy), Amber Holly and Casey Monagan (UGI Energy Services), Tom Ford (Pennsylvania Department of Conservation and Natural Resources), Heather Smiles (Pennsylvania Fish & Boat Commission), Marilyn Knight (U.S. Fish and Wildlife Service), J.R. Jacobson (New York Department of Environmental Conservation), Kris Heister (National Park Service), and Chad Pindar (Delaware River Basin Commission).

The involvement of these individuals and organizations in this conservation planning analysis should not be construed as an endorsement of the findings and conclusions Trout Unlimited presents in this report.

## Technical Appendix: Methods

Figure A1 provides an overview of our scoring scheme. For each theme, highest concern areas are scored a "2," concern areas are scored a "1," and areas with low concern are scored a "0." Each theme receives a combined score based on the maximum score across data sources for that theme. As the example in the left panel of the figure shows, if an area has overlapping data sources for a particular theme that include multiple layers scoring 2 and 1, the score for the area will only be the maximum single score (2, as for the center and lower right areas of the grid). The final four theme scores are combined by summing the score at each location (right panel). The final combined score therefore has a minimum value of 0 and a maximum value of 8.

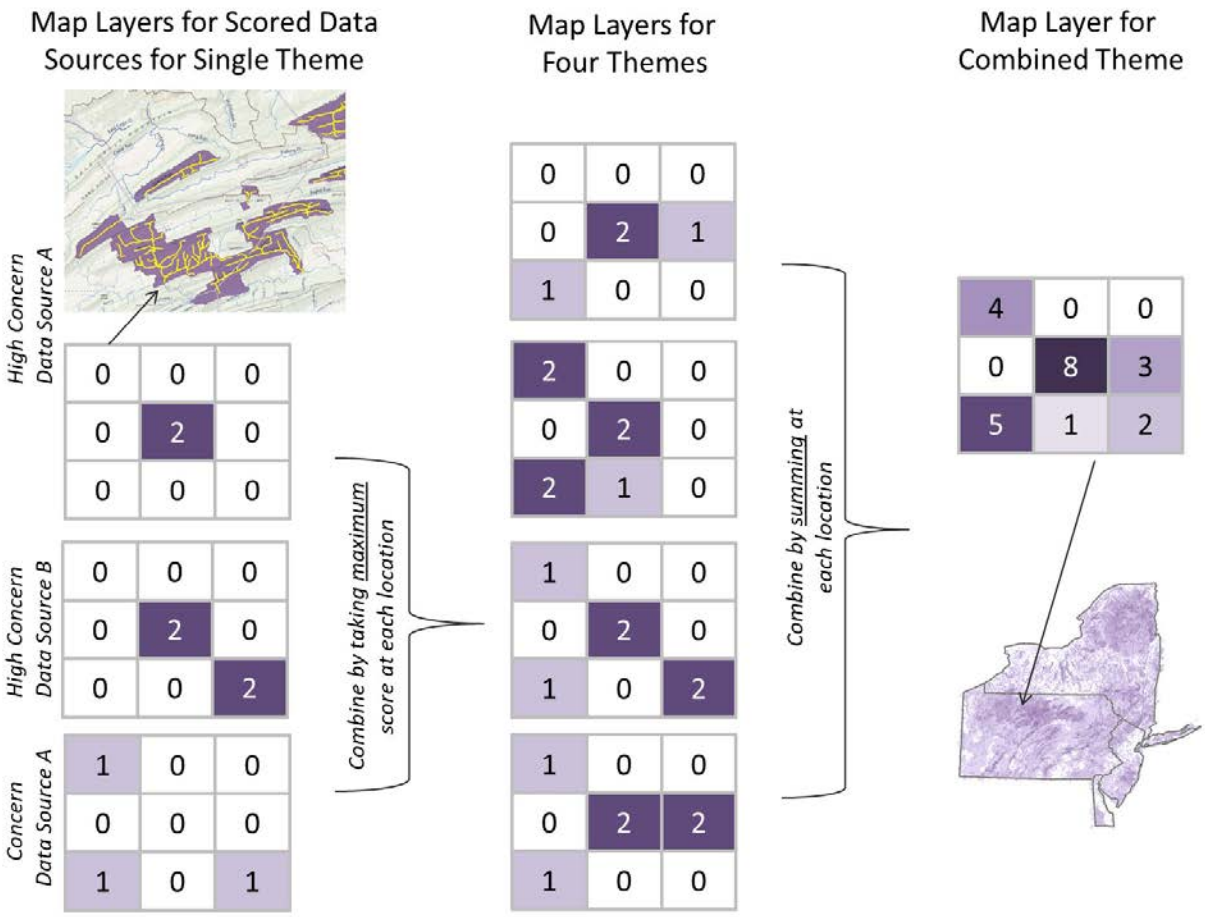


**Figure A1: Scoring scheme for source datasets, themes layer scores, and final combined score**

For all themes, source datasets that are polygon (area) format are retained in that format. Source datasets that are line features related to streams or rivers are converted to a polygon (area) format by selecting the immediate contributing area (catchment) associated with each stream segment in the National Hydrography Dataset Plus (EPA and USGS 2005). The inset at the top left of Figure A1

demonstrates how this conversion is applied: yellow lines represent stream reaches, and associated catchments are shown in purple. We chose this method of representing line features over other approaches, such as stream buffers, to reflect the upslope contributing areas of stream reaches and potential impacts to stream resources from activities on those slopes.

## *Cold Water Fisheries*

Cold water fisheries comprised of native and wild trout are known to be impacted by pipeline development due to the sensitivity of salmonids to sedimentation and increased stream temperatures (DeWeber and Wagner 2015), which can be associated with road construction and riparian vegetation removal during pipeline development (Entrekin et al. 2011, Weltman-Fahs and Taylor 2013). Our scoring scheme assigns the highest scores to the highest quality fisheries, areas which provide an exceptional angling experience, or fish populations predicted to have long-term viability based on their size and available habitat. All other cold water fisheries are considered concern areas.

### High Concern Areas (Score 2)

- ***Pennsylvania Fish & Boat Commission Class A Streams***
  Class A streams are "streams that support a population of naturally produced trout of sufficient size and abundance to support a long-term and rewarding sport fishery" (PFBC 2017a).
- ***Pennsylvania Fish & Boat Commission Wilderness Trout Streams***
  These streams provide "a wild trout fishing experience in a remote, natural and unspoiled environment where man's disruptive activities are minimized" (PFBC 2015).
- ***Trout Unlimited Conservation Portfolio resilient and redundant brook trout populations***
  TU's Conservation Portfolio uses Eastern Brook Trout Joint Venture population patch information to characterize a subset of brook trout populations – resilient and redundant populations – which will likely persist in the face of environmental change. This is based on how much quality, intact habitat is available, and on the mix of trout species present (Fesenmyer et al. 2017).

### Concern Areas (Score 1)

- ***Pennsylvania Fish & Boat Commission Wild Trout Production Streams***
  These streams "support naturally reproducing populations of trout. A wild trout stream section is a biological designation that does not determine how it is managed; therefore, these streams may also be stocked with hatchery trout by the Commission" (PFBC 2017b).
- ***New York Department of Environmental Conservation Water Quality Standards and Classifications***
  "Water Quality Standards are the basis for programs to protect the state waters. Standards set forth the maximum allowable levels of chemical pollutants and are used as the regulatory targets for permitting, compliance, enforcement, and monitoring and assessing the quality of the state's waters. Waters are classified for their best uses (fishing, source of drinking water, etc.) and standards (and guidance values) are set to protect those uses" (NYDEC 2017a). Our application includes all trout-bearing waters (T, TP, and TS).
- ***New Jersey Department of Environmental Protection Surface Water Quality Standards***

These standards “establish the designated uses and anti-degradation categories of the State's surface waters, classify surface waters based on those uses (i.e., stream classifications), and specify the water quality criteria and other policies and provisions necessary to attain those designated uses” (NJDEP 2017a). Our application includes the trout maintenance (TM) and trout production (TP) categories.

- ***Delaware Department of Natural Resources and Environmental Control Surface Water Quality Standards***
  The standards identify “the designated uses applicable to the various stream basins and represent the categories of beneficial use of waters of the state which must be maintained and protected through application of appropriate criteria” (DDNREC 2017). Our application includes the cold water fish category.

## *Water Quality*

Natural gas pipelines can affect water quality during the construction phase due to earth-moving and trenching required to place the pipeline, especially at stream crossings. Water quality concerns include sedimentation and potential chemical spills (Entrekin et al. 2011). Our scoring scheme assigns highest scores to water quality designations, which reflect the highest level of regulatory protection or exceptional stream condition. Lower scores are assigned to other protected waters.

### High Concern Areas (Score 2)

- ***Pennsylvania Department of Environmental Protection Existing and Designated Use***
  Pennsylvania’s Chapter 93 water quality standards allow for special protection designations for streams where water quality exceeds existing designated use standards (PDEP 2017a, 2017b). Our application for high concern areas includes EV (Exceptional Value Streams) and HQ (High Quality Streams; includes HQ-coldwater fisheries and HQ-warm water fisheries) designations.
- ***New York Department of Environmental Conservation Water Quality Standards and Classifications***
  New York’s Environmental Conservation Law, Title 5 of Article 15 protects state waters through the Water Quality Standards program. “Standards set forth the maximum allowable levels of chemical pollutants and are used as the regulatory targets for permitting, compliance, enforcement, and monitoring and assessing the quality of the state's waters. Waters are classified for their best uses (fishing, source of drinking water, etc.) and standards (and guidance values) are set to protect those uses” (NYDEC 2017a). Our application for high concern areas includes ‘protected waters’ designations A, A-S, AA, and AA-S (potable water supply waters).
- ***New Jersey Department of Environmental Protection Surface Water Quality Standards***
  New Jersey Administrative Code 7:9 B designates Surface Water Quality Standards which “establish the designated uses and anti-degradation categories of the State's surface waters, classify surface waters based on those uses (i.e., stream classifications), and specify the water quality criteria and other policies and provisions necessary to attain those designated uses” (NJDEP 2017a). Our application for high concern areas includes Outstanding National Resource Waters (including freshwater 1 or FW1 waters and Pinelands or PL waters), which shall not be subject to any manmade wastewater discharges or activity that might cause a lowering of

existing surface water quality, and Category One (C1) Waters, which are "protected from any measurable change in water quality because of their exceptional ecological significance, exceptional recreational significance, exceptional water supply significance, or exceptional fisheries resources."

- ***Delaware Department of Natural Resources and Environmental Control Surface Water Quality Standards***
  Delaware Administrative Code 7401 surface water quality standards identify "the designated uses applicable to the various stream basins and represent the categories of beneficial use of waters of the state which must be maintained and protected through application of appropriate criteria" (DDNREC 2017). Our application for high concern areas includes the ERES (Waters of Exceptional Recreational of Ecological Significance) category.

### Concern Areas (Score 1)

- ***New York Department of Environmental Conservation Water Quality Standards and Classifications***
  Our application for concern areas includes 'protected waters' designations B (primary and secondary contact recreation and fishing), and C(TS) (other waters, trout spawning).
- ***New Jersey Department of Environmental Protection Surface Water Quality Standards***
  Our application for concern areas includes SE1 (shellfish harvest) and TP (trout production waters), which can qualify for Category 1 (C1) Waters designation.
- ***Delaware Department of Natural Resources and Environmental Control Surface Water Quality Standards***
  Our application for concern areas includes the Drinking Water Supply category.

## *Biodiversity*

Biodiversity concerns associated with natural gas pipeline development include habitat loss or decline in habitat quality for rare plants and animals due to habitat conversion and fragmentation (Abrahams et al. 2015). These concerns are greatest for species which have experienced population declines such that they warrant protection under federal or state endangered species rules or similar regulations. Our scoring scheme assigns highest scores to areas with known rare species occurrences, and lower scores to areas supporting or adjacent to core habitats, or areas with unique natural communities. Biodiversity information is not currently publicly available for Delaware.

### High Concern Areas (Score 2)

- ***Pennsylvania Natural Heritage Program Core Habitats***
  Core Habitats "are areas containing plant or animal species of concern at the state or federal levels, exemplary natural communities, or exceptional native diversity. Core habitats delineate essential habitat that cannot absorb significant levels of activity without substantial impact to the elements of concern" (PNHP 2017a).
- ***New York Natural Heritage Program Element Occurrences***
  These data represent generalized observations of "animals and plants that are rare in New York, including those listed as Endangered and Threatened" (NYNHP 2017).

- ***New Jersey Natural Heritage Program Priority Sites***
  Priority Sites "identify critically important areas to conserve New Jersey's biological diversity, with particular emphasis on rare plant species and ecological communities. These areas should be considered top priorities for the preservation of biological diversity in New Jersey" (NJDEP 2007).

### Concern Areas (Score 1)

- ***Pennsylvania Natural Heritage Program Supporting Landscapes***
  Supporting Landscapes "refer to areas surrounding or contiguous to core habitats that maintain vital ecological processes or secondary habitat for sensitive natural features that may be able to accommodate some types of low-impact activities" (PNHP 2017b).
- ***New York Natural Heritage Program Natural Heritage Communities***
  Significant Natural Heritage Communities "are rare or high-quality wetlands, forests, grasslands, ponds, streams, and other types of habitats, ecosystems, and natural areas and are tracked because they serve as habitat for a wide range of plants and animals, both rare and common; and because community occurrences in good condition support intact ecological processes and provide ecological value and services" (NYNHP 2013).
- ***New Jersey Natural Heritage Program Grid Map***
  The Natural Heritage Grid Map "was produced to provide a general portrayal of the geographic locations of rare plant species and rare ecological communities for the entire state without providing sensitive detailed information. By consulting the map, users can do broad scale analysis of potentially sensitive areas to determine the generalized location of rare plant species and rare ecological community occurrences" (NJDEP 2009).

## *Intact Landscapes*

The intact landscape theme identifies existing protected conservation lands and important blocks of natural terrestrial and aquatic habitats. Existing protected areas received the highest scores. Lower scores were given to (a) unconverted lands – those natural habitats not converted to agriculture, urban, or ex-urban land uses – which act as connectivity corridors or represent high potential for hosting biodiversity due to their topographic setting, and (b) large patches of connected, diverse aquatic habitats.

### High Concern Areas (Score 2)

- ***US Geological Survey Protected Areas Database - US***
  The dataset is the "official national inventory of U.S. terrestrial and marine protected areas that are dedicated to the preservation of biological diversity and to other natural, recreation and cultural uses, managed for these purposes through legal or other effective means" (USGS 2016). The PAD-US includes federal, state, local, and private (nonprofit) conservation lands in public ownership or protected through designation or conservation easement.

### Concern Areas (Score 1)

- ***Resilient and Connected Landscapes for Terrestrial Conservation***

This product identifies important physical settings for biodiversity (including large blocks of undisturbed lands and locations with diverse elevation and geology) that are resistant to changes in climate, and connectivity corridors between those areas. The dataset incorporates existing protected status and includes large forest blocks, limestone geologies, and intact riparian corridors. (Anderson et al. 2016). Our application of concern areas includes "Climate Corridors," "Resilient Areas" with "Confirmed Diversity" or "Secured", and "Climate Flow Zones" with and without "Confirmed Diversity". We exclude from our analysis "Vulnerable" areas and "Resilient Only" areas that are unsecured.

- ***Freshwater Ecosystem Resilience***
  Resilient freshwater ecosystems "have extensive longitudinal connectivity linking tributaries of many sizes, gradients and temperatures, good lateral connectivity linking them to their floodplain, and relatively unaltered natural flows within a permeable watershed" (Anderson et al. 2013). Our application of concern areas includes resiliency classes "Complex: Highest Relative Resilience" and "Complex: High Relative Resilience."

## *Combined Themes*

The combined final score is a sum of the final scores for each of the four themes. We simplified the final combined score layer to a 90 x 90m spatial resolution grid to minimize dataset complexity. A GIS raster dataset of the combined final score is available for download here.

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