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Estimating the Influence of Land Protection on Water Quality

February 2021

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Executive Summary

This report details the results from modeling efforts to estimate water quality benefits of forest land protection in the Delaware River Watershed. The overall **objective** of this work was to ***provide information that quantifies and communicates the impact and value of forest land protection and conservation activities within the Delaware River Watershed Initiative (DRWI).***

In pursuit of these objectives, we ***considered a range of scales over time and space that provided different, yet synergistic, perspectives on how forest land protection can protect stream water quality, potentially reduce or protect downstream water quality, and may have a resulting economic benefit***. As a result, we deployed five different modeling approaches and multiple spatial and temporal scales in our analyses: (1) modeling hydrology (runoff and infiltration) and water quality (sediment, nitrogen, and phosphorus) resulting from a discrete storm event (over 24-hours) for parcels that were recently protected by DRWI efforts and comparing model output among hypothetical scenarios of development; (2) modeling hydrology and water quality changes related to parcel protection but at the watershed scale and over annual time-scales under various development scenarios; (3) delineating and modeling the contributing areas to forested riparian stream buffers intersecting with protected parcels to assess water quality benefits of this zone surrounding headwater streams; (4) modeling changes in water quality downstream from protected parcels to determine the downstream extent of the potential to dilute other sources of pollution from the watershed (i.e., a water quality "signal" that may be attributed to or derived from the protected parcel); and (5) modeling potential future land development and climate to better understand future landscape changes that land protection may ameliorate (or displace).

We focused on two primary benefits of preserved land parcels (particularly related to forest cover) on water quality: 1) Avoided loads: loads delivered to nearby streams if the parcels were developed in the future (this is essentially an "avoided" load), or 2) Filtered loads: forested land in parcels adjacent to streams can serve as riparian buffers that filter out pollutant loads from upland sources such as agricultural and developed land. There are myriad other influences that forest cover can have on streams and stream ecology (e.g., influencing the geomorphic condition, shading and water temperature influences, organic matter inputs) that were not studied here.

Results presented here demonstrate a range of possible negative water quality impacts that may result if forest land is developed. At the parcel scale, modeling of various hypothetical development intensities resulted in increasing storm runoff volume, decreased infiltration of stormwater, and increased sediment, nitrogen, and phosphorus loading to waterways (for development that does not include stormwater management infrastructure). At the watershed scale and over annual timeframes, increases in development within a watershed can result in greater annual sediment and nutrient loads and increased stormwater runoff and decreasing subsurface flow, even when developing parcels are small relative to the size of the watershed. These negative consequences can be somewhat constrained if stormwater management best practices are included.

All other things being equal, in terms of “avoided loads,” a parcel of a given size will generally have greater beneficial water quality impacts if it is located in a headwater area than if it were located further downstream. Although the increased pollutant loads delivered by the parcel to a nearby stream that would be caused by converting to developed land are essentially the same in both cases, the impact would be greater in the headwater case versus the downstream case. This is primarily due to the fact that the same load is being delivered to a smaller stream with less water volume, and therefore lower dilution potential, in the former case. In general, water quality in headwater areas is less influenced by pollutant loads from upstream sources simply due to a smaller upstream area. However, in either case, the beneficial effects of the preserved parcel could be negated by large upstream loads caused by myriad human activities such as agriculture and developed land with little to no stormwater management infrastructure.

With regard to the potential beneficial impacts of riparian buffers, the key findings were:

- Larger parcels along streams tended to have more riparian buffer acres than smaller parcels. However, larger riparian buffers did not always result in the largest contributing areas being drained/filtered by the buffers (i.e., the size of the contributing areas are primarily dictated by local topographic conditions both inside and outside of the conserved parcel).
- Parcels that wholly contained stream segments (i.e., had riparian buffers on both sides of the stream) tended to have more total acres of contributing area within the parcel boundary.
- Those parcels with riparian buffers receiving runoff from agricultural and developed land in the headwaters tended to be the most beneficial in terms of reducing nutrient and sediment loads with water quality benefits increasing with greater amounts of agricultural or developed land within the contributing area (contributing areas may have land within the preserved parcel and/or land outside the preserved parcel).
- In terms of overall reduction effectiveness, the results showed that some projects were much more effective than others in terms of potential pollutant load reduction. More specifically, when the projects were sorted based on estimated load reductions, the results showed that the top six projects could potentially reduce 60% of the total nitrogen loads delivered to all riparian buffers; the top six projects could potentially reduce 61% of the total phosphorus loads delivered to all riparian buffers; and the top six projects could potentially reduce 80% of the total sediment load delivered to all riparian buffers. In other words, of the approximately 25,000 acres of preserved land acres, about 18% of this land (~4,500 acres) removed between 60 and 80% of the total nutrient and sediment loads from runoff delivered to nearby streams.

Finally, potential future (2100) land development modeling compared two different development patterns: (1) future development constrained towards existing “Centers” of development and (2) sprawl along existing commercial “Corridors.” Both development models were simulated twice, once with protected land constrained from future development and once with protected land open and available for future development. For the 52 DRWI protection parcels representing 25,140 acres, it was found that if these lands remained unprotected, 756 acres (3%) under the Centers scenario or 2,297 acres (9.1%) under the Corridors scenario might be developed.

The presence or absence of protected lands had an impact on the spatial distribution of developed land at the whole-basin scale, with notable increases in development in the central and eastern regions of the Delaware River Basin. In the absence of protected lands, these regions of high development pressure were preferentially selected for development within these model simulations. At the same time, these model simulations without protected lands illustrated that in the northern part of the Delaware River Basin, development pressure in the future may remain low.. This pattern was apparent in both the Corridors and Centers scenarios where protected land was removed from simulations, although future development impact on water quality was more marked in the Corridors scenario because future growth was less constrained to existing centers of development.

Introduction

This report describes results from modeling efforts to estimate water quality benefits of forest land protection in the Delaware River Watershed. The overall **objective** of this work was to ***provide information that communicates the impact and value of forest protection/conservation activities within the Delaware River Watershed Initiative (DRWI).***

Launched in 2013 by the William Penn Foundation and implemented by over 50 conservation organizations, the DRWI had a goal of promoting "watersheds that provide high quality and sufficient water quantity for healthy ecosystems and human communities" through multiple strategies including land protection, restoration, and collaboration. This project analyzed a subset of forest land protection projects permanently protected through the Delaware River Watershed Protection Fund administered by the Open Space Institute (OSI). The analyses included between 48 and 53 project parcels depending on when the analysis was conducated.

The hypothesis guiding this work was:

> *Protection of natural lands (forests and wetlands) in headwater areas (watersheds of low order streams) maintains ecological stream quality (e.g., high water quality and biological integrity) by limiting, preventing or redirecting development (a range of land uses from low density residential to industrial), and therefore any negative impact on water quality, away from headwaters, stream buffers, and wetlands.*

In pursuit of these objectives, we ***considered a range of scales over time and space that provided different, yet synergistic, perspectives on how forest land protection can protect stream water quality, potentially reduce or protect downstream water quality, and may have a resulting economic benefit***. As a result, we utilized multiple modeling approaches and multiple spatial and temporal scales in our analyses. To further focus our efforts, we test the following predictions:

> *Prediction 1: Where land protection is used for forest protection, water quality is maintained*
>
> *Prediction 2: Protected lands reduce future water quality degradation stress/potential*

Five different modeling approaches were used to estimate and compare the potential for forest land protection to maintain water quality. These approaches are introduced below and described further in subsequent sections of this report (number below refer to each subsequent section number).

1. The “Site Storm Model” (SSModel) in Model My Watershed® (ModelMW) was used to generate and compare estimates of single-storm runoff volume and water quality (sediment, total nitrogen (TN) and total phosphorus (TP) loads from protected parcels under different potential development scenarios. This modeling approach was utilized primarily to estimate runoff volume from a 2-yr return interval storm and that volume was subsequently used to estimate stormwater infrastructure and maintenance costs.

2. The “Watershed Multi-Year Model” (WMYModel) in ModelMW was used to estimate annualized average hydrologic and water quality (sediment, TN, TP loads) benefits derived from preserved parcels compared to potential development scenarios, but at the scale of small watersheds and considering the context of other surrounding parcels/landscapes.
3. The WMYModel was used to evaluate the potential benefits that a forested parcel of land located on a stream might have in filtering out sediment and nutrient loads that flow through this “forested stream buffer area” from upland sources. We refer to this effort as “Riparian Contributing Area Analysis”.
4. The WMYModel was used to evaluate the extent to which any water quality benefit might be observed at a location downstream from the preserved parcel. We refer to this effort to determine the percent change in downstream water quality as “Watershed Multi-Year Model and Downstream Influences”.
5. Modeling of future land development and climate produced estimates of future changes in land use (specifically development) and precipitation and air temperature throughout the Delaware River watershed from 2011 to 2100.

All of the above approaches and results are described below.

1. Modeling Approach: Site Storm Model

Overview of Methods

The Site Storm Model (SSModel) in ModelMW was used to estimate runoff and infiltration volumes and total sediment, nitrogen (TN) and phosphorus (TP) loading rates, loads from each protected parcel, and the total load from all parcels subjected to various hypothetical land cover change scenarios. The SSModel simulates a hypothetical 24-hour storm event using a hybrid modeling approach that blends algorithms from TR-55 and SLAMM for hydrologic estimations and the EPA’s STEP-L model to predict sediment, TN, and TP. Documentation of SSModel algorithms and data sources can be found here, https://wikiwatershed.org/help/model-help/mmw-tech/#site-storm-model, and here, https://wikiwatershed.org/help/model-help/site-storm-guide/.

Parcel boundaries were received from OSI and were used in subsequent parcel-specific modeling using the SSModel. Forty eight different project areas were included in this analysis and summary statistics for total area, land cover, and stream length within each parcel is included in Appendix A Table 1. Each parcel boundary was added to ModelMW, used to analyze land cover, hydrologic soil groups, streams, and other spatial data (see ModelMW technical documentation), and then modeled using the SSModel. The SSModel automatically returns model results for hydrology and water quality based on the 2011 USGS National Land Cover Database and automatically provides a modeled scenario estimate for “Predominantly Forested” conditions (by automatically assigning agricultural and developed land covers to forested categories). In addition to these two land cover scenarios (Current Conditions and Predominantly Forested), the following scenarios were then run for each project parcel:

1. Predominantly Forested land cover;

2. Current Conditions (based on 2011 USGS National land cover database).
3. Forest cover was changed to developed cover based on OSI's best professional judgment regarding the Development Threat that was perceived at the time of land preservation;
4. Land cover (except wetlands & open water) was changed to Developed Open Space;
5. Land cover (except wetlands & open water) was changed to Developed Low Intensity;
6. Land cover (except wetlands, open water) was changed to Developed Medium Intensity;
7. Land cover (except wetlands, open water) was changed to Developed High Intensity;
8. Land cover was changed to predicted future development based on the "Centers" future (2100) land cover model (see "Future Development" section below);
9. Land cover was changed to predicted future development based on the "Corridors" future (2100) land cover model (see "Future Development" section below).

Developed land classifications from the National Land Cover Dataset (NLCD) are provided in Appendix Table 1. For the "Development Threat" scenarios, OSI provide the modeling team with descriptive analyses for each parcel that included a narrative on "Conversion Pressure," "Suitability for Development," "Conversion Threat," "Intent," and "Development Type/Zoning". This information was used to implement a variety of modifications to existing parcels that matched these descriptions at the discretion of the modeler (Stroud Center). For example: adding Developed Low Intensity acreage and debiting Forest Cover acreage, adding Developed Open Space acreage and debiting Forest Cover acreage.

The scenarios above were compared and contrasted for differences in model outcomes in order to estimate a range of possible changes to storm runoff and infiltration and water quality (sediment, TN, and TP). Specifically, precipitation intensity was set to 3.3 inches (for a 24-hr rainfall event) for all parcel/scenarios above. Output from SSModel for each of the 49 project parcels and all nine scenarios were then averaged to provide summary statistics to compare results among scenarios, listed below. Precipitation intensity was held constant (3.3 inches/24-hr event) across all parcels and scenarios. The 3.3 inch rainfall event represents a 2-year return interval storm, as measured at the Philadelphia Airport weather station (1960-1990). Summary statistics included:

- Average infiltration and runoff depth per scenario (average inches per scenario);
- The sum total of runoff volume from all 49 parcels/scenario (sum total cubic feet per scenario);
- The change (or difference) in total runoff volume from all 49 parcels within a scenario compared to the total runoff volume from "Current Conditions" of all 49 parcels*;
- Average sediment, TN, and TP loads (average lbs. per scenario);
- Average sediment, TN, and TP loading rates (average lbs./acre per scenario)
- The sum total of sediment, nitrogen, and phosphorus loads (sum total lbs. per scenario); and
- The change (or difference) in total loads of sediment, TN, and TP from all 49 parcels within a scenario (see list above) compared to the total runoff volume from "Current Conditions" of all 49 parcels*.

In addition to the scenarios above, we ran six additional scenarios where we varied rainfall intensity in order to provide further context of relative differences in runoff and infiltration due to more local estimates of rainfall intensity (holding land cover constant, specifically to "Current Conditions" based on 2011 national land cover). Historical and future weather data were summarized for 11 weather stations within or adjacent to the Delaware River watershed (see, Hawkins and Woltemade 2020 and Ensign et al. 2020). NOAA weather station locations used in this analysis included: Albany, Allentown, Atlantic City, Binghamton, Harrisburg, Newark (NJ), New York City, Philadelphia, Wilkes Barre, Williamsport, and Wilmington (DE) airport weather stations. Downscaled future global climate data were summarized by Hawkins and Woltemade (2020) for both RCP 4.5 and 8.5 predictions for each of the locations described above (also see "Future Climate (2080-2100)" section below). Two-year and 100-year recurrence intervals were calculated from the average of the two closest weather stations to each parcel boundary (this is automated in ModelMW when a user chooses "future weather" while deploying the WMYM, so we hand calculated these recurrence intervals from data archived by Ensign et al. (2020) for use in our SSModel efforts). The "precipitation scenarios" were:

- 3.3 inch rainfall (Philly 2-Yr Recur. 1960-1990) held constant for all parcels under "Current Conditions" land cover (2011);
- The NOAA 2-Yr Recur. 1960-90 rainfall intensity defined by "local" rainfall records;
- The 2100 RCP 4.5 2-Yr Recur. rainfall intensity (modeled data);
- The 2100 RCP 8.5 2-Yr Recur. rainfall intensity (modeled data);
- The NOAA 100-Yr Recur. 1960-90 rainfall intensity defined by "local" rainfall records;
- The 2100 RCP 4.5 100-Yr Recur. rainfall intensity (modeled data); and
- The 2100 RCP 8.5 100-Yr Recur. rainfall intensity (modeled data).

Results

Infiltration and Runoff from a Single Storm Event

Site Storm Model results demonstrate clear decreases in infiltration and increases in runoff among scenarios with increasing development intensity (and therefore increasing impervious surface cover) (Fig. 1.1). The "Predominantly Forested" scenario consistently had the greatest infiltration and lowest runoff for 3.3 inch rainfall events for all of the 51 parcels. As would be expected with increasing development intensity (from developed open space to low, medium, and high intensity developed), infiltration decreased and runoff increased substantially. In general, our implementation of the best professional judgment of potential development ("Development Threat" scenario) was similar to the changes that occurred when we added "Developed Open Space" to each project parcel.

The "Future Development" scenarios for both "Centers" and "Corridors" based growth models showed that, on average, there were only small differences from "Current Conditions" (e.g., ave. infiltration of 2.44 in. for "current conditions, 2.41 in. for "Centers", and 2.34 in. for "Corridors"). This small degree of change is in line with the predicted future development acreage for "Centers" at 3% and "Centers" at 9% (see Appendix Table 2 for "Centers" land cover changes and Appendix Table 3 for "Corridors" land cover changes).

The sum total of storm runoff volumes (Fig. 1.2) from all project parcels within each scenario was calculated after converting runoff depths to runoff volumes by multiplying by parcel acreages (excluding open water). Total runoff volume from the 3.3 inch modeled storm from all parcels under “Current Conditions” was ~59 M ft^3 and under “Predominantly Forested” conditions was ~ 56 M ft^3 (Fig. 1.2). Total volume estimates under all other scenarios increased sharply and ranged from ~62 M ft^3 (“Centers”) to ~200 M ft^3 (for high-intensity development). Differences compared to “Current Conditions” in runoff volumes are shown in the lower panel of Fig. 1.2 and these estimates were then used to calculate costs for implementing stormwater management systems and their annual maintenance should the parcels be developed (Fig. 1.3).

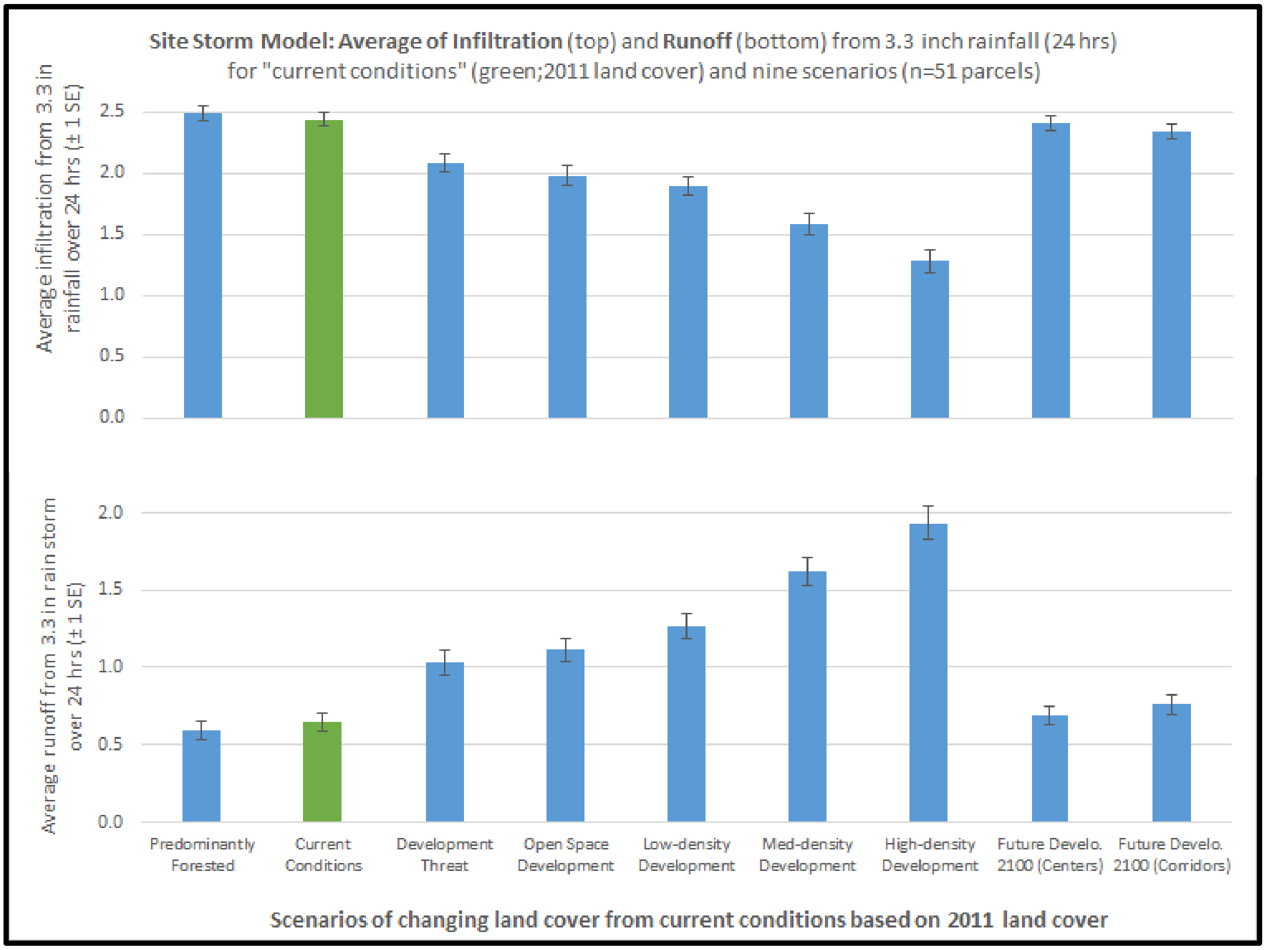

Figure 1.1: Average infiltration (top) and runoff (bottom) for 9 different scenarios where each scenario is the average (± 1 S.E.) result from 51 different project parcels that were modeled using the Site Storm Model in ModelMW. The green bar is emphasized, as it represents the “current conditions” based on 2011 land use/land cover.

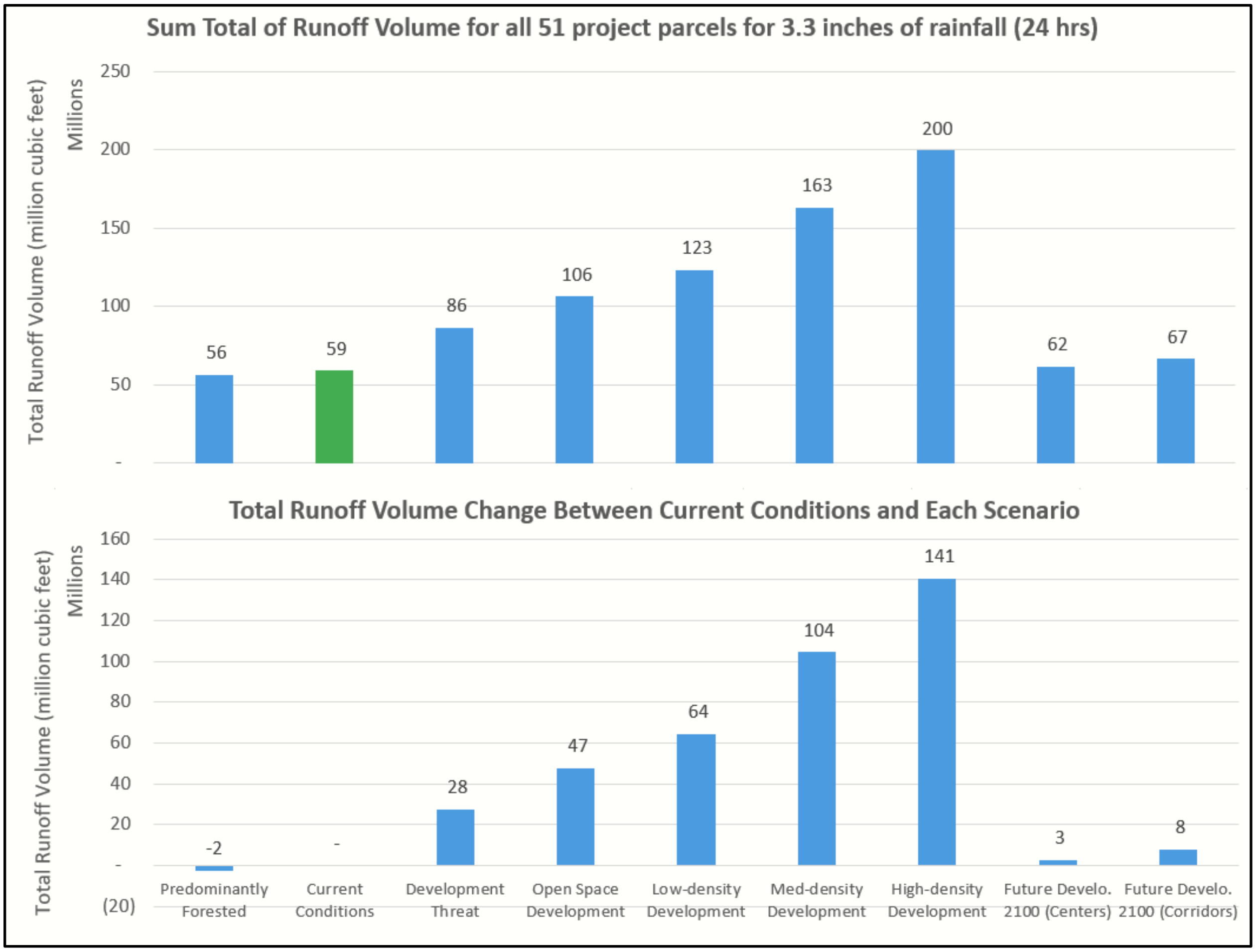

Figure 1.2: Top panel is the sum of the total volume of runoff from all modeled project parcels (51) in each scenario (in million cubic feet). Bottom panel shows the difference in total runoff volume for each scenario compared to the current conditions scenario (in million cubic feet). Note: bottom panel y-axis includes -2 million ft^3 reduction if 100% of a parcel is “forested” (including open water and wetland areas).

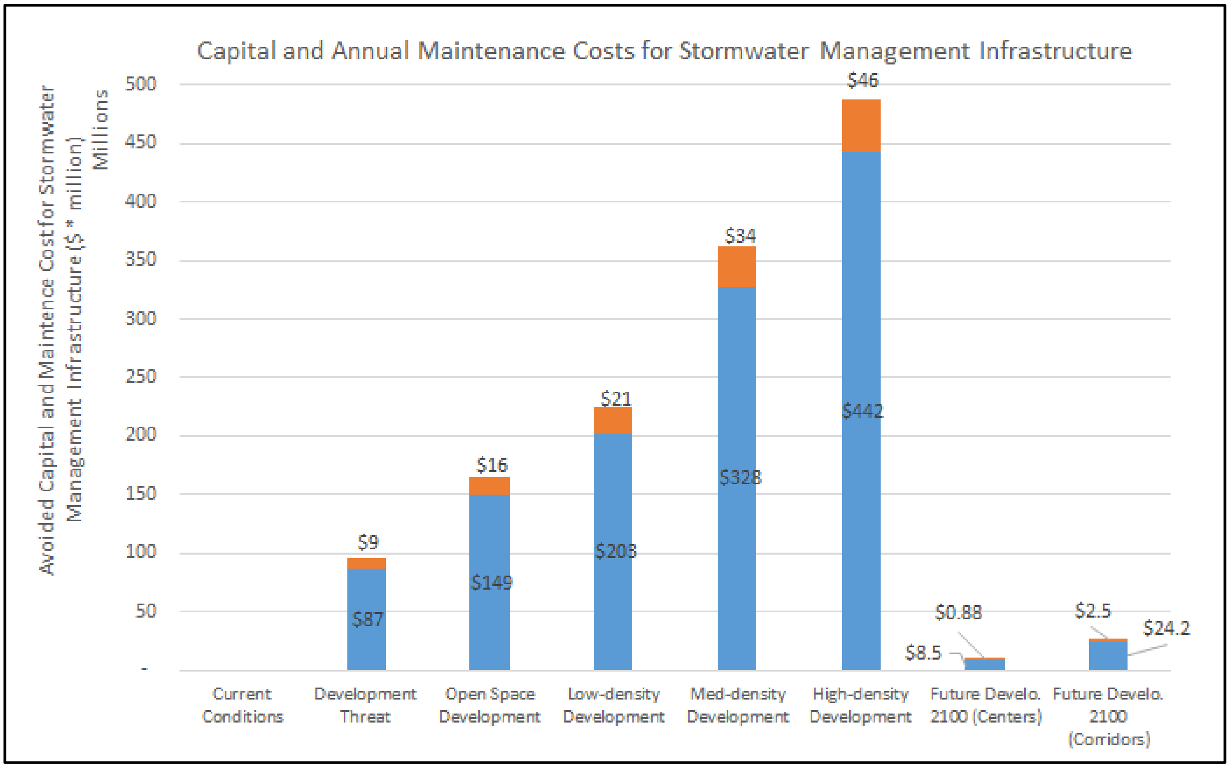

Figure 1.3: Estimated capital cost for stormwater management infrastructure (blue bars) and annual maintenance costs for stormwater management infrastructure (orange bars) to manage the increased runoff from a 3.3 inch rain storm if all parcels within a scenario were to be developed ($ in million). Costs were calculated based on estimates of $0.42/gallon for capital costs and $0.044/gallon for annual maintenance expenses (see U.S. EPA 1999, Houle et al. 2013, and Miles et al. 2019).

Total sediment, nitrogen, and phosphorus loading rates and total loads

Averages of total sediment, nitrogen, and phosphorus loaded loading rates (lbs/ac) show differences among scenarios that were similar to relative differences among scenarios for total runoff depth and volume (Fig. 1.4). All scenarios except “Predominantly Forested” had greater loading ratings (lbs/acre) than for “Current Conditions” and loading rates increased with increasing development intensity. The future development “Centers” and “Corridors” scenarios also resulted in increased average loading rates for sediment, TN, and TP, although the increases were less than observed with other scenarios. The “Corridors” scenario had slightly higher average loading rates compared to the “Centers” scenario, which is reflective of the greater change in acreage of developed land in the Corridors scenario (see Appendix Table 2 for “Centers” land cover changes and Appendix Table 3 for “Corridors” land cover changes).

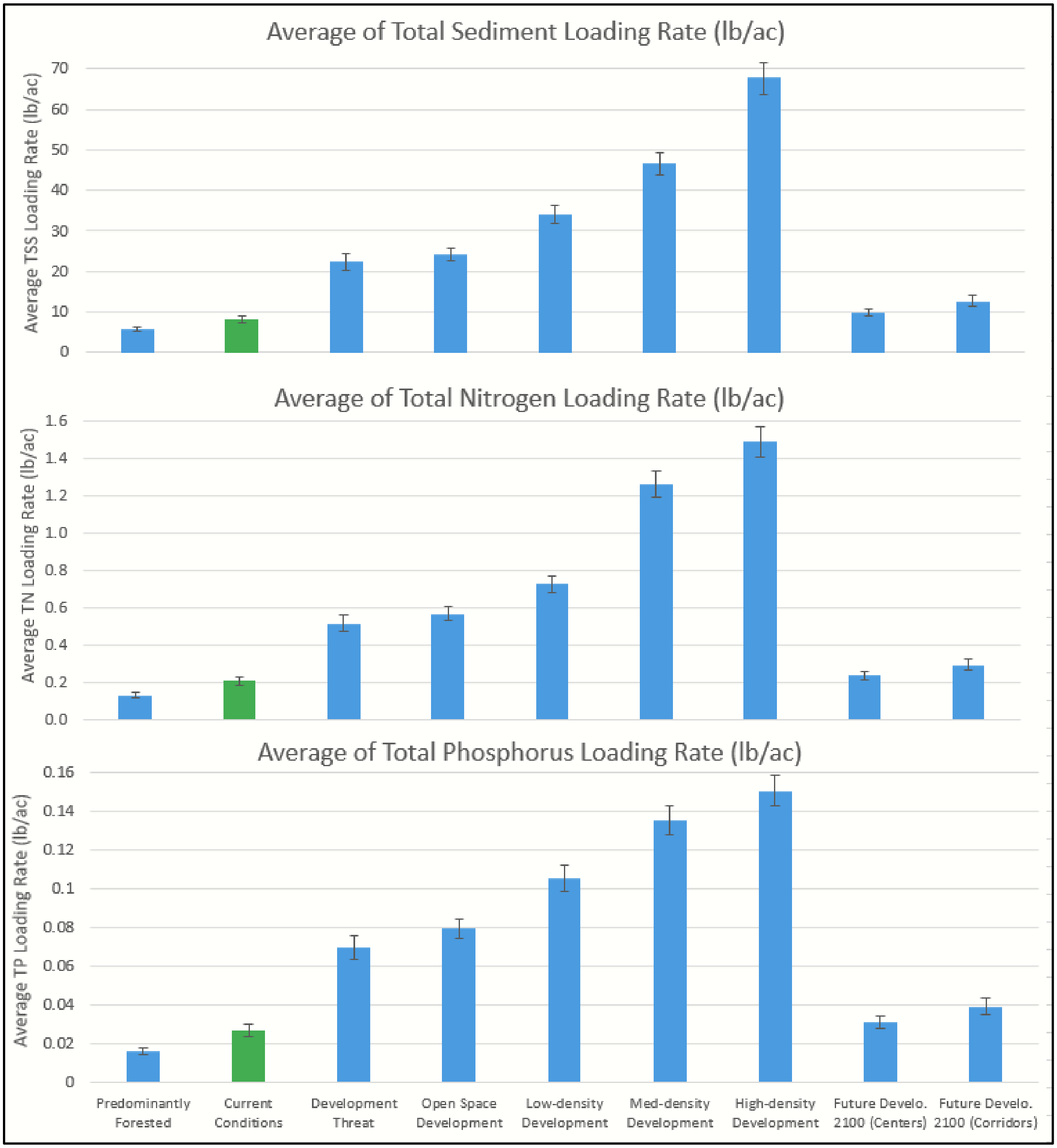

Figure 1.4: Average total sediment (upper panel), nitrogen (middle panel), and phosphorus (lower panel) loading rates (lbs/acre) of all project parcels (51) within each scenario. .

Total sediment, nitrogen, and phosphorus loads were calculated for each scenario in order to estimate the combined loading differences among scenarios for the entire portfolio of preserved parcels (Fig. 1.5). These total loads can be compared to “Current Conditions” to estimate the increase in load due to a range of development possibilities (Fig. 1.6). The range in total sediment, nitrogen, and phosphorus loads above “Current Conditions” (difference from “current conditions”) for the total portfolio of preserved parcels across scenarios was: 280,000 to 1,740,000 lbs. of sediment, 6,490 to 37,5500 lbs. of nitrogen, and 890 to 3,640 lbs. of phosphorus for “Development Threat” and “High-density Developed” scenarios, respectively.

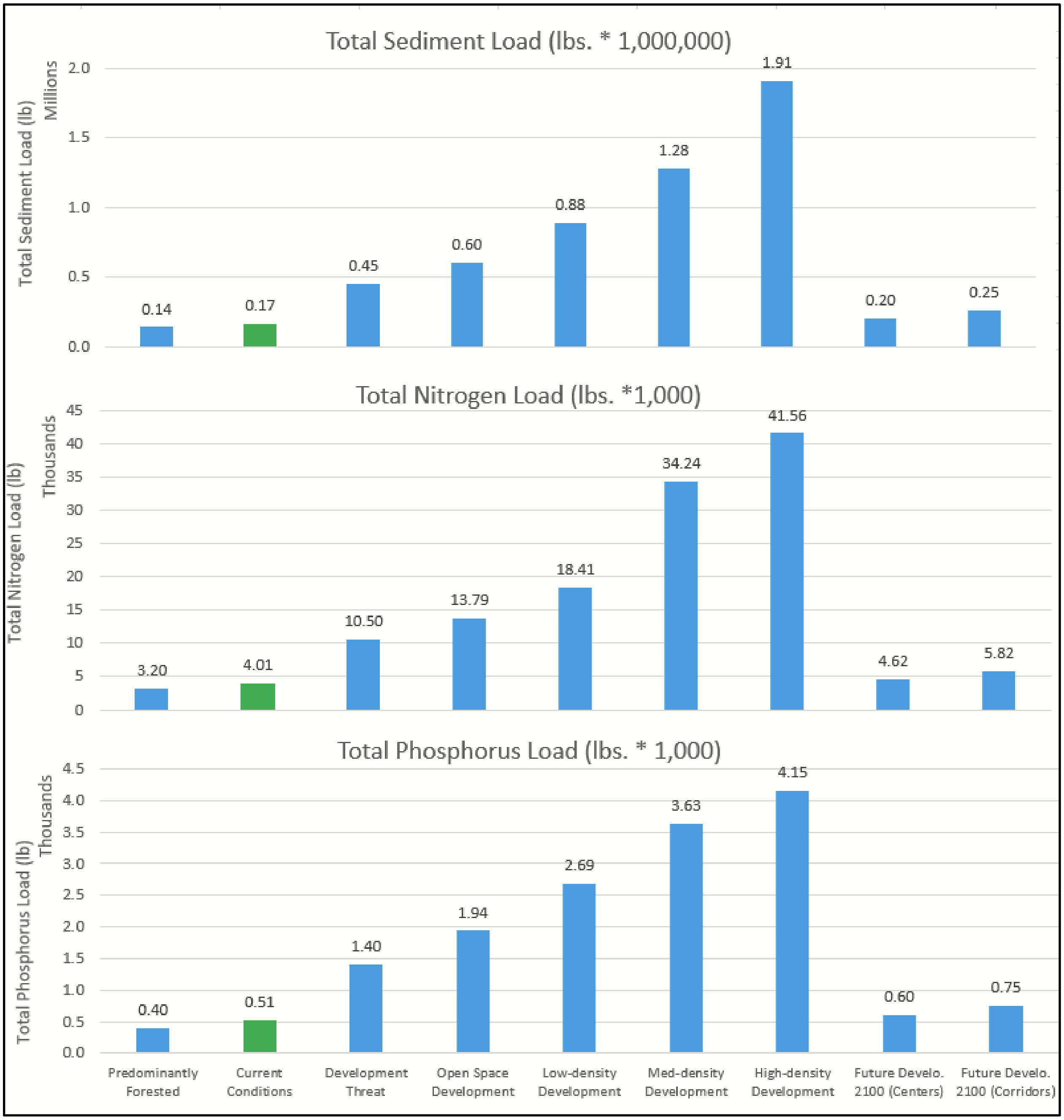

Figure 1.5: Total sediment (upper panel), nitrogen (middle panel), and phosphors (lower panel) loads summed from all project parcels within each modeled scenario. Note that y-axis values have multipliers (* million or * thousand).

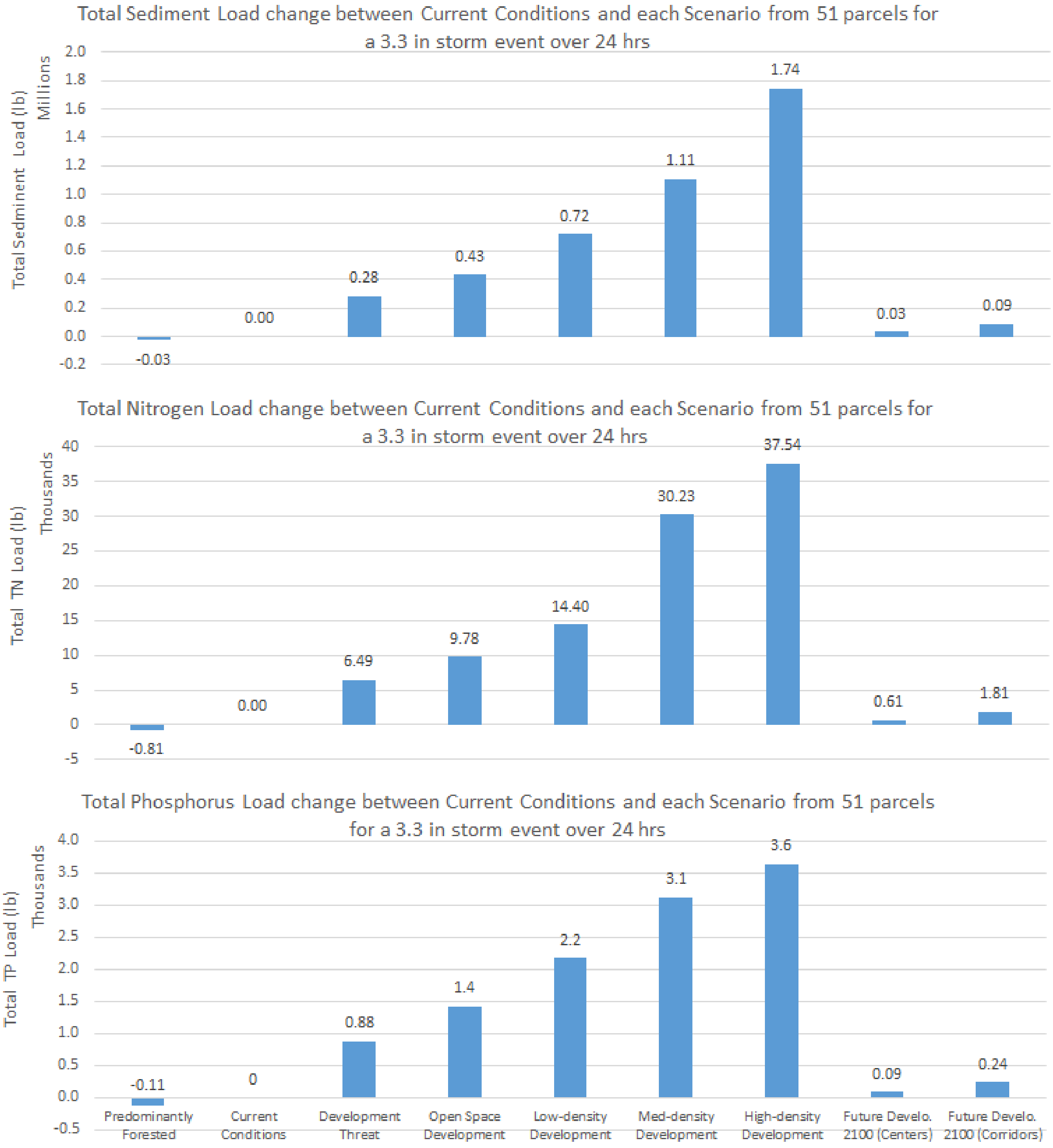

Figure 1.6: Change in total sediment (upper panel), nitrogen (middle panel), and phosphors (lower panel) loads compared to “Current Conditions” summed from all project parcels within each modeled scenario. Note that y-axis values have multipliers (* million or * thousand).

2. Modeling Approach: Watershed Multi-Year Model and Scenarios

Overview of Methods

The Watershed Multi-Year Model in ModelMW was used to derive annual estimates of hydrologic and water quality changes that could occur if preserved parcels were hypothetically not protected and were developed using the same scenarios as presented in section 1 (Site Storm Model). For detailed information on the WMYModel framework and function, visit the Technical Documentation[1] available on WikiWatershed.org.

For these model estimates, we delineated 21 separate watershed areas that encompassed most of the project parcel boundaries so that parcels were “nested” within larger watersheds (see examples in Fig. 2.1). Watershed areas ranged from 1.7 to 75 mi^2 and contained project parcel areas ranging from 19 to 3,129 acres. This nesting of parcels within larger watersheds

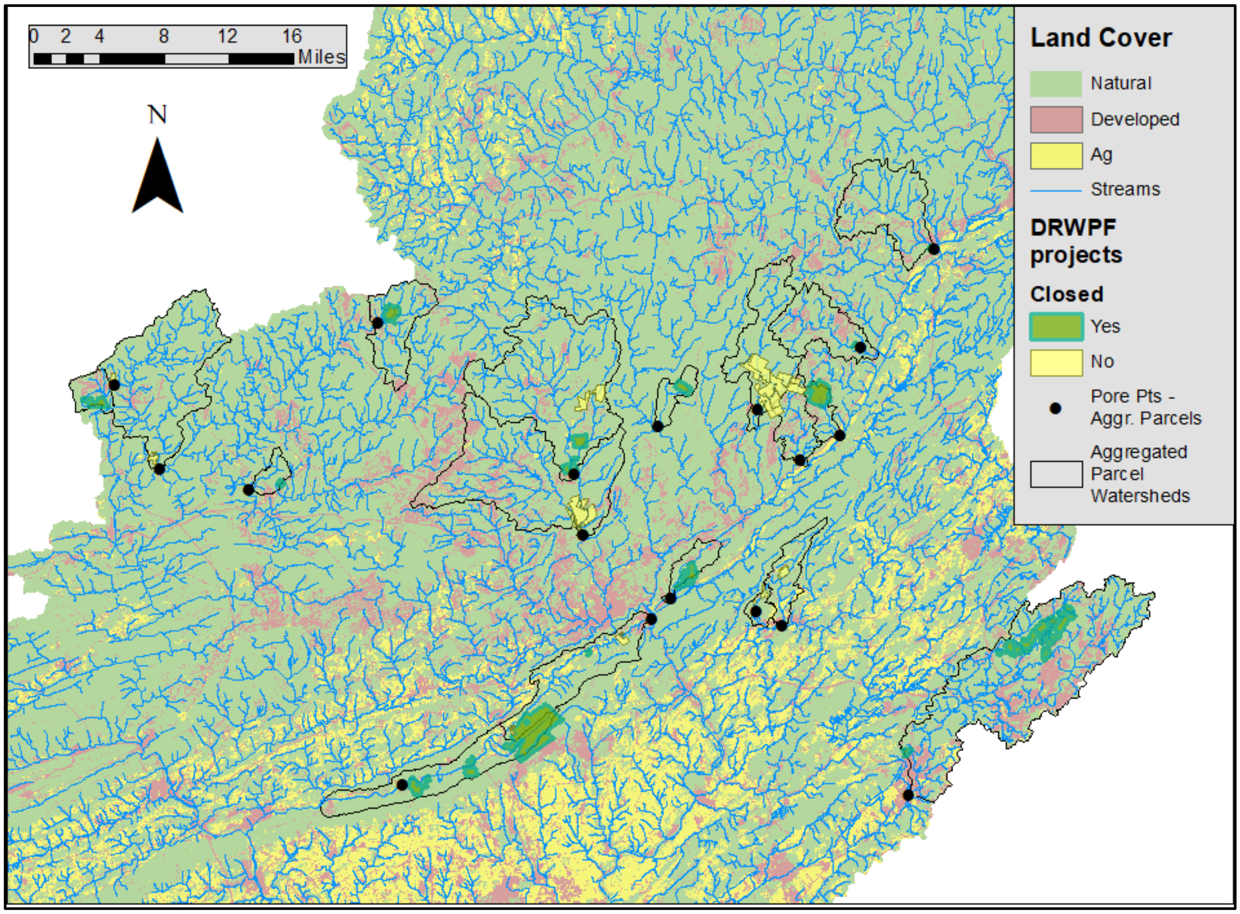

Figure 2.1: Example of watershed delineations (black boundaries) with nested project parcels (green or yellow polygons) and the “pore point” (black dot) showing the watershed outlet.

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[1] Model My Watershed Technical Documentation, 7.2.Watershed Multi-Year Model https://wikiwatershed.org/help/model-help/mmw-tech/#watershed-multi-year-model

resulted in project areas representing 0.2 to 71% of the watershed area. This range in nested percentage was perhaps less than ideal, but was a result of attempting to consolidate several parcels into a larger hydrologic unit (watershed) while also attempting to maximize the project:watershed area ratio. If a parcel boundary fell partially outside of the watershed area, the project parcel was "trimmed" in ARCGIS to align with the watershed boundary and the trimmed portion was ignored (or included in an adjacent watershed for analysis). The parcel area was then re-analyzed to determine the new total acreage and 2011 land cover distribution.

These watershed boundaries were then submitted to ModelMW for subsequent analysis and modeling. The initial run of the WMYModel produces a "Current Conditions" estimate for annualized and monthly hydrology (annual average surface runoff, subsurface flow, evapotranspiration, etc.) and water quality (annual average sediment, TN, and TP loads, loading rates, etc.). Current Conditions are defined by the base GIS data layers incorporated into ModelMW, which include: 2011 USGS National land cover database, Hydrologic Soil Groups from gSSURGO, 30-meter elevation data, point source discharges, county-level farm animal populations, estimates of shallow groundwater nitrogen concentration, estimates of soil nitrogen and phosphorus concentrations, estimates of baseflow, and national climate data from the time period 1960-1990 (daily precipitation and temperature). More information on these baseline datasets are available in the Technical Documentation (reference provided above).

Once the initial "Current Conditions" modeling run was completed, each land cover in each watershed was modified based on the project parcel acreages to add various levels of development in a manner nearly identical to scenario modifications made in the SSModel effort describe previously (except where parcels were "trimmed" to the edge of a watershed boundary). Thus, the land cover table was modified to debit acreage of Wooded Areas and credit acreages for Developed Open Space, Developed Low-Intensity, Developed Medium-Intensity, or Developed High-Intensity, depending on the scenario in question.

Model estimates for each watershed within a scenario were averaged and compared against "Current Conditions." Specifically, we present the differences from "Current Conditions" in the averages from each scenario for annual total subsurface flow, surface runoff, evapotranspiration and sediment, nitrogen and phosphorus loads.

We have also run the WMYModel for all watersheds for the following scenarios:

- Land cover changed for the parcel within the watershed to Future Development (Centers);
- Land cover changed for the parcel within the watershed to Future Development (Centers) AND weather data changed to Future Weather based on RCP 4.5;
- Land cover changed for the parcel within the watershed to Future Development (Centers) AND weather data changed to Future Weather based on RCP 8.5;
- Land cover changed for the parcel within the watershed to Future Development (Corridors);
- Land cover changed for the parcel within the watershed to Future Development (Corridors) AND weather data changed to Future Weather based on RCP 4.5; and

- Land cover changed for the parcel within the watershed to Future Development (Corridors) AND weather data changed to Future Weather based on RCP 8.5.

Results

There were clear changes among modeled scenarios in annual average hydrologic and water quality estimates (derived from the WMYModel; Fig. 2.2 and Fig. 2.3) despite having different watershed sizes with different proportions of their areas that were modified and significant differences among watersheds in other factors (e.g., different watershed-wide land cover and soil types, slopes, and different precipitation and temperature regimes). For example, average annual subsurface flow was lower for all land cover scenarios utilizing the 1960-1990 climate data compared to “Current Conditions” and average annual surface runoff was higher in all 1960-1990 climate scenarios compared to “Current Conditions” (Fig. 2.2). Differences in the average annual evaporative losses among those scenarios were variable, with “Development Threat,” “Developed Open Space,” and “Developed Low Density” scenarios all having slightly higher average annual evapotranspiration results. Average annual loads of sediment, nitrogen, and phosphorus also increased with increasing development intensity, when holding climate inputs consistent to the 1960-1990 data (Fig. 2.3). It should be noted that the variability among watersheds was high. Nevertheless, consistently stronger differences occurred as development intensity was increased among scenarios.

The comparisons of future development and future climate predictions revealed interesting patterns for discussion (Fig. 2.2 and Fig. 2.3). Evapotranspiration losses were predicted to increase greatly in both future climate scenarios (i.e., RCP 4.5 and 8.5), which was likely a function of increasing future air temperatures. Thus, future climate had an overriding influence compared to predicted future changes in development/land cover. There were also differences observed between future land cover using “Centers” and “Corridors” scenarios where there were increases in surface runoff and decreases in subsurface flow related to more aggressive land development (i.e., Corridors). However, these differences from “Current Conditions” were much smaller compared to the other land cover change scenarios. Combining predictions of both future land cover and future climate generates significant complexity in underlying data driving this modeling effort. Climate projections were downscaled (see Future Climate section below) and then a stochastic weather generator was used to adjust rainfall event magnitudes seasonally based on past rainfall intensity (see Ensign et al. 2020). This correction was performed because of the recognition that downscaled climate model data don’t adequately represent changes in the magnitude and duration for large infrequent events that some climate models suggest may occur more frequently. Often, downscaled GCM data tend to disperse the annual average rainfall over more days compared to historic data, thus generating more days with rainfall, over estimating the number of days with “drizzle” and under-representing large infrequent storms. The latter is a particularly important driver for erosion and sediment delivery through the fluvial system. Nevertheless, the modeling results for average sediment and phosphorus loading rates among these scenarios (Fig. 2.3) suggest that influences of future development patterns may be “overridden” by changes to our climate/weather. This may be an artifact produced by the evaporation estimates utilized in this particular model or by our manipulation of GCM precipitation predictions. However, these results, if valid, suggest that in spite of greater annual precipitation due to climate change (e.g., RCP 8.5), evaporative losses driven by higher temperatures may result in less or muted export of sediment and phosphorus from these watersheds. Under RCP 4.5 climate estimates, evapotranspiration losses were not as dramatic and the WMYModel predicts an increase in subsurface flow that may result in greater nitrogen movement through groundwater flow paths that could result in increased annual average loads.

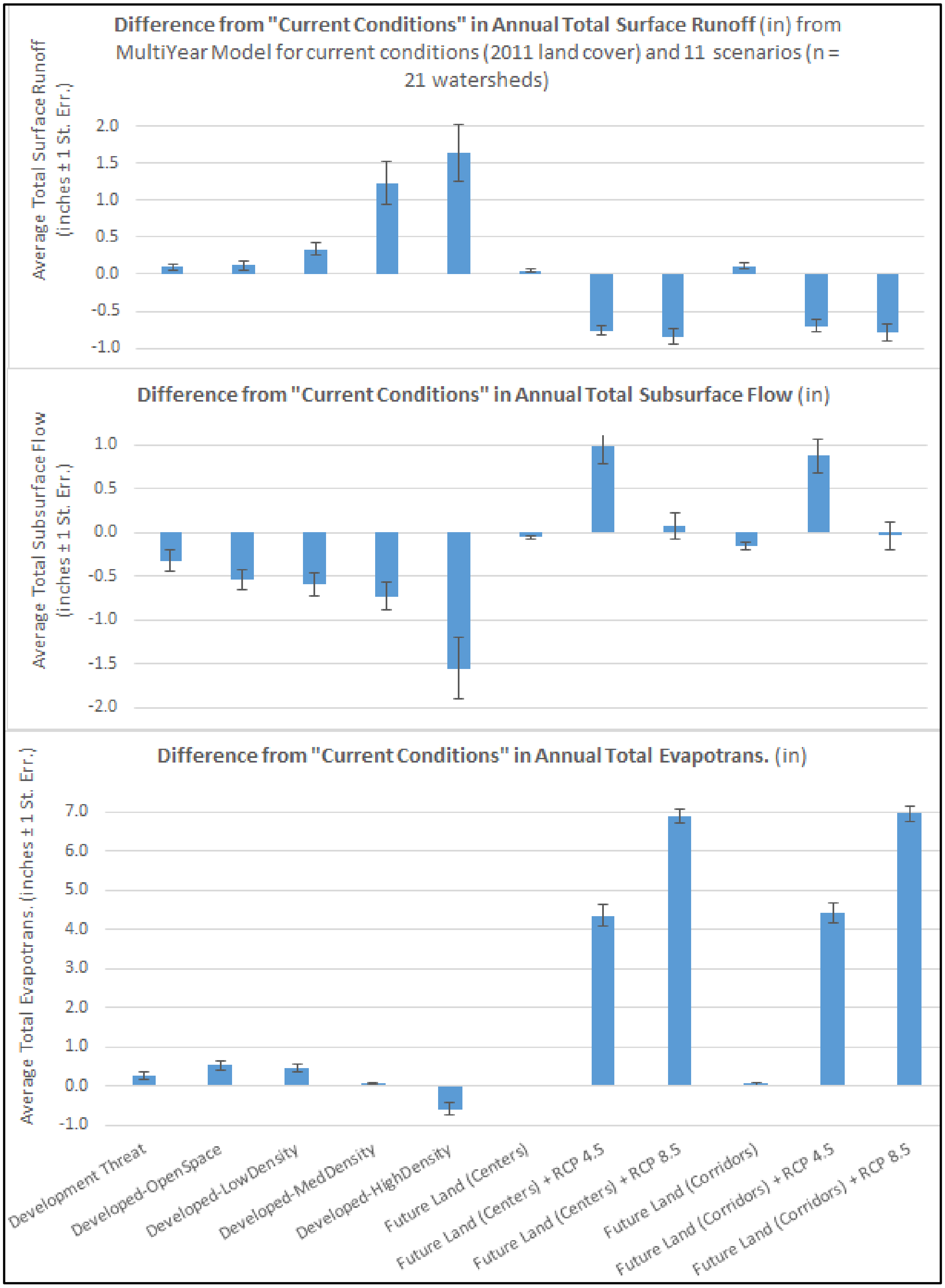
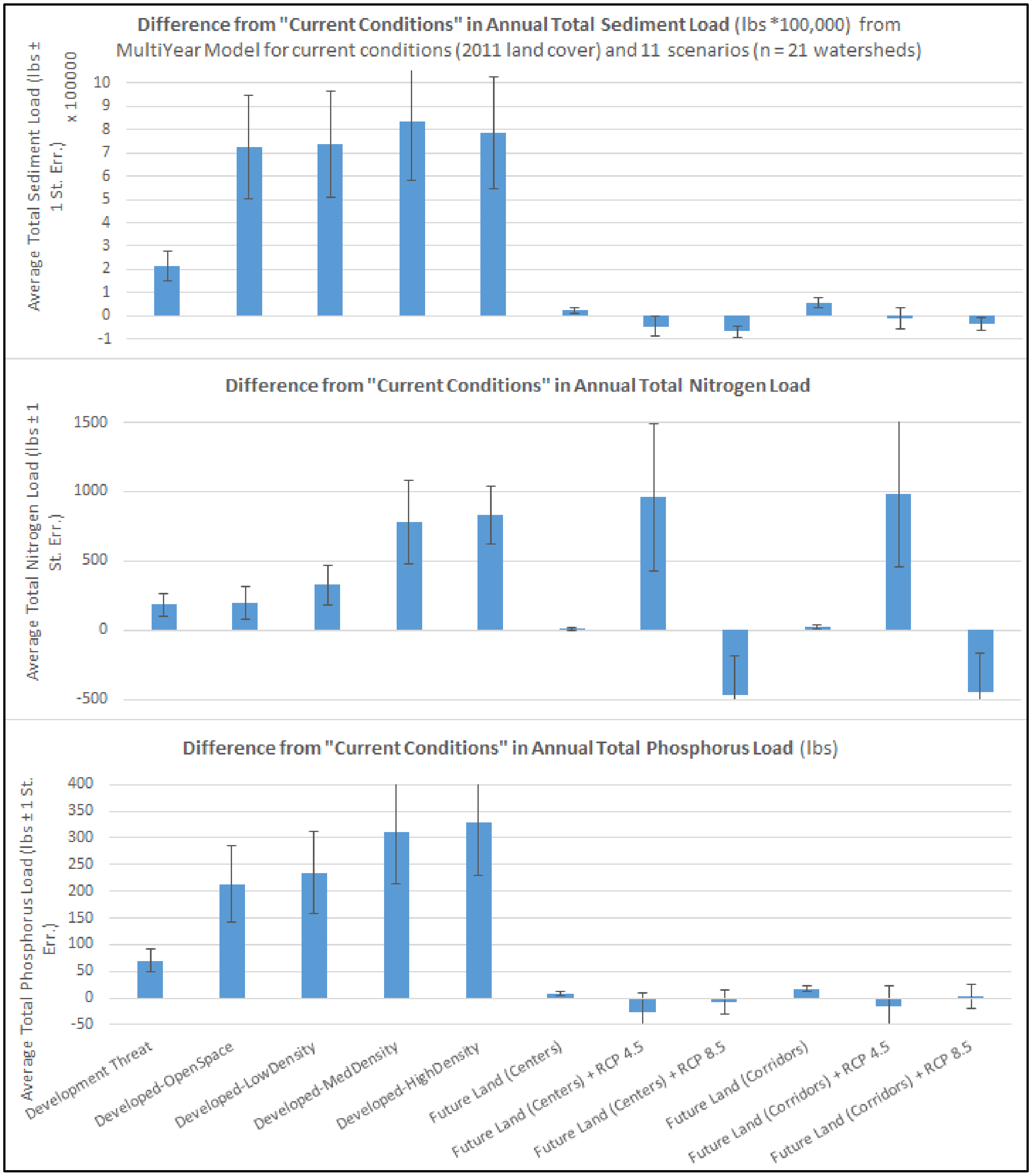


Figure 2.2: The difference from “Current Conditions” in estimates of average surface runoff (upper), subsurface flow (middle), and evapotranspiration (lower panel) (inches ± 1 st. error) from the Watershed Multi-Year Model for each scenario. Each bar is the average difference from 21 watersheds that were modeled under each scenario. Land cover was changed only for the preserved parcels/acreages within each watershed.


Difference from "Current Conditions" in Annual Total Sediment Load (lbs *100,000) from MultiYear Model for current conditions (2011 land cover) and 11 scenarios (n = 21 watersheds)

Difference from "Current Conditions" in Annual Total Nitrogen Load

Difference from "Current Conditions" in Annual Total Phosphorus Load (lbs)

Figure 2.3: The difference from "Current Conditions" in estimates of average annual loads for sediment (upper panel), nitrogen (middle) and phosphorus (lower panel) (lbs. ± 1 st. error) from the Watershed Multi-Year Model. Each bar is the average difference from 21 watersheds that were modeled under each scenario. Land cover was changed only for the preserved parcels/acreages within each watershed.

3. Modeling Approach: Riparian Contributing Area Analysis:

Overview of Methods

The focus of this modeling exercise was to evaluate the potential benefits that a forested parcel of land located on a stream might have in filtering out sediment and nutrient loads that flow through it from upland sources. As demonstrated by numerous studies undertaken by USDA and others (e.g., Sweeney and Newbold, 2014), functioning forested riparian buffers can filter out 25-85% of the nutrient and sediment loads delivered to them from upland sources depending upon site characteristics and maintenance levels. Such studies have also demonstrated that a curvilinear relationship exists between riparian buffer width and nitrogen, phosphorus and sediment removal efficiency, and that removal efficiency appears to level off at buffer widths of around 100 feet (with the removal efficiencies varying for each pollutant type).

For the purposes of this modeling exercise, the following steps were conducted:

- A new “riparian buffer” layer was generated that depicts 100-foot buffers around every stream segment contained within high-resolution (NHD) catchments available for the DRB.
- Using GIS, preserved parcels were clipped by the new riparian layer to generate a new dataset of parcels that were close enough to a stream to have a 100-foot buffer on one or both sides of the stream.
- For all parcels with at least one buffer, an analysis was run (with a new API developed by Drexel University) that resulted in the creation of one or more polygons that depicted the “contributing area” that drained to the buffer(s). As shown in Fig. 3.1, this contributing area may be completely contained within a given protected parcel, or it may extend outside the parcel. In the first instance, the protected riparian buffer is filtering pollutant loads generated within the parcel; in the second instance, the protected buffer is filtering pollutant loads coming from outside the protected parcel as well.
- For each contributing area created from the previous step, another API developed by Drexel University was run to produce the following output: 1) a tabulation of the land use/land cover (2011 NLCD) contained within each area, 2) the pollutant loads (N, P and sediment) that could potentially be generated by each area based on previously-derived loading rates for the DRB (see next section for further explanation), and 3) the reduced loads that might be achieved due to the filtering effects of the riparian buffers. (Note: for consistency and comparison purposes, mean pollutant reduction efficiencies of 41%, 40%, and 54% were used for TN, TP and sediment, respectively).
- Finally, the tabulation and reduction results were written to a file so that the results from each preserved parcel could be compared and scored with respect to their potential water quality benefits.

In Fig. 3.1, the analysis was fairly straight-forward in that the buffer(s) associated with a given parcel were situated along only a single stream segment. In some more complex cases, however, multiple parcels associated with a given project actually resulted in many riparian buffers and upland contributing areas associated with multiple streams. For example, the 2,224-acre parcel associated with the Little Bushkill Forest Preserve project actually resulted in many contributing areas draining to almost a dozen different stream segments along the Little Bushkill and Tom’s Creek as illustrated in Fig. 3.2. As described in the next section, the potential pollutant load reductions for all parcels were combined and reported on a project by project basis.

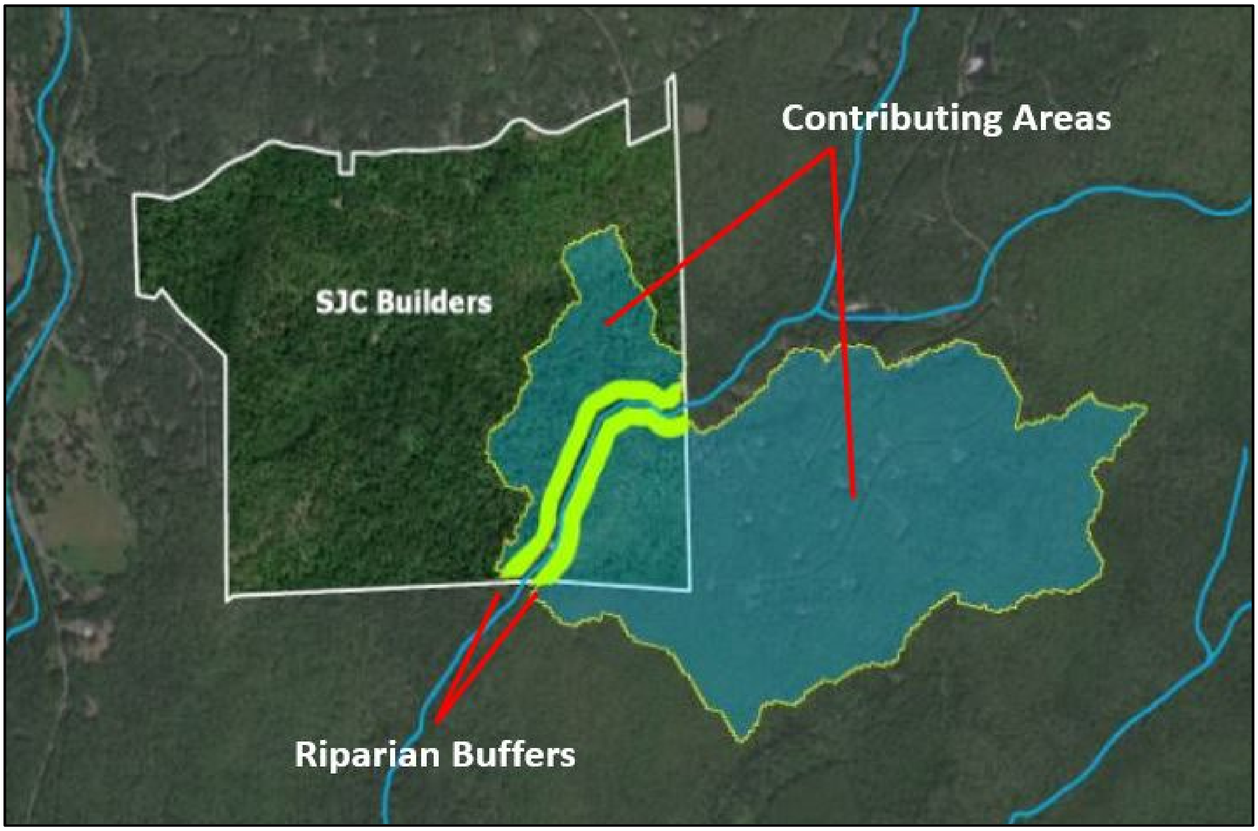


Figure 3.1: Preserved parcel with two riparian forest buffers.

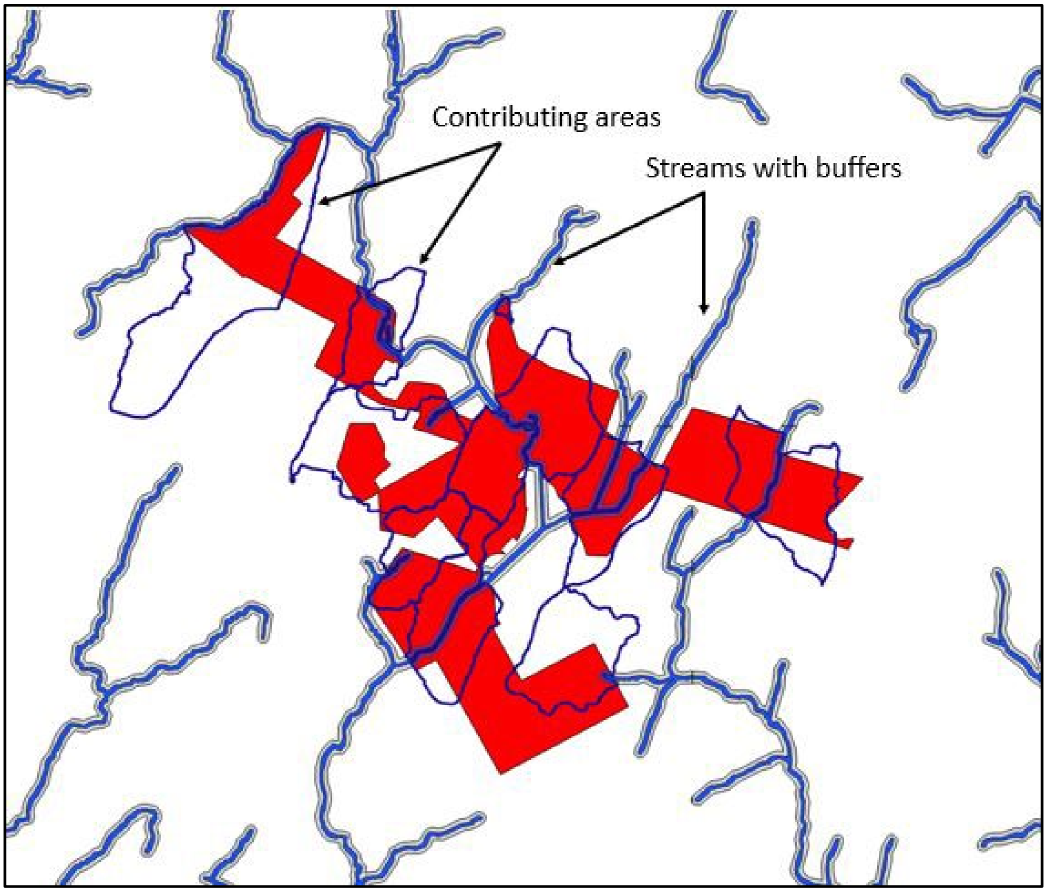


Figure 3.2: Multiple riparian buffers and contributing areas associated with the Little Bushkill Forest Preserve project.

Results

As described previously, the “contributing” areas flowing to riparian buffer zones associated with all of the project areas were delineated depending upon whether the land area associated with a given project was near a stream. In the case of project areas that did not border streams, no contributing areas were delineated. In cases where project areas bordered or spanned a stream, either one or two contributing areas were defined as shown earlier in Fig. 3.1. Subsequent to delineating these contributing areas, the acres of non-forest land contained within each were summed, and then the potential pollutant loads delivered to the riparian buffers were estimated using the previously-established land cover loading rates for any given HUC12 basin as described earlier.

The results of this modeling exercise are presented in Tables 3.1 and 3.2. Included for each project in Table 3.1 are the total riparian buffer acres associated with each project, the total area drained (filtered) by the riparian buffers associated with each project, and the total pollutant loads removed based on the reduction efficiencies used as described earlier. For the projects evaluated, the total buffer areas ranged from about 1 to 603 acres; the contributing areas that drained to these buffers ranged from about 3 to 13,521 acres; and the estimated pounds per year of sediment, nitrogen (TN), and phosphorus (TP) removed by the buffers ranged from 4.2 to 50,343.7, 0.1 to 763.2, and 0.01 to 76.01 lb/acre, respectively.

Using these results, each project was then scored based on its potential pollutant removal efficiency. The projects were first scored separately based on the total amounts of TN, TP and sediment removed. A final score was then made based on the average of the three pollutant removal scores. All of these project scores are shown in Table 3.2.

Overall, based on the modeling results described above, the most salient points regarding the water quality benefits associated with various protected parcels are as follows:

- Of the 52 projects evaluated, 49 were close enough to nearby streams to include potential riparian buffer zones. Projects that were not within 100 feet of a stream segment were assumed to not have sufficient “contact area” along streams to provide for beneficial pollutant removal services normally associated with riparian buffers.
- Larger parcels along streams tended to have more riparian buffer acres than smaller parcels. However, larger riparian buffers did not always result in the largest contributing areas being drained/filtered by the buffers (i.e., the size of the contributing areas are primarily dictated by local topographic conditions).
- Parcels that spanned stream segments (i.e., had riparian buffers on both sides of the stream) tended to have more total acres of contributing area.
- Those parcels with riparian buffers treating the most upland acres of agricultural and developed land tended to be the most beneficial in terms of reducing nutrient and sediment loads, with the treatment of agricultural runoff being more beneficial due to their higher combined nutrient and sediment loads in comparison to developed land.
- In terms of overall load reduction effectiveness, the results showed that some projects were much more effective than others in terms of potential pollutant load reduction. More specifically, when the projects were sorted based on estimated load reductions, the results showed that 60% of pollutants run into just six projects. These projects could potentially reduce 61% of the total phosphorus loads delivered to all riparian buffers; and the top six projects could potentially reduce 80% of the total sediment load delivered to all riparian buffers.

Table 3.1: Riparian buffer analysis results (Part 1).

Project	Total Buffer Acres (1)	Total Area Drained (2)	Sediment Load Removed (3)	TN Load Removed (3)	TP Load Removed (3)
16 Years	6.5	105.2	14132.3	48.0	16.16
18 Years	2.5	66.7	8871.6	29.4	9.67
Aquashicola Watershed Protection	283.3	1201.8	2293.9	41.7	4.90
Bartolacci	7.3	59.9	36.8	2.9	0.18
Bear Creek – Ten Mile Run	39.4	317.7	189.0	16.7	1.04
Bear Creek Addition	4.9	99.3	93.3	5.9	0.41
Bear Creek Properties LLC	8.9	78.0	59.5	3.9	0.26
Bear Swamp	65.7	616.6	3578.6	88.8	7.95
Beaver Run Forest	0.7	3.1	4.2	0.1	0.01
Blueberry Acres	26.6	136.0	427.7	16.2	1.24
Brodhead Creek Working Woodlands	95.8	1681.2	1682.6	86.7	5.87
Brodhead Flyfishers	23.1	509.7	424.2	25.2	1.65
Brodhead Watershed: SJC Builders	13.8	293.9	175.5	13.3	0.83
Bucks Cove Run Forest & Wetlands	37.2	198.0	68.7	21.0	1.14
Burnt Meadow	342.4	403.0	469.2	18.2	1.34
Bushkill Watershed: Lein	19.5	1024.4	765.1	71.7	3.97
Camp Hidden Falls	36.4	1110.5	863.2	59.7	3.80
Cherry Creek (Percudani)	16.1	238.5	860.6	16.9	1.65
Cherry Valley	92.3	1753.5	2002.3	57.2	4.79
Cranberry Overlook Greenway	44.7	55.6	29.2	2.4	0.15
Darling Preserve – Plank	22.2	93.4	132.9	5.8	0.42
Dingmans Creek	1.0	10.2	6.9	0.5	0.03
Fisher	20.0	228.4	596.1	5.5	0.77
Gerber	236.1	1560.1	2683.2	122.6	8.52
Graham	3.9	23.0	29.7	0.6	0.05
Hay Creek Riparian Buffer	55.7	216.4	1615.7	11.6	2.72
Holly Ridge Forest	24.1	740.3	1870.8	29.4	2.17
Jacksonburg Headwaters Greenway	25.8	230.6	203.9	19.6	4.26
Little Bushkill Forest Reserve	150.5	2464.1	929.7	122.6	7.05
Lubbers Run Greenway Phase II	603.2	2473.3	2993.6	163.6	11.53
Meister	32.4	72.2	218.2	2.4	0.31
Menantico Creek	61.6	1310.1	50343.7	429.6	38.25
Milford Glen	3.7	16.5	7.5	0.8	0.04
Mosiers Knob	1.9	102.5	67.4	4.4	0.28
Mt. Rascal	7.2	83.4	39.7	3.6	0.22
Northeast Connection Phase II	151.2	2051.4	725.2	101.6	5.75
Piccoli	5.0	422.7	10552.0	54.3	12.59
Pocono Mountain Bluestone	19.8	352.6	484.6	18.2	1.35
Pyle Woods	19.0	67.8	17836.0	50.7	17.85
Quaker Hill	80.0	252.8	654.7	5.9	0.85
South Branch Rancocas Creek	95.2	367.3	275.7	35.5	1.97
Spence	6.7	209.2	14004.1	73.5	20.81
Stony Run	25.0	237.8	138.6	10.5	0.66
Thompson/Wright	114.7	13521.3	42096.2	763.2	76.01
Upper Lehigh Headwaters	73.2	605.2	192.0	36.5	2.03
Warwick Furnace	20.6	138.7	14096.5	48.1	15.54
Yards Creek Phase 1	19.8	248.9	64.9	17.4	1.09
Yards Creek Phase 2	22.4	52.9	7.2	2.8	0.15
Young	7.0	59.3	2376.1	9.2	3.31
Zemel Pemberton	71.1	1211.5	670.5	21.8	1.34

(1) Total acres with a 100-foot buffers; (2) Includes areas on either or both sides of a stream segment; (3) Pounds removed per year by the buffers associated with any given project

Table 3.2: Riparian buffer analysis results (Part 2).

Project	Sed Load Removed	Sed Load Score (1)	TN Load Removed	TN Load Score (1)	TP Load Removed	TP Load Score (1)	Combined Score (2)
16 Years	14132.3	47	48.0	35	16.16	46	42.7
18 Years	8871.6	43	29.4	31	9.67	42	38.7
Aquashicola Watershed Protection	2293.9	38	41.7	34	4.90	36	36
Bartolacci	36.8	7	2.9	8	0.18	7	7.3
Bear Creek – Ten Mile Run	189.0	17	16.7	21	1.04	18	18.7
Bear Creek Addition	93.3	13	5.9	14	0.41	12	13
Bear Creek Properties LLC	59.5	9	3.9	10	0.26	9	9.3
Bear Swamp	3578.6	42	88.8	44	7.95	40	42
Beaver Run Forest	4.2	1	0.1	1	0.01	1	1
Blueberry Acres	427.7	23	16.2	20	1.24	21	21.3
Brodhead Creek Working Woodlands	1682.6	35	86.7	43	5.87	38	38.7
Brodhead Flyfishers	424.2	22	25.2	29	1.65	26	25.7
Brodhead Watershed: SJC Builders	175.5	16	13.3	19	0.83	16	17
Bucks Cove Run Forest & Wetlands	68.7	12	21.0	27	1.14	20	19.7
Burnt Meadow	469.2	24	18.2	25	1.34	22	23.7
Bushkill Watershed: Lein	765.1	30	71.7	41	3.97	33	34.7
Camp Hidden Falls	863.2	32	59.7	40	3.80	32	34.7
Cherry Creek (Percudani)	860.6	31	16.9	22	1.65	25	26
Cherry Valley	2002.3	37	57.2	39	4.79	35	37
Cranberry Overlook Greenway	29.2	5	2.4	6	0.15	5	5.3
Darling Preserve – Plank	132.9	14	5.8	13	0.42	13	13.3
Dingmans Creek	6.9	2	0.5	2	0.03	2	2
Fisher	596.1	26	5.5	12	0.77	15	17.7
Gerber	2683.2	40	122.6	47	8.52	41	42.7
Graham	29.7	6	0.6	3	0.05	4	4.3
Hay Creek Riparian Buffer	1615.7	34	11.6	18	2.72	30	27.3
Holly Ridge Forest	1870.8	36	29.4	30	2.17	29	31.7
Jacksonburg Headwaters Greenway	203.9	19	19.6	26	4.26	34	26.3
Little Bushkill Forest Reserve	929.7	33	122.6	46	7.05	39	39.3
Lubbers Run Greenway Phase II	2993.6	41	163.6	48	11.53	43	44
Meister	218.2	20	2.4	5	0.31	11	12
Menantico Creek	50343.7	50	429.6	49	38.25	49	49.3
Milford Glen	7.5	4	0.8	4	0.04	3	3.7
Mosiers Knob	67.4	11	4.4	11	0.28	10	10.7
Mt. Rascal	39.7	8	3.6	9	0.22	8	8.3
Northeast Connection Phase II	725.2	29	101.6	45	5.75	37	37
Piccoli	10552.0	44	54.3	38	12.59	44	42
Pocono Mountain Bluestone	484.6	25	18.2	24	1.35	24	24.3
Pyle Woods	17836.0	48	50.7	37	17.85	47	44
Quaker Hill	654.7	27	5.9	15	0.85	17	19.7
South Branch Rancocas Creek	275.7	21	35.5	32	1.97	27	26.7
Spence	14004.1	45	73.5	42	20.81	48	45
Stony Run	138.6	15	10.5	17	0.66	14	15.3
Thompson/Wright	42096.2	49	763.2	50	76.01	50	49.7
Upper Lehigh Headwaters	192.0	18	36.5	33	2.03	28	26.3
Warwick Furnace	14096.5	46	48.1	36	15.54	45	42.3
Yards Creek Phase 1	64.9	10	17.4	23	1.09	19	17.3
Yards Creek Phase 2	7.2	3	2.8	7	0.15	6	5.3
Young	2376.1	39	9.2	16	3.31	31	28.7
Zemel Pemberton	670.5	28	21.8	28	1.34	23	26.3

(1) Greater load removals yield higher scores; (2) Final (combined) score is the average of the scores for all three pollutants, with higher scores reflecting greater water quality benefits

4. Modeling Approach: Watershed Multi-Year Model and Downstream Influences

Overview of Methods

This modeling approach was comprised of the following basic steps or components:

- For each protected project area, the potential sediment load was calculated based on simulating the conversion of current “natural” land to developed land (in this case, medium-density developed land was used for consistency). For this analysis, sediment loadings were used as a basis of comparison due to the recognition that, from a non-point source load perspective, this particular pollutant is more important because of increased streambank erosion caused downstream of developed areas.

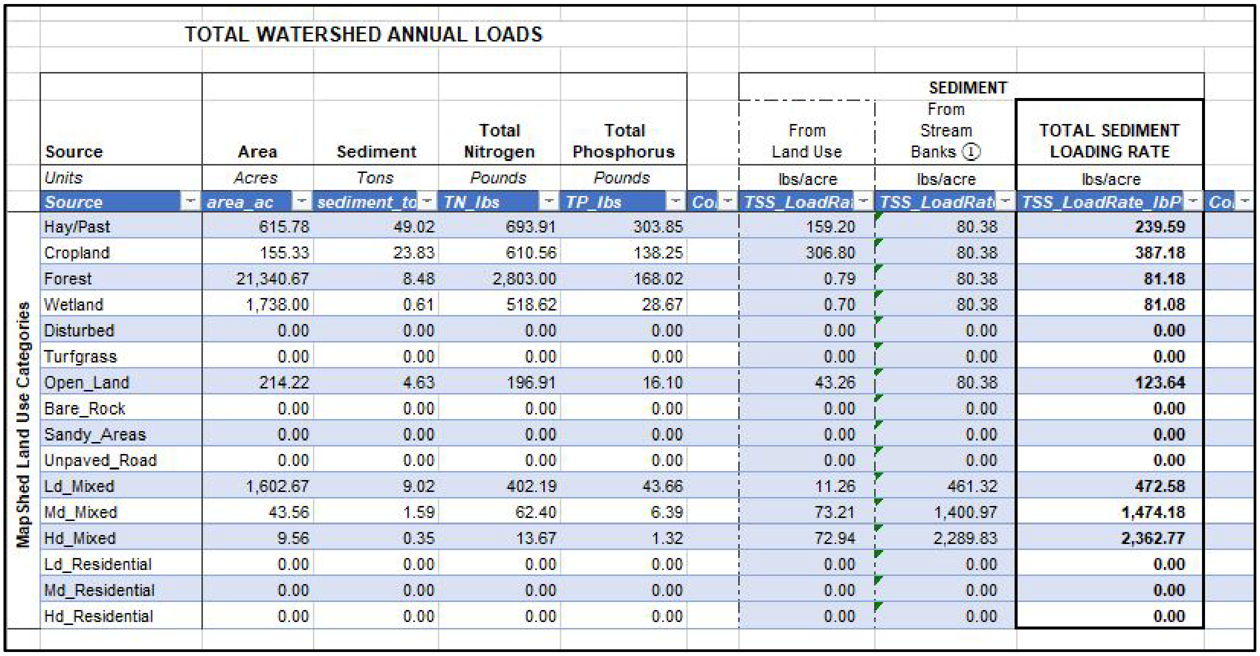
- The percent sediment load contribution of the “future development parcel” to the upstream drainage area in which it is located was calculated.

- The percent load contribution of that parcel to a successively expanding drainage area based on moving incrementally downstream was also calculated out to the point where the percent contribution was determined to be negligible (i.e., less than 5% of the total downstream load).

- At the point of “negligible contribution”, the stream length (distance) from the center of the parcel to the downstream “extinction” point was then calculated.

- This calculation of the downstream pollution “signal” was done for each project parcel (or collection of parcels that constituted a single project), and the distances calculated for each were compared and scored to assess the relative water quality benefit of each project parcel.

Sediment load calculations for each project parcel and drainage area were based on the results of model runs that were first completed using the Watershed Multi-Year Model in Model My Watershed. Specifically, model runs were conducted for all 426 HUC12 sub-basins comprising the larger Delaware River Basin. The simulated load results for each HUC12 were then used to develop “combined” loading rates that reflected the non-point source loads from both upland and streambank sources. An example of the “combined” loading rates derived for a selected HUC12 sub-basin within the DRB is shown in Fig. 4.1. In this case, the image shown is a screen capture of a portion of the spreadsheet tool that was used to calculate the combined loading rate for any given HUC12 basin in the Delaware River Basin.



TOTAL WATERSHED ANNUAL LOADS

							SEDIMENT			
	Source	Area	Sediment	Total Nitrogen	Total Phosphorus		From Land Use	From Stream Banks ①	TOTAL SEDIMENT LOADING RATE	
	Units	*Acres*	*Tons*	*Pounds*	*Pounds*		lbs/acre	lbs/acre	lbs/acre	
	Source	*area_ac*	*sediment_to*	*TN_lbs*	*TP_lbs*	*Co*	*TSS_LoadRa*	*TSS_LoadRat*	*TSS_LoadRate_lbP*	*Co*
MapShed Land Use Categories	Hay/Past	615.78	49.02	693.91	303.85		159.20	80.38	**239.59**	
	Cropland	155.33	23.83	610.56	138.25		306.80	80.38	**387.18**	
	Forest	21,340.67	8.48	2,803.00	168.02		0.79	80.38	**81.18**	
	Wetland	1,738.00	0.61	518.62	28.67		0.70	80.38	**81.08**	
	Disturbed	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Turfgrass	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Open_Land	214.22	4.63	196.91	16.10		43.26	80.38	**123.64**	
	Bare_Rock	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Sandy_Areas	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Unpaved_Road	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Ld_Mixed	1,602.67	9.02	402.19	43.66		11.26	461.32	**472.58**	
	Md_Mixed	43.56	1.59	62.40	6.39		73.21	1,400.97	**1,474.18**	
	Hd_Mixed	9.56	0.35	13.67	1.32		72.94	2,289.83	**2,362.77**	
	Ld_Residential	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Md_Residential	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	
	Hd_Residential	0.00	0.00	0.00	0.00		0.00	0.00	**0.00**	

Figure 4.1: Portion of a spreadsheet showing the combination of “upland” and “streambank” loads to produce a total “combined” loading rates for a given HUC12 basin in the Delaware River Basin.

For the particular model approach described in this section, it was assumed that a given parcel of protected forest land would be converted to medium-density developed land for consistency in all of the model runs. The potential sediment load that would be generated by this converted parcel was then estimated by using the size of the parcel along with the per-acre loading rates for each HUC12 sub-basin as described above. Similar loads were also calculated for the upstream drainage basin within which the parcel of interest was located as well as the load contribution of the particular parcel to that upstream drainage basin (see Fig. 4.2).

After these initial calculations, the upstream drainage area was successively expanded by “marching” downstream along the main stream channel. At discrete points downstream, the total sediment load of each expanded drainage area was re-calculated along with the new percent load contribution of the project parcel to the expanded drainage area. As shown in Fig. 4.3, new loads were added from both upstream and downstream areas as the “march” progressed downstream from the initial starting point. These new load calculations considered both the loading rates for the HUC12 sub-basins from which they originated along with the attenuation of pollutants caused by in-stream wetlands and open water bodies along the way.

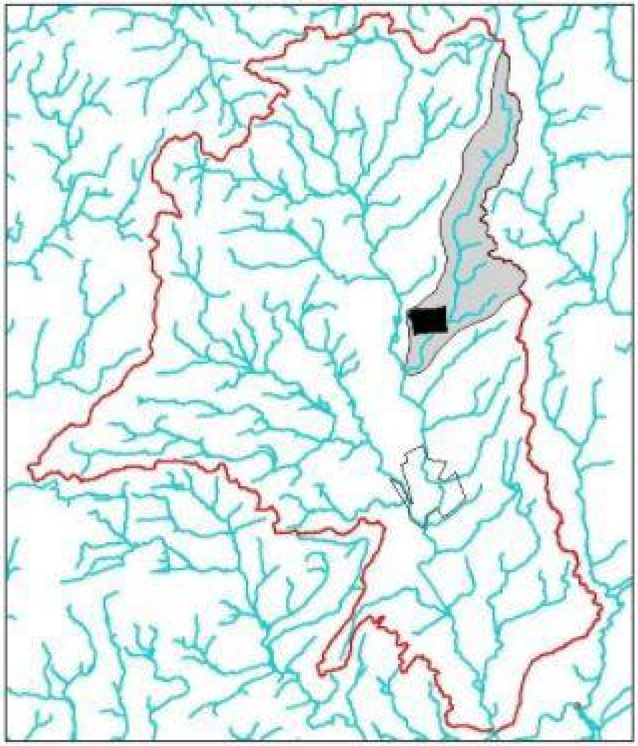


Figure 4.2: Location of a project parcel (shown in black) within an upstream drainage area.

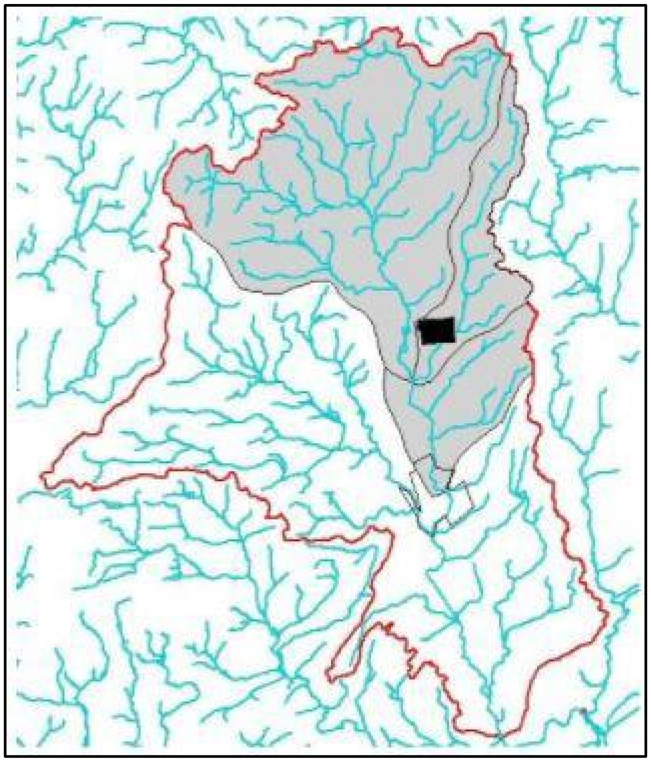


Figure 4.3: Expansion of the drainage area downstream of the parcel.

The sediment load for each expanding drainage area was re-calculated until a point was reached downstream where the percent load contribution of the converted forest parcel was less than 5% of the total load. The distance from the converted parcel to this downstream point was then calculated as shown in Fig. 4.4. In addition to downstream distance, the mean annual sediment loading rate was also calculated, and both the distances and loading rates were subsequently used to compare and score the potential water quality impact of each parcel as described later.

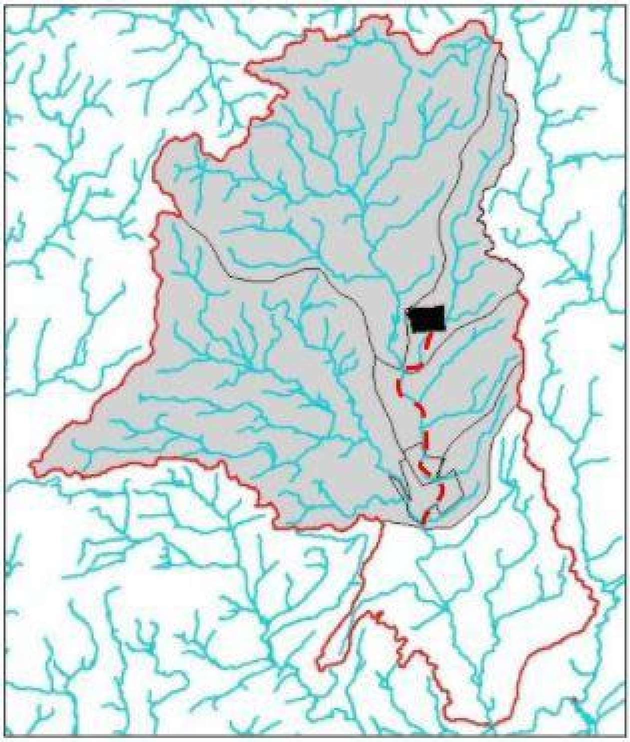


Figure 4.4: Calculation of the distance at the point downstream where the pollutant load contributed by a "converted" forest parcel is equal to 5% or less of the total load of the drainage area.

Results

As outlined earlier, for each project, the acres of forest land protected within that parcel (or group of parcels associated with that project) were converted to the medium-density developed land category for simulation purposes, and the entire upstream drainage area containing that parcel (or group of parcels) was delineated (see example in Fig. 4.2). Then, the mean annual sediment load produced by that drainage area was estimated for both "current" and "potential development" scenarios. Table 4.1 shows the "before" and "after" loading rates produced by the upstream drainage area associated with each project.

Subsequent to the initial calculations described above, the downstream distance at which the sediment loads produced by the conversion of forest land to developed land became insignificant (i.e., at or less than 5% of the total downstream load) was calculated for each project area. These downstream distances are also shown in Table 4.1.

Using the “load difference” and the “downstream distance” calculations shown in Table 4.1, the 49 projects shown were scored in terms of their relative impact on downstream water quality. This was accomplished by first assigning project scores based on the potential sediment load increases that might occur if the protected land parcels were converted to medium-density developed land. Those showing the largest potential load increase from current conditions were given the highest scores, which ranged from 1 to 49. In other words, those projects scoring higher indicated a greater potential for avoiding future in-stream water quality problems. Similarly, the “downstream distance” values were used to assign scores based on the presumed ability of a given project to maintain current “good” water quality at some distance downstream from the project. Those projects with higher “downstream distance” scores (which again ranged from 1 to 49) were assigned higher scores. Finally, the above two scores were averaged for each project, and a final score was assigned (also shown in Table 4.1) reflecting that project’s potential impact on future downstream water quality.

An example of a project that scored high in terms of avoiding future water quality impacts is the Bear Creek Properties LLC project. In this instance, converting the relatively large project area (about 375 acres) to developed land would have an immediate effect on water quality in the forested headwater drainage area in which it is located (see Fig. 4.5). In this case, the current sediment loading rate of 121 lb/acre could potentially increase to 1102 lb/acre if this particular parcel were developed with medium intensity development, resulting in almost a 10-fold increase. Also, as shown in Fig. 4.5, the potential sediment load produced by this converted area would not become relatively “insignificant” (less than 5% of the total load) until a point almost 2 miles downstream of this location.

On the other hand, the Warwick Furnace project is an example of one that does not appear to exhibit much of an impact on downstream water quality. This project, which comprises about 95 acres, has a fairly large upstream drainage area (about 6,178 acres in size) that it is located within (see Fig. 4.6). This particular drainage area already has a fairly high sediment loading rate due to the extensive amount of developed and agricultural land present, and the conversion of forest land to developed land only increases the loading rate for the drainage area by about 2% (from 578 to 587 lb/acre). Similarly, because the sediment load that could potentially be produced should the parcel be converted to developed land is far less than the load produced by other existing sources, the “downstream impact” becomes negligible after about 0.13 miles.

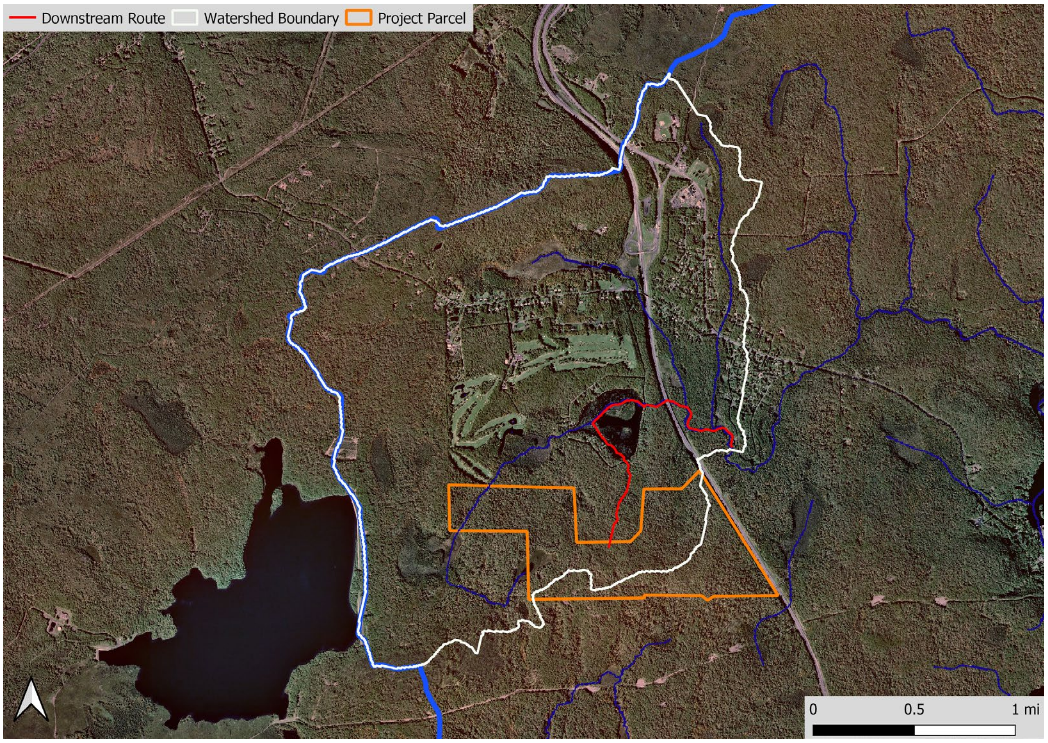


Figure 4.5: Downstream impact associated with the Bear Creek LLC project.

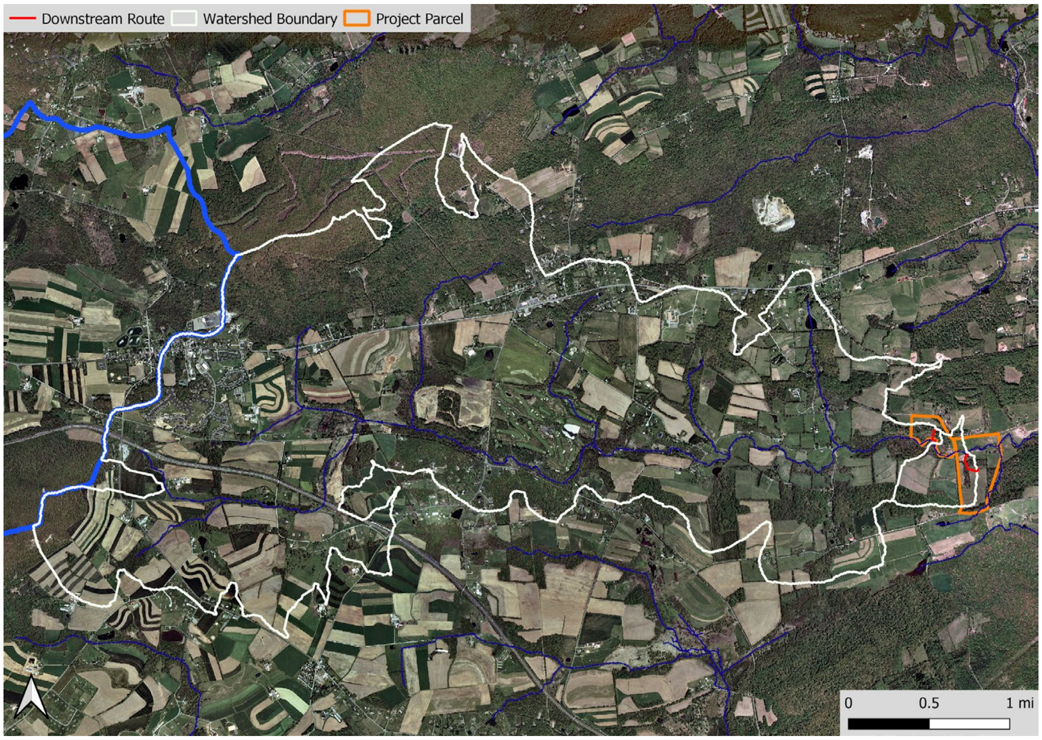


Figure 4.6: Downstream impact associated with the Warwick Furnace project.

Table 4.1: Results for Modeling of the Downstream Influence of Land Protection Projects

Project	Current Load (1)	Future Load (2)	Load Difference (3)	Load Score (4)	Downstream Distance (5)	Downstream Score (6)	Combined Score (7)
16 Years	547.8	914.0	366.2	36	1.71	46	41
18 Years	505.8	927.2	421.5	40	1.40	44	42
Aquashicola Watershed Protection	130.8	363.6	232.8	22	1.69	45	33.5
Bartolacci	74.0	82.4	8.4	4	0.29	15	9.5
Bear Creek – Ten Mile Run	232.1	331.4	99.3	15	0.81	29	22
Bear Creek Addition	114.9	511.4	396.6	38	0.56	25	31.5
Bear Creek Properties LLC	120.9	1101.8	980.9	46	1.72	47	46.5
Bear Swamp	296.5	534.0	237.5	24	0.23	11	17.5
Beaver Run Forest	429.7	453.0	23.3	8	0.10	1	4.5
Blueberry Acres	332.6	1318.4	985.9	47	0.15	5	26
Brodhead Creek Working Woodlands	204.7	284.1	79.4	12	0.23	10	11
Brodhead Flyfishers	88.3	339.3	251.0	26	0.20	8	17
Brodhead Watershed: SJC Builders	74.6	157.1	82.5	13	1.17	37	25
Bucks Cove Run Forest & Wetlands	230.3	658.1	427.8	41	0.13	4	22.5
Burnt Meadow	63.8	1214.5	1150.7	48	1.35	42	45
Bushkill Watershed: Lein	23.9	187.2	163.2	17	0.20	7	12
Camp Hidden Falls	214.0	1459.4	1245.5	49	1.30	41	45
Cherry Creek (Percudani)	156.4	163.4	7.0	3	0.34	17	10
Cranberry Overlook Greenway	214.8	1093.1	878.3	45	0.83	30	37.5
Darling Preserve – Plank	148.2	501.2	353.0	35	1.24	40	37.5
Dingmans Creek	143.9	391.8	247.8	25	0.26	12	18.5
Fisher	106.1	180.8	74.6	10	0.77	28	19
Gerber	253.0	525.0	272.0	29	0.38	19	24
Graham	380.2	391.3	11.1	6	0.13	3	4.5
Hay Creek Riparian Buffer	132.0	395.2	263.2	27	1.38	43	35
Holly Ridge Forest	189.3	597.1	407.8	39	2.05	49	44
Jacksonburg Headwaters Greenway	111.8	200.0	88.1	14	0.70	26	20
Little Bushkill Forest Reserve	77.9	248.0	170.1	19	0.86	31	25
Lubbers Run Greenway Phase II	235.5	585.5	349.9	34	0.51	22	28
Meister	115.5	497.6	382.1	37	1.22	39	38
Menantico Creek	330.8	347.0	16.3	7	0.32	16	11.5
Milford Glen	150.6	153.8	3.2	1	0.74	27	14
Mosiers Knob	214.0	804.4	590.4	44	1.77	48	46
Mt. Rascal	243.9	477.6	233.7	23	1.06	35	29
Northeast Connection Phase II	124.2	453.2	329.0	32	0.91	32	32
Piccoli	411.9	469.0	57.1	9	0.53	23	16
Pocono Mountain Bluestone	81.2	668.1	586.9	43	0.40	20	31.5
Pyle Woods	569.3	890.8	321.5	31	1.09	36	33.5
Quaker Hill	105.8	375.2	269.4	28	1.21	38	33
South Branch Rancocas Creek	364.7	654.2	289.6	30	0.26	13	21.5
Spence	169.1	174.4	5.3	2	0.18	6	4
Stony Run	60.0	247.1	187.1	21	0.55	24	22.5
Thompson/Wright	169.5	283.4	113.9	16	0.29	14	15
Upper Lehigh Headwaters	156.2	320.1	163.9	18	0.21	9	13.5
Warwick Furnace	577.7	586.7	8.9	5	0.13	2	3.5
Yards Creek Phase 1	107.7	437.2	329.5	33	0.38	18	25.5
Yards Creek Phase 2	103.1	603.5	500.4	42	0.47	21	31.5
Young	163.1	238.2	75.1	11	0.97	33	22
Zemel Pemberton	179.9	355.1	175.2	20	0.97	34	27

(1) Upstream load (lbs/ac) with current parcel land cover; (2) Upstream load (lb/ac) when parcel is converted to medium-density developed; (3) Difference between “future” and “current” loads; (4) Greater load differences yield higher scores; (5) Distance (in miles) at which future parcel load is 5% or less of total downstream load; (6) Longer distances yield higher scores; (7) Final (combined) score is the average of (4) and (6), with higher scores reflecting greater water quality benefits

Overall, based on the modeling results described above, the most salient points regarding the water quality benefits associated with various protected parcels are as follows:

- The magnitude of potential water quality benefits associated with preserved parcels are primarily affected by such factors as parcel size, the size of the drainage area "upstream" of the parcel, and the land cover composition of the "upstream" drainage area.

- The preservation of forest land in headwater areas will generally have greater immediate water quality benefits than those located further downstream. However, such benefits will be diminished depending on the amount of developed and/or agricultural land already existing in the headwater area. For example, preserving a forested parcel in such an area that has a substantial amount of developed and/or cultivated land would have minimal effect on downstream water quality.
- If the protected parcel is located farther downstream in a given stream network, potential water quality benefits will generally be more affected by the size of the parcel and the land cover composition of the drainage area upstream of the parcel. For example, if a small parcel is located in an area where the upstream drainage area is much larger than the parcel, then the contribution of the "converted" parcel would be quite small with respect to the overall load contributed to a nearby stream. This relative contribution to the total load (and the associated water quality benefits) would be smaller still if the upstream area were extensively developed and/or cultivated. In this situation, the size of the preserved parcel would have to be relatively large in comparison to the total "upstream" drainage area in order to override the water quality influences of the upstream land cover.

5. Modeling Approach: Future (2100) Development Land Cover and Climate

Future Development (2100)

Overview of Methods

Under this Land Protection Impact Assessment work, Shippensburg University developed a new suite of data products that project land cover change to 2100 under multiple scenarios, DRB2100 Version 3.1[2]. This product builds on previous Delaware River Watershed Initiative work. DRB2100 Versions 1-2 were funded through a grant from the William Penn Foundation. DRB2100 Version 3 was supported by a second grant through the Delaware Watershed Research Fund, and DRB2100 Version 3.1 includes components supported by a contract from the Open Space Institute for this land protection impact assessment.

Like previous versions, DRB2100 v3.1 modeling relies on the SLEUTH urban growth model (NCGIA). To reflect urban growth patterns, the model is calibrated on historic urban land change from 2001-2006 and validated with 2011 data. To generate projections of future urban land from 2011-2100, projections of population are incorporated, along with a number of other demographic, economic, and environmental data sets, that vary by scenario. Each scenario consists of 1) an overall projection of the demand for new development, and 2) an "exclusion/attraction layer" that describes what areas are more or less suitable for development and areas are completely off limits for development.

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[2] Future Land Cover Scenarios (DRB2100 Version 3.1). Delaware River Basin Land Use Dynamics. Shippensburg University. https://drbproject.org/products/

While Version 3.1 does not include a “business as usual” scenario, it does include the “Corridors” and “Centers” scenarios of urban growth from previous product versions. The “Corridors” scenario envisions climate-induced westward expansion of growth in the Delaware River Basin, where higher-than-baseline population growth and urban development sprawls along major transportation corridors. The “Centers” scenario explores a future with higher-than-baseline conservation efforts and denser growth occurring in existing historic centers. Urban land cover change trajectories within the Delaware River Basin boundary for the two scenarios are summarized in Fig. 5.1 and an example of the exclusion/attraction layer (for the Corridors scenario) is shown in Fig. 5.2.

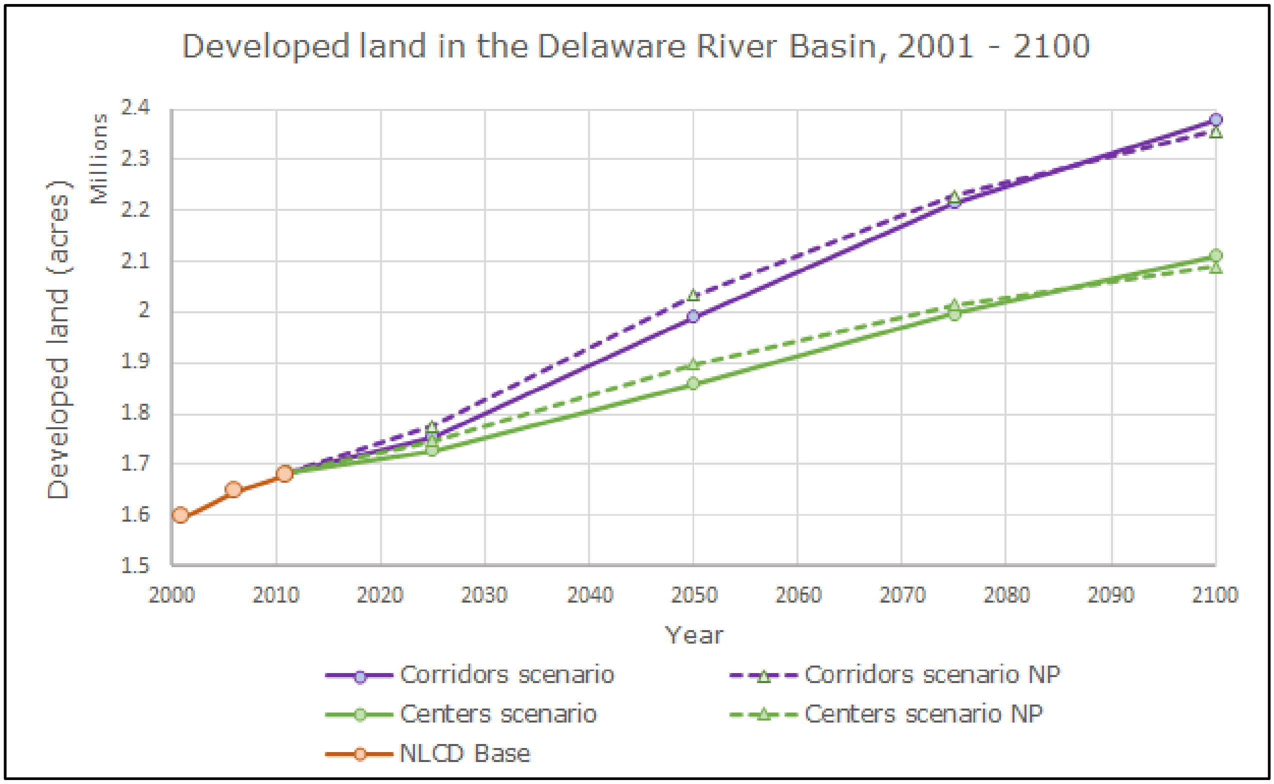

Figure 5.1: Urban land cover change trajectory within the Delaware River Basin boundary from 2001 - 2011 (observed from NLCD 2011 edition) and from 2011 - 2100 (DRB2100 Version 3 forecast) for the alternative scenarios.

Note that the Corridors scenario predicts the highest levels of development, while the Centers scenario has the lowest (Fig. 5.1). The OSI-funded project areas were assessed in terms of their effectiveness in protecting land given projected growth pressure under these two scenarios.

Version 3.1 adds another two scenarios, considering “No Protection” scenarios for both urban growth scenarios (Fig. 5.2). The “No Protection” land cover scenario explores a hypothetical future where protected lands were removed. These “No Protection” scenarios consider the “what if” scenario: “what if land protections were to be entirely removed?” These scenarios allow us to envision what the future landscape would look like without any protected areas, highlighting the potential value of our existing protected lands network.

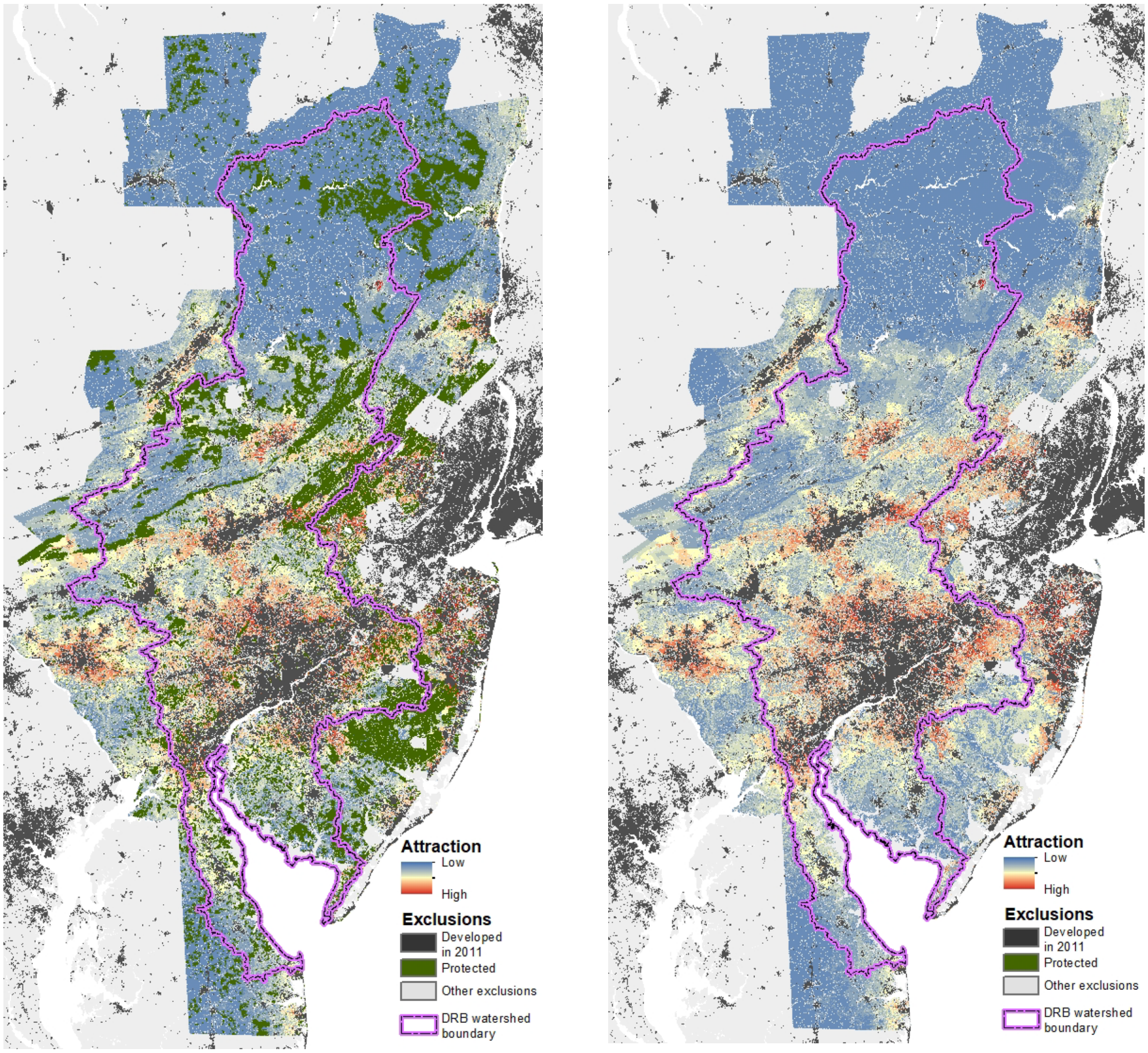

Figure 5.2: The exclusion/attraction layer for the Corridors scenario (left) and the Corridors-No Protection scenario (right). These maps are primary inputs into the growth model and designate suitability for development as well as projected development pressure; the "attraction" to development is shown as a color scale from blue (low attraction) to red (high attraction). Areas excluded from growth are protected areas (dark green) and other exclusions (e.g. slope restricted zones, open water, etc.), which appear as white gaps in the attraction gradient.

There are two "No Protection" scenarios, one with the growth projections related to "Corridors" and one with the growth projections related to "Centers." Also note that the overall levels of growth in the No Protection scenarios are more or less the same for the corresponding Centers and Corridor scenarios (Fig. 5.1), so that differences can largely be attributed to changes in development patterns that occur in the absence of protected lands, rather than changes in the overall amount of growth.

For complete documentation of DRB2100 Version 3.1, see the Delaware River Basin Land Use Dynamics products page: https://drbproject.org/products/.

Results

Beginning with the assessment of the 52 OSI funded project areas, which represent a total of 25,000 acres, it was found that if these lands remained unprotected, 756 acres under the Centers scenario or 2,297 acres under the Corridors scenario could be developed. Project-by-project results are summarized in this spreadsheet or can be found in Appendix Table 2 and Table 3.

As noted above, the Corridors & Corridors-No Protection scenarios are both informed by higher projections of urban growth, while the Centers & Centers-No Protection are informed by lower projections of urban growth (Fig. 5.1). This means that, for example, the primary difference between the Corridors & Corridors-No Protection scenarios is driven by *how protected lands influence development patterns* (Fig. 5.3). Notably, development intensifies in the central and eastern regions of the DRB. In the absence of protected lands, these regions of high development pressure are preferentially selected for development by the model resulting in lower development intensity in the northern part of the DRB.

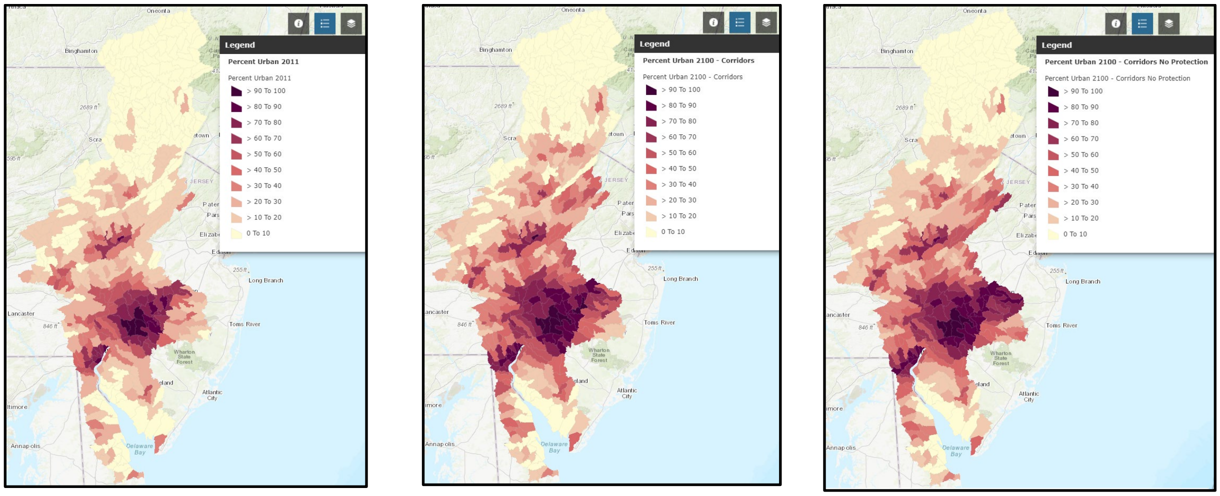

Figure 5.3: Percent urban land in HUC 12 watersheds in 2011 (left), 2100 for the Corridors scenario (middle), and 2100 for the Corridors scenario without protected lands (right).

This pattern is apparent in both the Corridors and Centers scenario, although it is more marked in the Corridors scenario because of the higher amount of growth. For interactive maps of all of these results at the HUC 12 watershed scale, see DRB 2100 Version 3.1 Urban Land Cover Projections.

Looking specifically at impacts on forest lands, when protected lands are removed, more intense forest loss is seen in the easternmost regions of the Delaware River Basin (e.g., Philadelphia and Trenton) (Fig. 5.4). These are largely areas where forest cover in 2011 is lower to begin with, so protected lands in these regions play an important role in preserving remnant forests in these urbanizing landscapes. Meanwhile, forest loss is less intense in the northern parts of the Delaware River Basin. For interactive maps of all of these results at the HUC 12 watershed scale, see DRB 2100 Version 3.1 Forest Loss Projections.

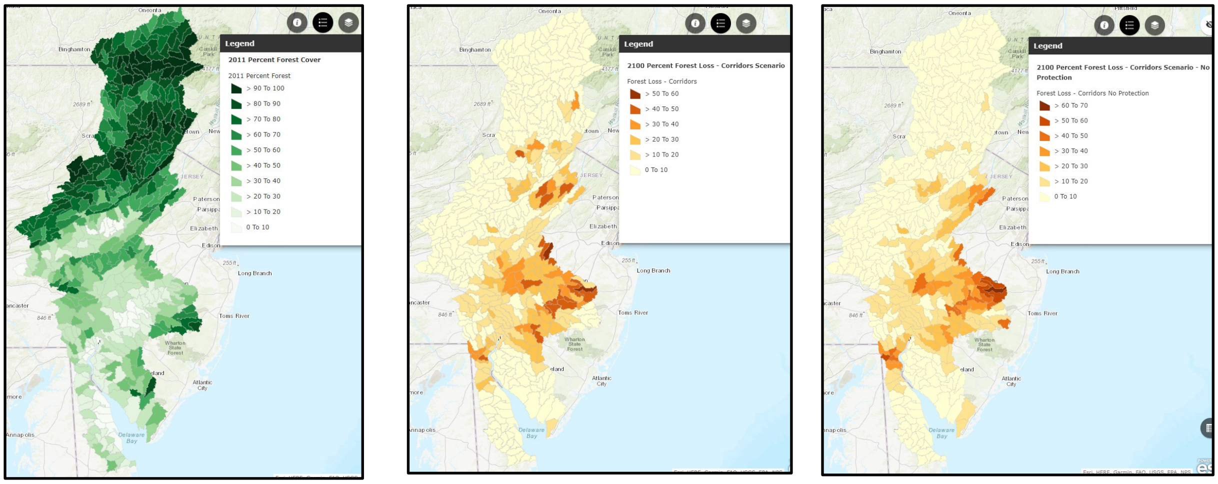

Figure 5.4: Percent forest in HUC 12 watersheds in 2011 (left), the percent of 2011 forest loss by 2100 for the Corridors scenario (middle), and the percent of 2011 forest loss by 2011 for the Corridors scenario without protected lands (right).

At the Basin scale, overall impacts on forest loss in general are most evident between the Corridors and Centers scenarios, and minimal differences are observed when protected lands are removed. For example, in 2011 the DRB was 52.4% forested (4.43 million acres). In the Corridors scenarios, forest cover is projected to decrease to 48.3% by 2100 and in the Corridors-No Protection scenario forest cover is estimated to be 48.7%. In the Centers scenario, forest cover is estimated to decrease less, to 50.3%, and Centers-No Protection the estimate is 50.5%.

There are three potential explanations for these findings related to forest loss. First, most of the forests (protected and non-protected) are in areas of low development pressure and so at the Basin scale, differences in protection and non-protection scenarios are less apparent. Second, many forests are located on steep terrain, and so that offers some “built in” protection from development. Finally, even though we do not see significant differences at the Basin scale, we do see differential impacts at local scales. Specifically, watersheds near the centers of growth are projected to lose more forest, and this is offset by lower losses in more remote watersheds.

When protected lands are considered, we estimate that 1.18 million acres of forest are currently protected in the Delaware River Basin. When protected lands are removed, 3.98% (about 47,000 acres) of those protected forests are projected to be lost to development under the Centers scenario, while 9.27% (about 109,000 acres) of those forests may be lost under the Corridors scenario.

Future Climate (2080-2099)

In previous work funded by the Delaware Watershed Research Fund, Hawkins and Woltemade (2019) assessed the impact of projected 21st century climate change on basin hydrology and runoff in the Delaware River Basin. These data were adapted for this project, for integration into

Model My Watershed. Predictions of daily precipitation (P) and temperature (daily maximum, T_{max}, and minimum, T_{min}, and average, T_{avg}) for 2080-2100 were obtained from the World Climate Research Programme's Coupled Model Intercomparison Project phase 5 (CMIP5) (Taylor et al., 2012). Two sets of predictions were used: Representative Concentration Pathway (RCP) 4.5 and 8.5. CMIP5 data were bias-corrected and spatially downscaled to 1/8° resolution (~12 km) (available at https://gdo-dcp.ucllnl.org/downscaled_cmip_projections/) (Mauer et al., 2007; Bureau of Reclamation, 2013). Daily downscaled CMIP5 data for 38 different climate projections (19 each for both RCP 4.5 and 8.5) were collected for historic (2000 – 2019) and future (2080 – 2099) time periods for a grid that encompassed all the counties that intersected the Delaware River Basin. The entire grid domain was 36 rows x 24 columns and contained 864 grid cells. The Delaware River Basin itself contained 225 grid cells. For each grid cell, P and T_{avg} daily time series, averaged by each RCP, were generated for both time periods.

Additionally, following Maimone (2019), four seasonal sets of precipitation delta change factors between the historic and future time periods and averaged by RCP, were calculated for each grid cell. Delta change factors are the percent change between the future and historic periods for each integer percentile value of precipitation. These factors were used to replicate the observed distribution of storm event frequency and magnitude and the inter-event duration; further details on this procedure are available in Ensign (2020). These datasets were ultimately incorporated into Model My Watershed and allow a user to select either of these future climate estimates to build new modeling scenarios with the Watershed Multi-Year Model for projects within the Delaware River Basin (see https://wikiwatershed.org/help/model-help/mmw-tech/#description-and-editing-of-key-model-input-data-and-parameters)

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Appendix

NLCD Developed Land Classification/Definitions

(https://www.mrlc.gov/data/legends/national-land-cover-database-2011-nlcd2011-legend)

- Developed, Open Space is NLCD (National Land Cover Database) Class 21: Areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These are areas most commonly including large-lot single-family housing units, parks, playing fields, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic.
    - Model My Watershed algorithms assign 20% impervious cover to this classification.
- Developed, Low Intensity is NLCD Class 22: Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
    - Model My Watershed algorithms assign 38% impervious cover to this classification.
- Developed, Medium Intensity is NLCD Class 23: Areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
    - Model My Watershed algorithms assign 65% impervious cover to this classification.
- Developed High Intensity is NLCD Class 24: Highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
    - Model My Watershed algorithms assign 85% impervious cover to this classification.

Model My Watershed code repository for the Site Storm Model containing % impervious surface, curve numbers, and landscape factors (ki) can be found here: https://github.com/WikiWatershed/tr-55/blob/develop/tr55/tables.py

Appendix Table 1: Summary land use/land cover (%) and stream length (miles) statistics for each project area parcel (51) included in parcel-specific modeling efforts. Note: N Lubbers Greenway and S Lubbers Greenway were treated as separate parcels but were part of the same project; N Little Bushkill and S Little Bushkill were treated as separate parcels but were part of the same project

			Land Cover/Land Use (%)															Stream Length by Order					
Parcels	Area (acres)	% of natural land cover (forest, shrub, wetland)	Deciduous Forest	Evergreen Forest	Mixed Forest	Shrub/Scrub	Grassland/Herbaceous	Woody Wetlands	Emergent Herbaceous Wetlands	Pasture/Hay	Cultivated Crops	Developed, Open Space	Developed, Low Intensity	Developed, Medium Intensity	Developed, High Intensity	Barren Land (Rock/Sand/Clay)	Open Water	1st	2nd	3rd	4th	Other	Total Stream Length (mi)
16 Years	98.2	16.3	13.3	-	-	2.5	-	0.5	-	81.7	0.7	1.4	-	-	-	-	-	1.3	-	-	-	-	1.3
18 Years	50.3	48.0	48.0	-	-	-	-	-	-	1.8	49.8	0.4	-	-	-	-	-	-	-	-	-	-	-
Aquashicola WS Protection Proj	774.4	95.4	85.8	2.2	5.9	-	-	1.5	-	1.2	-	3.4	0.1	-	-	-	-	-	12.7	-	-	-	12.7
Bartolacci	39.2	97.7	40.1	16.4	25.4	-	-	15.8	-	-	-	2.3	-	-	-	-	-	-	2.1	-	-	-	2.1
Bear Creek Addition	159.6	92.8	79.6	13.2	-	-	-	-	-	-	-	5.8	-	-	-	1.4	-	-	-	-	-	-	-
Bear Creek Prop LLC	375.3	94.6	89.9	3.2	-	-	-	1.5	-	-	-	5.3	-	-	-	-	0.1	1.6	-	-	-	-	1.6
Bear Creek Ten Mile Run	184.4	98.7	89.2	4.9	1.7	-	-	2.3	0.6	-	-	1.3	-	-	-	-	-	1.3	1.5	-	-	-	2.8
Bear Swamp	404.4	95.6	9.5	1.8	2.9	0.3	-	81.1	-	-	1.3	3.1	0.1	-	-	-	-	2.2	1.6	-	-	-	3.8
Beaver Run Forest	5.1	100.0	95.7	-	-	-	-	4.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Blueberry Acres	204.2	92.4	15.3	1.0	2.3	4.1	-	69.7	-	-	7.6	-	-	-	-	-	-	-	-	-	-	0.1	0.1
Brodhead Flyfishers	192.4	95.7	34.1	46.8	9.4	-	-	5.4	-	-	-	3.7	-	-	-	-	0.6	-	-	1.8	-	-	1.8
Brodhead SJC Builders	368.4	99.7	82.0	2.7	8.4	1.7	-	4.9	-	-	-	0.3	-	-	-	-	-	-	2.1	-	-	-	2.1
Bucks Cove Run Forest	200.4	96.5	1.0	5.3	2.3	-	-	87.9	-	-	-	2.4	1.0	-	-	-	-	2.1	-	-	-	-	2.1
Burnt Meadow	341.6	100.0	94.5	-	3.2	-	-	2.3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Bushkill Lein	309.0	100.0	9.6	0.2	0.3	51.1	-	38.8	-	-	-	-	-	-	-	-	-	4.3	-	-	-	-	4.3
Camp Hidden Falls	1,049.6	95.3	86.5	-	0.4	0.3	-	8.1	-	-	-	3.4	0.1	-	-	-	1.1	1.8	-	-	-	-	1.8
Cherry Creek Percudani	188.4	50.2	49.6	-	0.6	-	-	-	-	-	-	48.8	0.6	0.4	-	-	-	-	4.9	-	-	-	4.9
Cherry Valley	3,808.0	99.4	97.7	0.4	1.2	0.1	-	-	-	-	-	0.6	-	-	-	-	-	8.7	-	-	-	-	8.7
Cranberry Overlook Greenway	44.1	99.5	94.0	-	5.5	-	-	-	-	-	-	0.5	-	-	-	-	-	-	-	-	-	-	-
Darling Preserve Plank	69.2	89.8	16.7	68.9	1.6	-	-	2.6	-	-	-	10.3	-	-	-	-	-	-	-	-	-	-	-
Dingmans Creek	21.5	97.9	76.3	-	21.6	-	-	-	-	-	-	2.1	-	-	-	-	-	-	-	-	-	-	-
Fisher	20.0	96.6	93.3	-	3.3	-	-	-	-	-	-	3.3	-	-	-	-	-	-	-	-	-	-	-
Graham	22.4	98.0	86.1	-	-	-	-	11.9	-	-	-	2.0	-	-	-	-	-	3.6	1.3	-	-	-	4.9
Graystone	3,737.6	95.5	80.5	11.4	3.6	-	-	-	-	0.5	0.1	3.8	-	-	-	-	0.1	1.6	-	4.8	-	-	6.4
Hay Creek Riparian Buffer	79.4	68.9	62.8	-	-	3.6	2.5	-	-	17.6	-	13.1	0.3	-	-	-	-	-	-	-	-	-	-
Holly Ridge Forest	1,345.3	87.6	25.6	10.0	27.1	14.3	0.6	10.0	-	0.6	2.7	4.2	0.6	0.1	-	3.4	0.8	-	-	-	-	-	-
Meister	32.4	82.2	67.1	-	15.1	-	-	-	-	-	-	17.8	-	-	-	-	-	-	-	-	-	-	-
Menantico Creek	592.7	96.7	13.9	2.5	5.5	3.9	-	70.9	-	-	0.1	2.2	0.3	-	-	-	-	-	-	5.4	-	-	5.4
Milford Glen	39.2	99.4	29.9	10.2	59.3	-	-	-	-	-	-	0.6	-	-	-	-	-	-	-	1.0	-	-	1.0
Mosiers Knob	554.2	95.8	82.8	6.2	6.8	-	-	-	-	-	-	4.1	-	-	-	-	0.1	2.3	-	-	-	-	2.3
Mt Rascal	111.5	100.0	99.0	-	-	-	-	1.0	-	-	-	-	-	-	-	-	-	-	-	-	-	3.0	3.0
NE Connection Ph2	1,452.8	84.4	67.3	-	1.2	-	0.2	15.6	0.1	-	-	0.6	-	-	-	-	15.1	6.5	1.0	4.0	-	-	11.5
N Little Bushkill	825.6	98.1	80.8	0.4	2.0	0.7	-	14.2	-	-	-	2.0	-	-	-	-	-	1.8	-	2.4	-	-	4.2
N Lubbers Greenway Ph2	1,388.8	92.4	71.1	-	2.0	2.0	-	16.6	0.7	1.2	-	2.7	-	-	-	-	3.7	-	3.5	-	-	-	3.5
Piccoli	25.5	66.1	45.2	-	-	6.1	-	14.8	-	-	13.9	19.1	0.9	-	-	-	-	0.9	-	-	-	-	0.9
Pocono Mountain Bluestone	281.3	96.1	91.2	-	1.5	2.9	-	0.5	-	-	-	3.9	-	-	-	-	-	-	-	1.3	-	-	1.3
Pyle Woods	19.1	100.0	100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Quaker Mill	79.1	100.0	94.1	-	3.1	2.8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
S Branch Rancocas Creek	485.6	90.9	1.7	-	3.4	-	-	85.8	-	-	-	-	-	-	-	-	9.1	2.9	-	-	-	0.5	3.3
S Little Bushkill	1,388.8	90.6	80.4	0.5	2.3	-	-	7.3	0.1	-	-	1.0	-	-	-	-	8.3	6.1	-	3.2	-	-	9.3
S Lubbers Greenway Ph2	1,049.6	95.7	91.1	-	0.8	-	-	3.8	-	-	-	0.6	-	-	-	-	3.7	-	0.7	-	-	-	0.7
Spence	50.1	47.3	29.6	-	-	-	-	17.7	-	13.3	29.2	10.2	-	-	-	-	-	-	4.0	-	-	-	4.0
Stony Run	355.8	99.0	94.5	0.4	0.7	-	-	3.4	-	-	-	-	-	-	-	-	1.1	3.1	-	-	-	-	3.1
Thompson Wright	436.6	90.4	25.9	0.4	11.3	0.4	-	51.5	0.9	-	3.3	4.6	0.1	-	-	-	1.8	1.4	-	3.8	-	-	5.2
Upper Lehigh Headwaters	491.9	90.6	58.8	1.1	-	-	0.4	29.6	0.7	-	-	0.7	-	-	-	-	8.7	1.6	1.8	-	-	-	3.3
Warwick Furnace	94.4	58.6	38.7	-	-	13.8	-	6.1	-	11.7	24.6	4.9	-	-	-	-	-	-	2.2	-	-	-	2.2
Yard Creek Ph1	113.5	99.8	67.2	-	5.1	-	-	27.5	-	-	-	0.2	-	-	-	-	-	0.4	-	-	-	-	0.4
Yard Creek Ph2	22.4	100.0	89.1	-	10.9	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Zemel Pemberton	807.9	95.5	6.7	66.6	1.8	1.6	4.7	14.1	-	-	2.9	1.2	0.5	-	-	-	-	-	-	3.5	-	-	3.5
Zemel Woodland N	460.1	96.7	1.3	89.9	-	0.6	0.5	4.4	-	-	-	0.5	1.3	-	-	1.4	-	4.9	-	-	-	-	4.9
Zemel Woodland S	1,120.0	97.4	0.1	76.4	0.4	0.1	1.0	19.4	-	-	0.6	1.1	0.8	-	-	-	-	5.9	1.0	1.2	-	-	8.1

Appendix Table 2: Summary of land cover change (acres) from 2011 land cover to 2100 future development "Centers" for each parcel. Data also available here.

CENTERS SCENARIO. Simulations from 2011 to 2100							
	Project Name	Urban 2011 (Acres)	Urban 2100 (Acres)	Growth (Acres)	Available Land for Development (%)	Development Intensity (%)	Attraction Index
1	Zemel Woodland North	13.4	13.4	0	0	-	22
2	Zemel Pemberton	33.1	33.9	0.8	0.7	15.7	21
3	Zemel Woodland South	35.8	106.1	70.3	100	6.4	20
4	Mosiers Knob	36.5	46.7	10.2	27.1	7.2	21
5	Bear Swamp	13.3	21.5	8.2	100	2.1	9
6	Milford Glen	0.3	1	0.7	29.5	6	14
7	Mt. Rascal	0	0.3	0.3	2.8	9.7	25
8	Brodhead Watershed: SJC Builders	5.5	13.1	7.6	74.5	2.8	17
9	Bushkill Watershed: Lein	0	7	7	98.1	2.3	10
10	Dingmans Creek	0.7	0.8	0.1	34	1.4	8
11	Pyle Woods	0	1.2	1.2	90.7	6.9	36
12	Lubbers Run Greenway Phase II	53.5	160	106.5	7.4	64.5	40
13	Bear Creek Addition	13.3	19.3	6	95.5	4.3	13
14	Quaker Hill	0.4	0.4	0	9.3	0	9
15	Cherry Creek (Percudani)	94.7	94.9	0.2	7.1	3	17
16	Upper Lehigh Headwaters	9.5	16.2	6.7	97.5	1.6	7
17	Aquashicola Watershed Protection Project	30.9	33.6	2.7	18.6	2	12
18	Cherry Valley	57.4	163.2	105.8	44.5	6.3	22
19	Warwick Furnace	7.1	9.3	2.2	88.1	2.9	21
20	Camp Hidden Falls	36.7	60.8	24.1	91.5	2.6	12
21	Brodhead Flyfishers	10.9	18.2	7.3	46.5	8.6	30
22	Bartolacci	1.3	2.5	1.2	96.9	3.5	20
23	Pocono Mountain Bluestone	12	19.8	7.8	65.8	4.4	21
24	Spence	5.8	9.1	3.3	71.5	10.4	28

25	Darling Preserve - Plank	9.6	12.1	2.5	99.6	4.2	10
26	Thompson/Wright	33.1	43.3	10.2	69.9	4.9	18
27	Cranberry Overlook Greenway	0.3	0.3	0	0	-	35
28	Graham	0.5	0.5	0	25.3	0	15
29	Fisher	1.1	1.1	0	8.2	0	9
30	Menantico Creek	16	24.1	8.1	98.7	1.4	8
31	Gerber	8.2	58.5	50.3	28.1	20.6	26
32	Young	2	3.5	1.5	41.7	7.9	20
33	Piccoli	5.3	9.8	4.5	97.5	26.3	51
34	16 Years	2.2	33.4	31.2	94.2	34.4	55
35	Meister	6.5	6.6	0.1	55.6	0.7	13
36	Bear Creek Properties LLC	27.3	44.7	17.4	74.9	6.7	17
37	Little Bushkill Forest Reserve	58	108.7	50.7	85.5	2.9	12
38	Northeast Connection Phase II	12.5	29.2	16.7	40.4	3.4	11
39	Brodhead Creek Working Woodlands	52	136.1	84.1	50.3	14.5	32
40	Jacksonburg Headwaters Greenway	0.6	4.1	3.5	77.6	2.3	12
41	Beaver Run Forest	0	0	0	52.2	0	20
42	Blueberry Acres	2	4.4	2.4	100	1.2	8
43	Bucks Cove Run Forest and Wetlands	7.3	12.5	5.2	98.4	3.4	12
44	Hay Creek Riparian Buffer	13.4	14.7	1.3	59.5	3.3	22
45	Holly Ridge Forest	65.8	99	33.2	99	2.7	13
46	Stony Run	17.2	21.1	3.9	88	1.3	10
47	Burnt Meadow	2	8.6	6.6	96.7	2	13
48	South Branch Rancocas Creek	4	8.5	4.5	99.2	1	7
49	Bear Creek - Ten Mile Run	3.1	26.5	23.4	93.3	13.8	27
50	18 Years	2	10.4	8.4	96.8	18	48
51	Yards Creek Phase 1	0.3	5.7	5.4	93.3	5.1	17
52	Yards Creek Phase 2	0	0.8	0.8	100	3.6	18

Appendix Table 3: Summary of land cover change (acres) from 2011 land cover to 2100 future development “Corridors” for each parcel. Data also available here.

CORRIDORS SCENARIO. Simulations from 2011 to 2100							
	Project Name	Urban 2011 (Acres)	Urban 2100 (Acres)	Growth (Acres)	Available Land for Development (%)	Development Intensity (%)	Attraction Index
1	Zemel Woodland North	13.4	13.4	0	0	-	35
2	Zemel Pemberton	33.1	34.3	1.2	0.7	23.5	31
3	Zemel Woodland South	35.8	326	290.2	100	26.6	32
4	Mosiers Knob	36.5	56	19.5	47.9	7.8	28
5	Bear Swamp	13.3	38.3	25	100	6.4	14
6	Milford Glen	0.3	5.5	5.2	47.7	27.8	21
7	Mt. Rascal	0	0.7	0.7	2.8	22.6	34
8	Brodhead Watershed: SJC Builders	5.5	15.8	10.3	87.3	3.2	22
9	Bushkill Watershed: Lein	0	126	126	99.3	41.7	21
10	Dingmans Creek	0.7	1.3	0.6	44.7	6.5	12
11	Pyle Woods	0	3.6	3.6	90.7	20.8	43
12	Lubbers Run Greenway Phase II	53.5	229.2	175.7	8.3	94	46
13	Bear Creek Addition	13.3	20.3	7	98.5	4.8	25
14	Quaker Hill	0.4	0.6	0.2	47.3	0.5	12
15	Cherry Creek (Percudani)	94.7	95.4	0.7	53.3	1.4	22
16	Upper Lehigh Headwaters	9.5	17.3	7.8	98	1.8	14
17	Aquashicola Watershed Protection Project	30.9	36	5.1	35.1	2	17
18	Cherry Valley	57.4	206.5	149.1	57.9	6.8	26
19	Warwick Furnace	7.1	14.2	7.1	93.5	8.9	29
20	Camp Hidden Falls	36.7	257	220.3	98.7	22.4	19
21	Brodhead Flyfishers	10.9	22	11.1	69.4	8.8	31
22	Bartolacci	1.3	3	1.7	98.1	4.9	26
23	Pocono Mountain Bluestone	12	22.8	10.8	77	5.2	24
24	Spence	5.8	11.2	5.4	87	14	38

25	Darling Preserve - Plank	9.6	12.1	2.5	99.6	4.2	20
26	Thompson/Wright	33.1	53.3	20.2	69.9	9.6	24
27	Cranberry Overlook Greenway	0.3	0.3	0	0	-	40
28	Graham	0.5	0.6	0.1	56.6	0.8	19
29	Fisher	1.1	1.1	0	43.5	0	12
30	Menantico Creek	16	29.1	13.1	98.7	2.3	10
31	Gerber	8.2	110.6	102.4	28.1	41.9	34
32	Young	2	3.8	1.8	68.9	5.7	23
33	Piccoli	5.3	12.5	7.2	97.5	42.1	58
34	16 Years	2.2	49.6	47.4	99.8	49.3	59
35	Meister	6.5	6.7	0.2	84.6	0.9	16
36	Bear Creek Properties LLC	27.3	56	28.7	88.3	9.3	35
37	Little Bushkill Forest Reserve	58	495.3	437.3	91.4	23.7	19
38	Northeast Connection Phase II	12.5	150.8	138.3	42.3	27	17
39	Brodhead Creek Working Woodlands	52	158.4	106.4	71.5	12.9	35
40	Jacksonburg Headwaters Greenway	0.6	59.5	58.9	95.8	30.7	22
41	Beaver Run Forest	0	0.2	0.2	65.2	6.1	26
42	Blueberry Acres	2	8.3	6.3	100	3.1	12
43	Bucks Cove Run Forest and Wetlands	7.3	19.3	12	98.4	7.9	18
44	Hay Creek Riparian Buffer	13.4	15.9	2.5	92.2	4.1	25
45	Holly Ridge Forest	65.8	129.4	63.6	99.1	5.2	17
46	Stony Run	17.2	22.2	5	96.7	1.6	15
47	Burnt Meadow	2	9.7	7.7	99.9	2.3	18
48	South Branch Rancocas Creek	4	14.4	10.4	99.2	2.2	11
49	Bear Creek - Ten Mile Run	3.1	34.1	31	97.8	17.4	46
50	18 Years	2	20.8	18.8	100	38.9	53
51	Yards Creek Phase 1	0.3	74.4	74.1	98.8	66	29
52	Yards Creek Phase 2	0	16.8	16.8	100	74.7	33