A LAND COVER MAPPING, MODELING AND MONITORING SYSTEM FOR THE DELAWARE RIVER BASIN

IN SUPPORT OF MAINTAINING AND RESTORING WATER RESOURCES

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A watershed of over 13,000 square miles, the Delaware River Basin (DRB, Figure 1) provides water resources for roughly 5% of the US population – over 15 million people – including roughly 7 million people in New York City and northern New Jersey who live outside of the Basin (DRBC 2013). Management of the DRB is complex, requiring a balance between diverse stakeholders and priorities that include maintenance of drinking water supply and drought/flood mitigation (Mandarano and Mason 2013). There have been many successes, particularly in restoring the tidal portions of the Delaware River, and many portions of the upper and middle sections of the Delaware River Basin are considered to be exceptional waterways (DRBC 2012). Yet there are still significant challenges facing water resources in the DRB: many waterways still do not meet the stated goals of the Clean Water Act to be fishable and swimmable (DRBC 2012), population growth and associated land cover changes are a concern for water supply and water quality (Jantz and Morlock 2011), gas drilling is emerging as a new industry with impacts on water supply and water quality (Entrekin *et al.* 2011), and climate change brings threats of sea level rise and the potential for more extreme droughts and flooding (Stroup 2011).

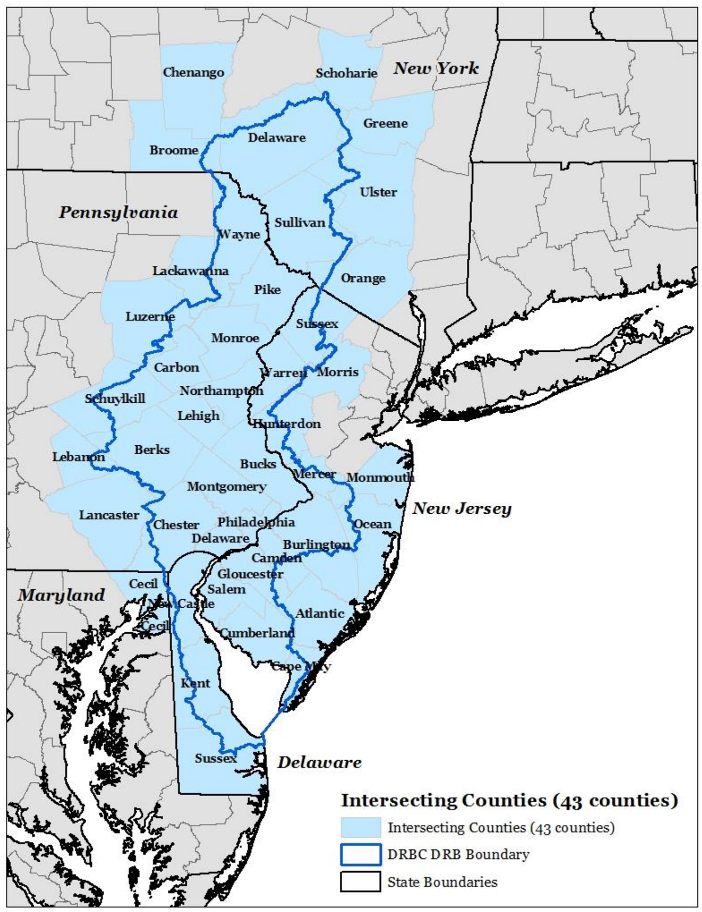

Figure 1. **The Delaware River Basin and intersecting counties.**

Given these challenges and the need to account for an uncertain future, reliable and regular land cover data are essential, as is the need for forecasting land cover changes in order to continually prioritize restoration and protection investments for maximum effect. Further, these products need to be available Basin-wide in order to ensure conservation actions are targeted in a strategically-prioritized way to those geographies and projects offering the greatest potential for positive conservation outcomes. To address these needs for the DRB, we propose an ambitious project comprised of three related components:

- High resolution Lidar-based land cover mapping
- Development of a Basin-wide land cover modeling tool
- Feasibility study for long-term land cover change monitoring

We note that these products will address specific needs that were identified in June of 2013 by the Science of Source Water Workshop, which was organized by the Pinchot Institute and the Common Waters Fund to identify the top information needs of water users and other stakeholders. This group identified land use/land cover change, demographic change, and land cover/climate change interactions as key areas of research to understand the relationships between land use/land cover and water resources. High-resolution land cover data and land cover change modeling were identified as critical to support these efforts (Common Waters Fund 2013). Similarly, the Delaware River Basin Commission recently articulated a need for enhanced information related to land use changes to improve planning for future flood events and scenario planning under land use and population change to inform coupled freshwater-coastal models (NOAA 2014).

HIGH RESOLUTION LIDAR-BASED LAND COVER MAPPING

At the national scale, existing data products provide a consistent basis for assessing historic and current land cover. Products such as the United States Geological Survey's (USGS) National Land Cover Database (NLCD) data provide a Basin-wide view of land cover change from 1992 - 2011. However, these products are at a resolution of 30 m x 30 m (98 ft x 98 ft) pixels (900 m^2 or 0.22 acres) and are limited for many applications that require finer scale information. For example, the benefits of forested riparian buffers can occur when the forested area adjacent to a stream is as narrow as 25 feet, and typical restoration goals for forested buffer zones are 25 – 100 feet. These narrow, linear features are often not detectable using 900 m^2 resolution data. In addition, the coarser scale data sets like NLCD often underestimate or fail to capture very low density development in forested areas, including the construction of well pads for gas drilling and/or houses underneath tree canopies. Existing high-resolution land cover datasets are incomplete, only accounting for "gray" infrastructure features such as buildings and roads.

High resolution (1 m x 1 m) Lidar-based land cover is already available for roughly 1/3 of the DRB and offers many benefits. This dataset is so detailed that even individual trees as short as 8 feet are mapped (Figure 2). The high-resolution nature, combined with the accuracy and precision allow the data to be summarized from the property parcel to the basin scale. This gives resource managers, from the urban forester to the watershed planner, a common, consistent and accurate dataset for decision-making and long-term planning.

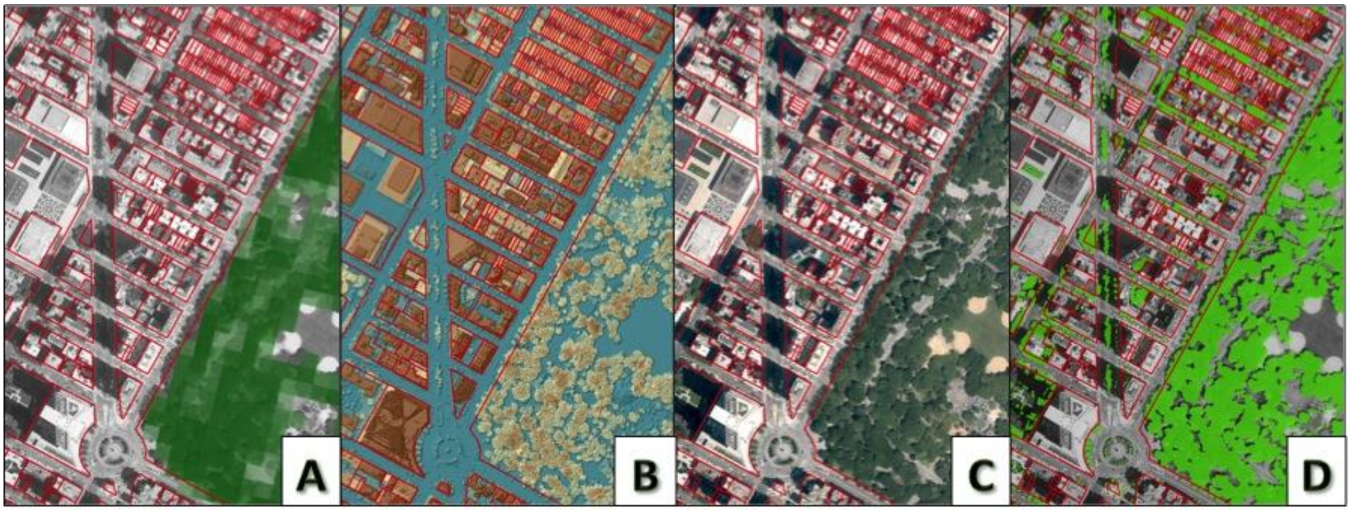

Figure 2. **Tree canopy comparison between the 30m National Land Cover Database (NLCD) and the 1m land cover proposed for this study. NLCD fails to capture individual trees and small forested patches and the pixels cross property parcel boundaries (red lines). Lidar data is unaffected by shadows, allowing for more accurate mapping, particularly in urban areas and locations with high topographic relief (B). When the Lidar data is combined with high-resolution imagery (C) tree canopy can be mapped with such accuracy, than even young street trees in building shadows can be mapped (D).**

DEVELOPMENT OF A BASIN-WIDE LAND COVER MODELING TOOL

Understanding land cover trends and patterns is critical for understanding current and future impacts on water resources. While the high-resolution data sets would allow for an accurate assessment of current conditions, the ability to forecast future land change under alternative scenarios would support the development of land use policies that would minimize impacts on water resources. Modeling work that has already been conducted in the Upper Delaware Watershed demonstrates the need and utility for land cover change forecasting (Figure 3) (Jantz, Mrozinski, and Coar 2009; Jantz and Morlock 2011). In these prior studies, we worked strategically with core end-use conservation practitioners, such as county land use planning staff in Pennsylvania, New York and New Jersey; the National Park Service; regional organizations such as the Delaware River Basin Commission and the Common Waters Partnership; and non-profits such as the Nature Conservancy. The involvement of so many mission-invested stakeholders throughout the modeling process meant that we were able to obtain the best and most relevant data sets for the end-users and draw on a wide range of expert and local knowledge, which ultimately improved the performance of the land change model as well as its use and targeted application. These groups, who were also the end-users for the

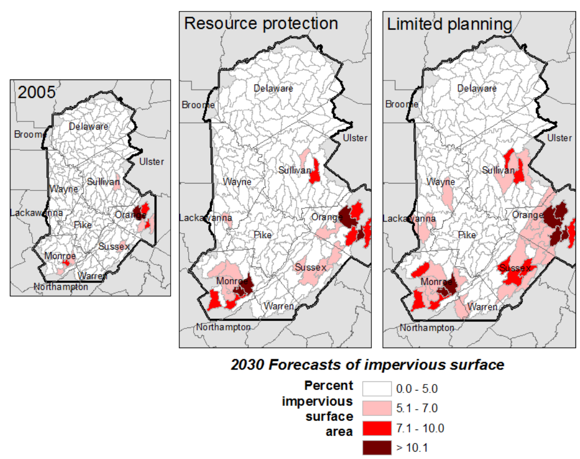

Figure 3. **Example of land cover change modeling results for the Upper Delaware. The left map shows the observed percentage of impervious surfaces in 2005 for small watersheds and the two maps to the right show forecasted impervious surfaces for 2030 for two alternative scenarios.**

work, were actively engaged in developing alternative future scenarios so that the final products were highly relevant and widely adopted. For example, Wayne and Pike counties in Pennsylvania used the growth modeling tool to inform their growth management and open space plans (Hulse 2005; Wayne County Planning Commission 2010). The Common Waters Fund utilizes the maps of projected growth to inform the prioritization of forests for drinking water protection (Common Waters Fund 2014) and the EPA has used these forecasts to assess risks to headwater streams and wetlands in the Upper Delaware (Berner et al. 2008).

We propose to extend this modeling approach for the entire DRB to 1) develop a Basin-wide library of spatial data sets that are relevant to land cover change processes; 2) work with targeted conservation practitioners, local and regional experts, and other end-user groups to formulate alternative future scenarios (including climate change impacts); 3) use national data sets (i.e. CCAP) and the Basin-wide high resolution data sets to calibrate and validate an urban land cover change model and generate forecasts given the criteria developed for each scenario. Throughout this entire process we will be working with stakeholders in the DRB via in-person and web-based workshops, presentations, and meetings, which will keep end-users engaged and invested, increasing adoption and use of the end products.

A FEASIBILITY STUDY FOR LONG-TERM LAND COVER CHANGE MONITORING

While the objectives presented above are important first steps in developing tools and data sets in support of long-term water quality maintenance and restoration goals, the establishment of a long-range land cover monitoring program is vital for setting goals and monitoring progress. As noted above, we will be working closely with state, regional, and local end-user groups and conservation practitioners throughout the mapping and modeling tasks. As part of these interactions, we propose to additionally conduct a feasibility study, concurrently, to explore the potential of establishing a long-term monitoring program. A long-term program would need to be tied to the acquisition of Lidar data, which is usually conducted at the state level. However, processing those data sets to generate land cover maps requires an investment of resources. The feasibility study will therefore gauge the willingness and ability of various stakeholder groups to invest in a long-term monitoring program. We note that once the base data sets proposed here are generated, building on them will be much more cost effective – a key point that will be communicated as part of the feasibility study.

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