A Framework for Long-term Land Cover Change Monitoring in the Delaware River Basin

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Background

The Need for Land Cover Change Monitoring in the Delaware River Basin

A watershed of over 13,000 square miles, the Delaware River Basin (DRB) 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.[1] 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.[2] 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.[3] 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,[3] population growth and associated land cover changes are a concern for water supply and water quality,[4] gas drilling and alternative energy are emerging industries with impacts on water supply and water quality,[5] and climate change brings threats of sea level rise and the potential for more extreme droughts and flooding.[6]

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 to prioritize restoration and protection investments for maximum effect. Further, these products need to be available Basin-wide in order to ensure conservation actions are strategically targeted to those geographies and projects offering the greatest potential for positive conservation outcomes. The

[1] Delaware River Basin Commission (DRBC). 2013. "Basin Information." Last modified February 27, 2013. http://www.state.nj.us/drbc/basin/. Accessed April 22, 2014.
[2] Mandarano, Lynn A. and Robert J. Mason. 2013. "Adaptive Management and Governance of Delaware River Water Resources." Water Policy 15: 364-385.
[3] Delaware River Basin Commission (DRBC). 2012. "Delaware River Water Quality: A Brief Recap ." Last modified May 24, 2012. http://www.state.nj.us/drbc/quality/. Accessed April 22, 2014.
[4] Jantz, Claire and Leslie Morlock. 2011. "Modeling Urban Land Use Change in the Upper Delaware River Basin." http://webspace.ship.edu/cajant/documents/UPDE_modeling_final_report_051211.pdf
[5] Entrekin, Sally, Michelle Evans-White, Brent Johnson, and Elisabeth Hagenbuch. 2011. "Rapid Expansion of Natural Gas Development Poses a Threat to Surface Waters." Frontiers in Ecology and the Environment 9(9): 503-511.
[6] Stroup, Laura J. 2011. "Adaptation of U.S. Water Management to Climate and Environmental Change." Professional Geographer 63(4): 414-428.

need for this information on a continuing and timely basis is critical to support planning and implementation activities related to the Delaware River Watershed Initiative (DRWI).

At the time of this writing and to the best of our knowledge, there is currently no strategic, sustainable framework in place for long-term land cover change monitoring in the DRB, despite recent and ongoing investments in developing tools, data, and planning efforts that rely on this information.

Efforts previously funded by the William Penn Foundation

The William Penn Foundation "supports projects that protect and restore the Delaware River watershed's natural environment to ensure there is an adequate supply of clean water for generations to come." Watershed-wide efforts support projects addressing four priority stressors: loss of forested headwaters, stormwater, agricultural run-off, and depletion of underground water supply. In 2015, the foundation awarded a $1M grant to Shippensburg University entitled "A land cover mapping, modeling, and monitoring system for the Delaware River Basin (DRB) in support of maintaining and restoring water resources," which included support for a feasibility study for long-term land cover change monitoring.

High-Resolution Land Cover Mapping

Through this project, the University of Vermont Spatial Analysis Lab developed a high-resolution (1m x 1m) LiDAR-based land cover dataset for all 43 counties that cover the Delaware River Basin watershed. By late summer 2017, the data will be available via PASDA to stakeholders as a basin-wide mosaic or clipped by counties to provide resource specialists with a common, consistent, and reliable baseline that supports decision making and long-term planning.

Alternative Scenarios of Future Land Cover

SU developed a baseline and two alternative forecasts ("corridors" and "centers") of urban land cover in the Delaware River Basin out to the year 2070, a set of products we refer to as DRB2070. To develop these forecasts, we calibrated the SLEUTH[7] urban growth model for the entire 43 county region of the DRB over the 2001-2006 time period and validated the model for the 2006-2011 time period. Using broad stakeholder and end-user input, we identified a baseline and two alternative scenarios of future development trajectories. We used the National Land Cover Database (NLCD) urban classes to represent urban land cover as developed or not developed. This model was run at the 30-meter resolution and aggregated to National Hydrography Dataset Plus (NHDPlus, version 2.0)[8] catchments. These data are being processed at the Academy of Natural Sciences of Drexel University (ANS) to provide estimates of land converted to developed land, by catchment, under each scenario, for inclusion in the Stream Reach Assessment Tool (SRAT), and are currently available via an online viewer and ArcMap package at http://drbproject.org/products/.

[7] The National Center for Geographic Information and Analysis. University of California, Santa Barbara. Project Gigalopolis. http://www.ncgia.ucsb.edu/projects/gig/
[8] U.S. Geological Survey. National Hydrography Dataset. https://nhd.usgs.gov/

Ongoing and Emerging Challenges

Throughout our project, we gathered feedback from stakeholders related to LiDAR mapping, high-resolution land cover, future land use modeling, and interest in a long term monitoring plan. We also discussed the identity of the Delaware River Basin, and whether or not it is important to plan for the future by thinking about the whole watershed. Observations related to ongoing or emerging challenges include:

- As part of the DRB2070 workshops, we asked participants "Does the Delaware River Basin have a cohesive regional identity or fragmented identities?" Most participants responded that the Basin is comprised of fragmented identities, based on states, commuting regions, metropolitan areas, counties, etc. However, when asked "How important is it to plan for the future by thinking about the whole watershed?" most respondents said it was "important" or "very important." This indicates that while there is broad interest in the watershed perspective and forming a watershed-wide identity, work remains to build this perception.
- County, state, and federal high-resolution monitoring efforts vary dramatically, especially related to new LiDAR acquisitions, and do not always cover the entire region of interest. Within the DRB, efforts are piecemeal, and communication about these efforts is not necessarily organized or efficient. Furthermore, and to the best of our knowledge, there are no strategic plans at the state, local, or regional level that outline an approach for regular LiDAR acquisition.
- At the national level, the USGS has launched the 3D Elevation Program (3DEP) initiative (https://nationalmap.gov/3DEP/). The primary goal of 3DEP is to collect LiDAR data for the conterminous United States, Hawaii, and U.S. territories, with data acquired over an 8-year period. The USGS provides cost-share funds for local, regional, and state agencies to acquire LiDAR data, and also offers infrastructure to enhance collaboration and communication for LiDAR acquisitions. The DRB as an area of interest is notably absent from the 3DEP program and under-represented in funding requests to the 3DEP program.
- Users will require support to maximize the adoption and utility of these new data products. Our observations below address both the high-resolution land cover data from UVM as well as the DRB2070 products, and are based on multiple conversations with a range of end users (i.e. conservation practitioners, GIS specialists, water resource scientists).
  - For the high-resolution data products from UVM:
    - Most end users are familiar and comfortable with the 30m NLCD, but the UVM product differs dramatically in resolution (1m) and in how it represents land cover classes. For example, the UVM product represents the built environment as structures, roads/railroads, and other paved surfaces, while NLCD has urban open space and low, medium, and high intensity urban.
    - This product will require post-processing to integrate it into water quality or other ecosystem models. For example, the "low vegetation" class in the UVM product represents lawns, pasture, and row crops, all of which have different impacts on water resources.

    - Due to differences in the minimum mapping unit, estimates of a number of land cover types (e.g. forest cover) will differ between the NLCD and the UVM product. In urban areas, for example, forest cover as estimated from the UVM product may be higher than NLCD because the 1m data can map forests at a finer scale.
    - While many target end users are interested in high-resolution data, we found that the computational infrastructure to adequately evaluate or use these data was not always present. For example, county planning offices, especially in rural areas, may not have someone with GIS skills or expertise, and if they do that person is often tasked with many other responsibilities. These new, large data sets require faster download speed, more storage space, and significant computational resources to perform desired analyses.
    - This product is currently just one snapshot in time, so it is less relevant for applications that require a look back or forward in time.
  - For the DRB2070 data products from SU:
    - Like the high-resolution land cover, the full suite of DRB2070 products represents a large and complex data set. Users will require support and guidance in the proper use of these data in analyses that inform their work, for example, identifying the types of land that may be replaced by future development.
    - While the online viewer, ArcMap package, and forthcoming integration into SRAT will enable novice and expert users to view and explore the DRB2070 forecasts, there will be an ongoing need for custom mapping. This is especially true for rural areas where current and forecasted levels of development are small relative to the entire Basin.
    - In order to evaluate potential future impacts on water resources, the DRB2070 data will need additional processing to transform the single category of “developed land” into estimates of developed land cover categories that are relevant to watershed modeling tools like MapSheds/Generalized Watershed Loading Function (GWLF). While Stroud Water Research Center will be exploring the feasibility of this application in their current work, to our knowledge this is not an analysis that is planned to be available for current or future DRWI planning and implementation efforts.
    - As the data products age, they will become less relevant, requiring adjustment of trajectories and scenario assumptions.

Opportunities on the Horizon

We are in a phase where the tools, techniques, and theory regarding land use and land cover mapping, change detection, and modeling are experiencing rapid development. As such, there are a number of new products and approaches that present opportunities to support the monitoring and modeling of land use change in the DRB.

- A new USGS initiative, the Land Change Monitoring, Assessment, and Projection (LCMAP) program, is scheduled to release its first round of products at the end of 2017. LCMAP intends to put "near real-time information in the hands of land and resource managers who need to understand the effects these changes have on landscapes"[9] by estimating annual and seasonal land use and land cover changes at the 30m scale. Meanwhile, the Web-enabled Landsat Data (WELD) program has already generated annual data at the 30m resolution from 2006-2010 to track forest changes in the US, and the USGS has simulated historic land use/land cover from 1938-1992 and generated forecasts from 1992-2100 at the 250m scale.
- A variety of coarse resolution (250m - 1km) products are available through NASA's Moderate Imaging Spectroradiometer (MODIS) program, including vegetation indices and land cover maps. The strength of these data products is in their temporal resolution: since 2000, processed and ready-to-use data are available on a monthly to annual basis.
- In the adjacent Chesapeake Bay Watershed (CBW), the decades-old restoration partnership offers many lessons that can be applied to the DRB. We have a strong partnership with the Chesapeake Bay Program (CBP) and other entities in the CBW that allow for faster transfer of knowledge, ideas, and technology.
    - For example, the Chesapeake Bay Land Change Model (CBLCM) has been applied to the DRB in parallel to the SLEUTH model, offering multiple perspectives on land cover and land use change that will inform interpretation of current model results and future model development.
    - Using analogous 1m LiDAR-based land cover, the CBP has already developed methods to generate a 10m land use/land cover data set that is more relevant for water quality modeling (Peter Claggett, personal communication).
- The USGS launched the 3DEP program in 2014, with the first awards made in 2015. Annual calls for funding come out under a Broad Agency Announcement (BAA), offering cost-share funds and encouraging coordination and collaboration to "map once, use many times."

Recommendations for a Monitoring Framework

Below we describe a multi-resolution approach for monitoring and modeling land use and land cover change in the DRB. This framework addresses many of the challenges described above, and takes advantage of the opportunities that are now available in order to maximize efficiency and collaboration, and minimize cost.

Monitoring Land Use and Land Cover Change

- On an annual basis, perform basin-wide "hotspot" analysis of change at the 30m scale using the new LCMAP products and MODIS. The results of this analysis should be broadly disseminated across the DRB, targeting county, regional, and state agencies; conservation practitioners; and DRWI stakeholders.

[9] Young, S.M. 2017. Land Change Monitoring, Assessment, and Projection (LCMAP) revolutionizes land cover and land change research: U.S. Geological Survey General Information Product 172, 4 p., https://doi.org/10.3133/gip172

- Appoint 3DEP coordinator(s) to build basin-wide awareness of the 3DEP program, coordinate efforts among potential collaborators, and guide the process such that 3DEP applications target the areas that are in most need of LiDAR updates, using criteria such as time since last update, location within a DRWI cluster, and the hotspot analysis.
  - These efforts will also help to promote the idea of the DRB as an area of interest and will build regional identity
- Perform interim updates to the high-resolution land cover data product every few years as updated imagery (e.g. NAIP and state orthophotos) become available, emphasizing areas that have experienced the most change based on the broad scale hotspot analysis. Because of the baseline data that have recently been produced, updates will be much more cost effective.
- Perform full, comprehensive updates to the high-resolution land cover data product as new LiDAR becomes available (~10 years).

Land Cover and Land Use Change Modeling

- Compare and contrast current forecast data available for the DRB: the SU-CLUS SLEUTH model (30m), the CBLCM (30m), and the LCMAP (250m) products. Synthesize products if possible, and communicate findings across the DRB stakeholder groups such that users can select the most suitable data product for their particular application.
- Reassess and repeat scenario building and forecasting work on a 5 to 10-year time frame. Models will need to be realigned with new change trajectories, and stakeholder and policy attitudes. The timing and scope of model updating should be prioritized based on hotspot analysis.

Integration into Water Quality Assessments

- The new high-resolution land use/land cover data and the DRB2070 products provide an unprecedented opportunity to inform current and future assessments of water quality, which is the ultimate focus of the DRWI. However, new investments will be required to process these new data sets such that they can be integrated into watershed models. This is a process that should begin as soon as possible to capitalize on these new data sets, and to deliver watershed model results that will support DRWI implementation and planning efforts, but should be designed to integrate into the monitoring and modeling framework described above.

Conclusion

Establishing a long-term land cover monitoring program in the Delaware River Basin is essential for helping decision makers set land and resource goals and assess progress toward those goals. The investment the William Penn Foundation made in the development of high-resolution, LiDAR-based land use/land cover maps and in the DRB2070 products provides a strong foundation on which to build an efficient and cost-effective monitoring system. To capitalize on this investment, we urge the WPF and its partners to consider implementing the most critical components of this proposed framework.