The Peculiarities of Pervious Cover:

A Research Synthesis
on Allocating Pollutant Loads to Urban Land Uses in the Chesapeake Bay

STAC Workshop Report
April 22-23, 2014
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Section 1: Summary of findings and recommendations

Part 1. Context for this report

The purpose of this report is to ensure that a scientifically credible approach is taken to develop urban land use/cover data to inform the suite of Chesapeake Bay Program (CBP) models and accounting systems. The specific objective was to make recommendations on where and how to allocate pollutant loads from various urban land uses/covers to improve the simulation of the urban sector in Phase 6 of the Chesapeake Bay Watershed Model (CBWM). Since the timeline for making final urban land use decisions was November, 2014, the recommendations presented in this report are critical to next steps in the assessment.

The broader purpose of this report is to give Bay managers a better understanding of nutrient and sediment sources and dynamics in the urban landscape so they can effectively target Best Management Practices (BMPs) to achieve pollutant reductions from the most controllable and cost-effective urban sources.

Table 1 provides a summary of how the urban sector is currently represented in the CBWM. The model simulates three urban land categories: Impervious cover, pervious cover, and construction sites.

Table 1. How Urban Land Cover is Represented in the Current Version of the CBWM.

	Impervious Cover	Pervious Cover	Construction
Acres in watershed[1]	1,269,030	3,398,732	84,500
Average Total Nitrogen (TN) load[2]	15.5 lbs/ac/yr	12.4 lbs/ac/yr	26.4 lbs/ac/yr
Average Total Phosphorus (TP) load[2]	1.93 lbs/ac/yr	0.55 lbs/ac/yr	8.8 lbs/ac/yr
Average Total Suspended Solids (TSS) load[2]	0.65 t/ac/yr	0.09 t/ac/yr	24.4 t/ac/yr
Key inputs	Air deposition build-up/wash-off	Air deposition fertilizer[3]	Air deposition No fertilizer
Key outputs	Flow volumes and N/P event mean concentrations (EMCs) for surface runoff only	Flow volumes and N/P EMCs in runoff, interflow and groundwater	Flow volumes and sediment yield, attached nutrients

[1]Acres as reported in most recent CBWM version 5.3.2.
[2]Average values, as reported in Tetra Tech (2014a) and Erosion and Sediment Control Expert (ESC EP 2014) (construction sites), although actual values are regionally variable.
[3]Unit fertilizer input of 43 lbs/ac/yr of TN and 1.3 lbs/ac/yr of TP applied to all pervious acres.

Part 2. Potential additional land use categories under consideration

Recent improvements in mapping and remote sensing capability have enabled managers to consider many more land use categories than the three currently used in the CBWM. The LUWG developed a series of alternative options for urban land use in a review paper summarized in Table 2 (LUWG 2014).

Table 2. Range of Urban Land Cover/Uses Considered by the LUWG.

Land Cover	Potential Sub-Class
Impervious surfaces	Residential/non-residential; commercial, industrial, institutional, roads, connected/disconnected
Pervious surfaces	Residential/non-residential, hi-fertilized turf, lo-fertilized, golf course, landscaping, scrub-shrub, connected/disconnected
Urban tree canopy	Forest, street trees, residential trees, mixed-open
Construction	None
Extractive[1]	Surface mines, quarries, gravel pits, abandoned mines
Stream corridor	Floodplain, riparian forest, wetland
Other layers[2]	Municipally Separate Storm Sewer System (MS4) - regulated/non-regulated, combined sewer service area, federal lands

[1]Not considered in the following report, as it is not really an urban land use.
[2]Layers are defined as an acreage subset of an existing land use category and are only used by managers to track implementation in these sectors (i.e., not used for simulation purposes).

Part 3. Review of the science on urban land use and cover

Information to prepare this report was compiled over the last several months and included the following specific activities:

- A STAC research workshop was held on April 22-23, 2014 in Annapolis, Maryland that featured presentations from 36 researchers and managers. The workshop was specifically structured around the key urban land use/cover issues and more than 60 individuals participated in the discussions. A copy of the workshop agenda is provided in Appendix A and a participant list is provided in Appendix B.

- The CBP contracted with Tetra Tech to perform a major literature review and analysis of urban land use loading rates. A major element of the review involved an analysis of the most recent edition of the National Stormwater Quality Database (NSQD; Pitt 2014), which included event mean concentration (EMC) statistics for 5000 and 7000 storm events over a wide range of urban land use land cover. The final memo was released coincidently with the workshop (Tetra Tech 2014b).

- At least 6 recent or ongoing urban BMP expert panels have reviewed the science on the nutrient and sediment dynamics within their respective urban source areas, which contributed substantially more data to the discussions. The panels include: Erosion and Sediment Control Expert Panel (ESC EP 2014), Urban Nutrient Management Expert

Panel (UNM EP 2013), Urban Stream Restoration Expert Panel (USR EP 2013), Stormwater Retrofits Expert Panel (SR EP 2012), Street Cleaning (SC EP in prep), and Elimination of Discovered Nutrient Discharges Expert Panel (EDND EP 2014).

- During 2013-2014, the LUWG and CBP staff assessed the quality and availability of local urban land use mapping datasets and evaluated various mapping techniques to address urban land use/cover combinations. These investigations helped inform the workshop on the status of these important mapping issues.

- Following the workshop, several meetings were held by the USWG, the LUWG, and the Forestry Workgroup (FWG), along with the CBPO modelers, to review the workshop findings. A joint meeting was held on July 15, 2014, which resulted in the consensus viewpoint reflected in this report.

Part 4. The four fundamental criteria to make an urban land use change

The workshop steering committee established four criteria to determine if a proposed change in urban land use/cover was feasible to utilize in the context of Phase 6 of the CBWM. The four criteria were expressed as questions, as shown below:

1. Does the source or cover type depart in a meaningful way from the average nutrient or sediment loading for generic impervious and/or pervious land?

2. If so, are mapping tools available or planned in the near future that can accurately measure the source or cover type at the scale of a county and the entire Bay watershed?

3. If so, can the pollutant dynamics of the source or cover type be accurately simulated in the context of existing or future versions of the CBWM?

4. If so, would the source or cover type respond in a unique manner to the application of a new or existing urban BMP type?

Part 5. The six major land use/cover decisions

Based on the results from the workshop and supporting research, the steering committee narrowed its focus to the six critical decisions on land use categories, as shown below:

1. Do different types of impervious cover have different pollutant loading rates?

2. Should we recommend a lower target load for disconnected impervious cover?

3. Should there be a new land use representing the urban stream corridor?

4. What changes in nutrient inputs to urban land can be expected in the future (atmospheric deposition, fertilization, discovered nutrient discharges, etc.)?

5. Does it make sense to split pervious land based on fertilizer wash-off risk or fertilization status?

6. How should we handle urban tree canopy and forest fragments on pervious land?

Part 5a. Do different types of impervious cover have different pollutant loading rates?

FINDINGS: Two extensive analyses of national stormwater outfall monitoring data clearly indicated there is little, or no statistical difference in the EMC of total nitrogen (TN), total phosphorus (TP), and total suspended solids (TSS) between "generic" impervious cover and its commercial, residential, institutional, and industrial components (CWP, 2003, Tetra Tech, Inc 2014b).

There was strong evidence, however, to support the case to create a transport land use sub-category within impervious cover to include streets, roads, and highways, as there was a modest, but statistically significantly difference in TN EMCs for transport land uses (Tetra Tech, Inc, 2014b). Transportation land uses can also be effectively identified and mapped in the Bay watershed, given currently available spatial data using a geographic information system (GIS).

The stormwater monitoring analysis also revealed that outfall total suspended solids (TSS) concentrations from all urban land uses were at least an order of magnitude lower than what is observed in urban streams (CWP, 2003, Tetra Tech, Inc. 2014b). This suggests that other downstream sources were responsible for a significant fraction of the urban sediment budget. This finding was also reinforced by stream sediment research profiled in Section 4 of this report.

The workshop also examined the degree of sediment nutrient enrichment in the urban landscape, from upland soils, street solids, leaf detritus, catch basins, BMP sediments, and stream bank sediments. There is considerable range in nutrient enrichment from the upland to instream source areas, with significant increases along this pathway downstream, most notably where leaf material is present in the sample material. While the workshop consensus was that this data was not particularly useful for the CBWM simulations, it may be quite valuable to help potential nutrient removal rates for select urban BMPs that either capture or prevent sediment loss (e.g., stream restoration- USR EP, 2013 and street cleaning SC EP, in prep).

RECOMMENDATION: The workshop consensus was that no further subdivision of impervious cover is warranted on the basis of general land use, given that the loads are not different at the watershed scale (with the exception of the proposed transport land use sub-category).

CAVEAT: There was consensus at the workshop that the stormwater outfall monitoring data only provide information on what materials wash off impervious surfaces into storm drains, and because of location, it does not help identify downstream and groundwater nutrient sources. These sources can produce potentially significant nutrient loads via:

- Fertilizer wash-off and leaching;
- Stream channel erosion;
- Sewage exfiltration and overflows;

- Groundwater migration;
- Relict and existing septic systems;
- Illicit discharges;
- Drinking water transmission loss; and
- BMP return flows.

At the watershed scale, these sources may only be identifiable in an aggregate manner. A key management challenge will be how to isolate the relative contribution of nutrient and sediment loads generated from these sources (either individually or collectively), so loads can be properly allocated to the appropriate urban land use category.

Part 5b. Should we recommend a lower target load for disconnected impervious cover?

FINDINGS: There is some scientific and engineering evidence that suggests pollutant EMCs and/or runoff coefficients may be lower for historically impervious areas that discharge runoff to pervious areas prior to a storm drain or stream channel (Alley and Veenhuis, 1983; Boyd et al.; 1994; Sutherland 1995; Roy and Shuster 2009). However, it is very difficult to assign a lower unit load to them, given the great variability in the strength of the "disconnection effect" across the Bay watershed.

While some land use categories are expected to experience a high degree of presumed disconnection (e.g., rural highways, large lot developments, open section roads, etc.), each individual disconnection is subject to unique local conditions, such as the hydrologic soil group, infiltration rate, slope, sheet flow path length, and density of vegetative cover. This makes it difficult to assign a universal load to disconnected areas. It is likely that site-based engineering estimates and/or calibrated hydrologic models would be needed to compute the actual degree of disconnection for each individual disconnected area.

Another key theme was that many urban pervious areas are not as "spongy" in retaining runoff, given the mass grading and engineered soil compaction that is attributed to common practices in the land development process. Urban soils thus have a much reduced infiltration capacity.

Speakers at the workshop also noted that it will be extremely difficult to accurately map the spatial extent of disconnected impervious cover at the scale of the Bay watershed, given current mapping capabilities and the difficulties in isolating these areas.

RECOMMENDATION: Due to all of these factors, the consensus was that it is not advisable at this time to differentiate connected/disconnected impervious cover in the CBWM.

This should not preclude a local government from conducting its own impervious cover mapping analysis, supplemented with on-site surveys and applying hydrologic and engineering models, to determine a site-based disconnection credit as a BMP. The rules for doing so, however, would need to be developed by a future urban expert panel. Such a panel was recently voted the top priority of the USWG (June 2014).

Part 5c. Should there be a new land use representing the urban stream corridor?

FINDINGS: This proposed new land use passed the four criteria test (p.4), and the consensus of the workshop was to investigate urban stream corridors as a potential new land use for the Phase 6 model, pending some additional analysis.

The first criterion is whether the stream corridor loads differently. Numerous speakers (see Appendix A) presented research that urban stream channel erosion is a major component of the urban sediment budget, and delivering sediment and attached nutrients to the Bay. The magnitude of these loadings is often influenced by the flow regime from their respective contributing watershed.

A recent expert panel (EDND EP 2014) also concluded that unique dry weather nutrient discharges occurring in the urban stream corridor were a significant source of the annual nutrient loads. In addition, numerous speakers (Appendix B) presented strong evidence of significant N dynamics within the urban stream corridor, either in the hyporheic zone, stream, floodplain, wetlands, or via groundwater migration.

The second criterion is whether the stream corridor can be adequately mapped. Several speakers (Appendix A) suggested that it may be possible to use the floodplain to help define the core of the stream corridor, along with additional mapping layers to define its full extent. The initial consensus was that SSURGO (Soil Survey Geographic database) data could be used to define the base floodplain, supplemented with National Wetland Inventory (NWI) data, stream network data from USGS National Hydrologic Dataset (NHD), and possibly additional terrain-based methods to provide better local resolution. Excluding existing impervious cover within the floodplain is a capability that may also be needed.

The third criterion relates to whether the pollutant dynamics of the urban stream corridor can be accurately simulated in the context of the CBWM. The consensus was that it could not be done in the current version of 5.3.2, but could be accomplished in Phase 6 through multiple approaches.

The fourth criterion involves whether the stream corridor would respond in a unique manner to urban BMPs, and the answer is clearly yes. Many current urban BMPs are spatially applied within, or in close proximity, to the urban stream corridor (e.g., riparian reforestation, stream buffers, palustrine wetland restoration, stream restoration, and discovered nutrient discharges).

RECOMMENDATION: The consensus at the workshop was to form a small group to develop operational methods to allocate sediment and nutrient loads to the urban stream corridor, and make corresponding reductions to target loads for impervious and pervious cover. Participants also recommended that the methods should be piloted in several "data-rich" urban watersheds in the Bay watershed, such as Difficult Run in Virginia and/or Baltimore City/County streams.

Part 5d. What changes in nutrient inputs to urban land can be expected in the future (atmospheric deposition, fertilization, discovered nutrient discharges, etc.)?

FINDINGS: Numerous speakers (Appendix B) and expert panels have provided forecasts on how urban nutrient inputs might change in the future. If these changes actually occur, they will need to be explicitly considered in Phase 6 of the CBWM. Five changes in urban nutrient inputs commanded the most discussion at the workshop:

1. Long term Bay-wide and regional declines in air deposition loads for N (and to a lesser extent P) over pervious and impervious lands are forecasted due to improvements in air pollution controls resulting from more stringent regulation.

A key implication associated with this encouraging drop in N deposition is how the decline in nutrient inputs will affect future N build-up and wash-off from impervious land (i.e., will the surface runoff loads decline in direct proportion to the reduced inputs, or is some other manner)? The same question also applies to the projected reduction in N deposition over pervious land.

2. Changes in N and P fertilization rates due to state-wide lawn fertilizer laws and the Bay-wide effect both have had on the nutrient content of fertilizer applied to pervious land.

In recent years, MD, VA, DC, and NY have adopted legislation to sharply reduce the P content (and in some cases N as well) of lawn maintenance fertilizer. In anticipation, the fertilizer industry has gradually been phasing out the use of P in most of its "do it yourself" (DIY) home fertilizer formulations. According to data summarized by the UNM expert panel, this should result in a 55% to 85% reduction in P inputs to fertilized pervious areas, and smaller, state-specific declines in N inputs (UNM EP 2013).

The forecasted drop in fertilizer inputs to pervious land is encouraging, although the expert panel cautioned that there are many uncertainties in understanding of non-farm fertilizer sales and the actual fertilization behaviors of both commercial applicators and homeowners. Therefore, the consensus from the workshop was that improved urban fertilizer input statistics are critically needed to confirm whether the presumed nutrient reductions are real and can be sustained in the future.

3. Lower target loads for sediment discharge from active construction sites and incorporation of higher fertilizer applications at construction sites.

The best understanding of the nutrient and sediment dynamics at construction sites is contained within the recently approved Erosion and Sediment Control expert panel report (ESC EP 2014). Based on its deliberations, the panel recommended that sediment target loads be dropped from the current 24.4 t/ac/yr in Phase 5.3.2 of CBWM to around 12 t/ac/yr in Phase 6. The second relevant finding from the expert panel is that Phase 5.3.2 does not reflect the considerable fertilizer inputs that are applied to construction sites to rapidly stabilize the exposed soils with grass and other vegetation. Recommended construction site fertilization rates are extremely high (115 lbs/ac/yr of N, 75 lbs/ac/yr of P) yet the current version of CBWM assumes no fertilizer inputs.

4. What is the significance of the nutrient loading derived from organic matter from the tree canopy/pervious areas that reaches impervious areas and is actually delivered through the storm drain to the urban stream corridor?

One of the more intriguing but unresolved nutrient loading sources was leaf drop (and to a lesser degree, pollen and green fall during the growing season). Nowak (2014) provided data for Baltimore, MD estimating an urban tree canopy biomass nutrient load at 28.8 lbs/ac/yr and 2.95 lbs/ac/yr of N and P, respectively. If a fraction of this load washes off into the stream, leaf drop alone would be a considerable component of CBWM nutrient loadings rates. It should be noted that the understanding of the fate, transport, and processing of leaf litter in urban watersheds is limited, but to date this load has largely not been accounted for in urban nutrient mass balances. Further, both of these "loading rates" significantly exceed the current nutrient loads from impervious and pervious cover, as simulated by the CBWM (see Table 1).

The unresolved issue at this time is how much of the leaf drop moves through the urban landscape and is actually delivered to the urban stream corridor. Consequently, there was no consensus at the workshop on how to define the significance of this loading source to the overall nutrient budget, and that further research was warranted.

5. Accounting for dry weather nutrient loads generated by nutrient discharges from grey infrastructure.

This nutrient source was covered in detail by a recently released urban expert panel report (EDND EP 2014). The current version of the CBWM does not explicitly simulate nutrient discharges from grey infrastructure (e.g., illicit discharges to storm drain, sewer exfiltration, and sanitary sewer overflows).

The expert panel concluded that there was conclusive evidence that these discharges increase N and P levels in dry weather urban stream flow and may collectively account for as much as 20% to 40% of the annual nutrient load in urban watersheds, depending on the age and condition of its grey infrastructure (EDND EP 2014).

RECOMMENDATION: Several critical research projects are needed to improve our understanding of urban nutrient inputs that should be completed during the Mid-Point Assessment to better simulate them in the Phase 6 model.

- Improved lawn fertilizer input data, based on better analysis of the non-farm N and P fertilizer sales statistics in each of the Bay states (for more detail, see UNM EP 2013);
- Monitoring to characterize the discharge of nutrients from construction sites, following the study design proposed by the ESC EP (2014); and
- Further research to define the significance of organic matter loads produced from pervious surfaces and delivered to the urban stream corridor by the urban storm drain system.

Part 5e. Does it make sense to split pervious land based on fertilizer wash-off risk or fertilization status?

FINDINGS: The CBWM currently simulates a unit fertilizer application rate for all pervious lands reflecting the fact that approximately half of pervious land in the watershed is fertilized. A recurrent question discussed at the workshop is whether it would be feasible to split pervious land into categories that would reflect either:

1. Fertilization status (fertilized/unfertilized);

2. Its export risk status (high risk/low risk, as defined in UNM EP 2013); or

3. Some hybrid of the two.

Another approach consists of mapping the 12 risk factors for high site nutrient export resulting from fertilizer use, as defined by the UNM panel (UNM EP 2013). Given the local variability in each of these factors, however, the workshop consensus was the resolution to spatially represent these risk factors is lacking, both within an individual river basin segment and even more so at the Bay watershed scale. Many local governments possess high quality GIS systems that have the capability of mapping many, if not all, risk factors at the local scale. This practice should be encouraged, thus allowing UNM outreach campaigns to identify and target the highest risk parcels.

There was strong evidence that an "open space" sub-category would be useful within the pervious land category, given statistically significant different (lower) N, P, and sediment loadings from this category, as reflected in the Tetra Tech (2014b) monitoring data review.

RECOMMENDATION: The workshop consensus was that while these new pervious land sub-categories made sense in theory, it would be impractical to implement in Phase 6 due to a lack of source information and mapping capability. For example, even what would appear to be a relatively simple split between fertilized and non-fertilized pervious land is hard to distinguish at the river-basin segment or Bay-wide scale, because there is a lack of reliable spatial data identifying which parcels are actually fertilized and which are not. In the absence of such mapping data, creating a new fertilization status category for pervious land would add little value.

Part 5f. How should we handle urban tree canopy and forest fragments on pervious land?

FINDINGS: Measurements of the extent of tree canopy in Bay urban areas have greatly improved. Figure 1 portrays the estimated tree canopy percentages in 20 different communities in the Bay watershed and East Coast.

David Nowak of the USFS presented data on the i-Tree Hydro model which quantifies the joint effect of impervious and forest cover on urban hydrology and water quality. The i-Tree Hydro model has been recently adapted to 5 urban watersheds in the mid-Atlantic and Northeast. The modeling results suggest that the forest canopy can reduce runoff volumes, an effect that increases with impervious cover. Based on these reductions in urban flow, the i-Tree Hydro model also simulates a modest nutrient reduction for urban watersheds with a high tree canopy.

The current version of the model, however, does not explicitly account for any nutrient loading caused by leaf drop or green fall.

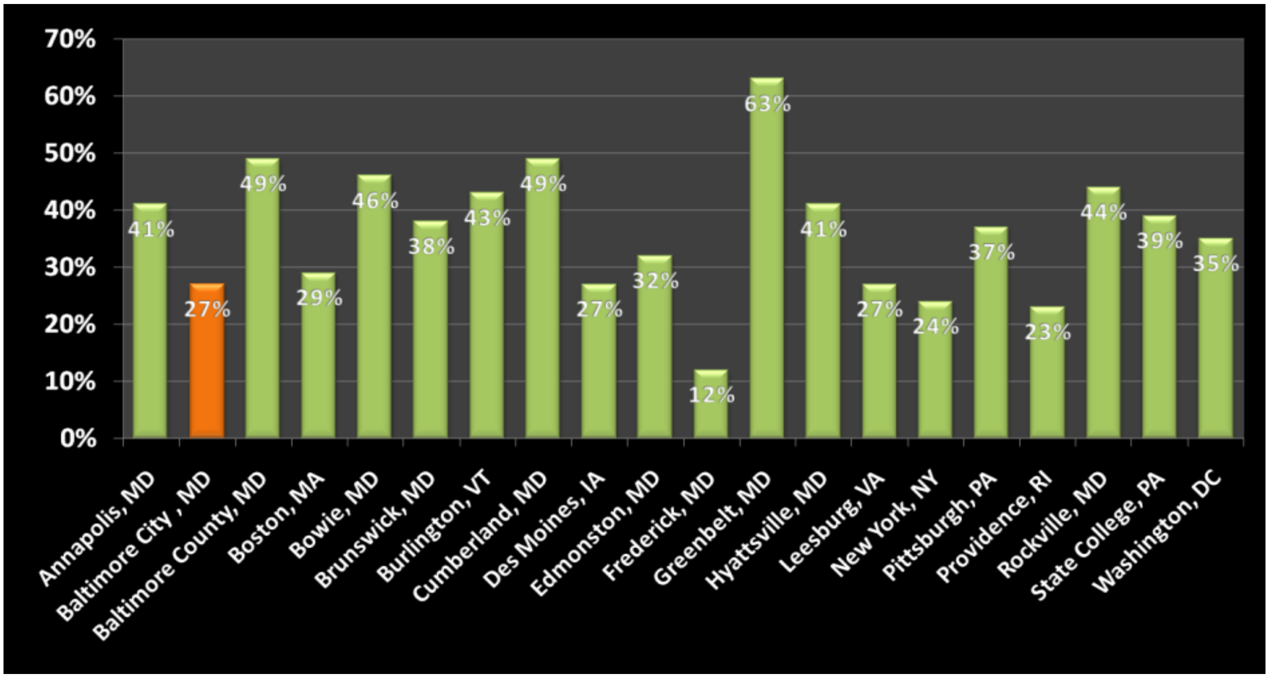

Figure 1. Urban tree canopy measurements in 14 Bay communities (source: O'Neil-Dunne 2009).

RECOMMENDATION: The general workshop consensus was that urban tree canopy should be considered as either (a) a unique category of pervious land, (b) a pervious land use layer, or (c) treated as an urban BMP, depending on the science available. More work is needed from the FWG (Forestry Work Group) and LUWG in the coming months to make a consensus recommendation.

Part 6. Implications for Bay managers, needed research, and next steps

Over the last decade, understanding of the complexity and variability of the nutrient and sediment dynamics that occur in the urban landscape has grown enormously.

Consequently, many of the traditional simplifications and technical assumptions that have been used to map and model urban areas in the past may need to be adapted, or modified, to reflect improved understanding. This is evident in the algorithms in the CBP watershed model for simulating impervious and pervious land which have not significantly changed in the last four decades.

While the steering committee has proposed several modest changes to how urban loads are re-allocated to new sources, it also concurs that urban pollutant mass-balance must be conserved, so that the total calibrated urban load remains unchanged regardless of whatever load re-allocation is ultimately chosen.

Perhaps the biggest unintended consequence of any proposed load re-allocation involves the spatial change in where urban pollutant loads are generated. For example, if more sediment and nutrient loads were shifted from upland pervious and impervious areas to the downstream corridor, than it would have the net effect of reducing the load delivered to upland BMPs, and assuming no change in their current BMP efficiency, a net reduction in nutrient removal for upland BMPs.

Therefore, the workshop consensus was that as existing expert panels are reconvened in 2016/2017, sensitivity analyses should be conducted to identify the specific urban BMPs that would experience the greatest positive or negative change in removal efficiency, based on their position in the urban landscape.

Section 2: Do different types of impervious cover have different pollutant loading rates?

Background:

Researchers have sampled the stormwater runoff from different kinds of urban land use to determine if they generate higher or lower nutrient loads. This session examined what we have learned from these monitoring studies over the last three decades. The CBWM currently simulates urban areas with two "generic" land uses - pervious and impervious cover. This session focused on whether the accuracy of the urban nutrient loading simulation of the watershed model could be improved by including more types of urban land cover.

Key Questions:

1. What have we learned about pollutant concentrations from mixed urban land over the past three decades?

2. How does that knowledge inform how we manage or classify pervious and impervious land?

3. Can different levels of nutrient enrichment in urban soils, street solids, BMP sediments, bank sediments, and vegetative detritus be used to define or predict nutrient loadings in the urban landscape? Or help predict the impact of certain BMPs?

Key Speakers:

- What we have learned about sediment and nutrient dynamics from urban source area sampling - Dr. Shirley Clark, Pennsylvania State University (PSU)-Harrisburg.

- What we have learned about sediment and nutrient dynamics from urban stormwater outfall monitoring - Tom Schueler, CSN.

- Sediment and nutrient concentrations and loads in small urban streams in Fairfax County, Virginia - John Jastram, USGS.

- Urban nutrient stream data as a function of land cover/land use at various spatial and temporal scales - Claire Welty, University of Maryland, Baltimore County (UMBC) and Baltimore Ecosystem Study (BES).

- Nutrient content of urban soils - Richard Pouyat and Ian Yesilonis, U.S. Forest Service (USFS).

- Nutrient content and particle size distribution of street solids - Neely Law, CWP, CBP Stream and Sediment Coordinator.

- Magnitude and fate of leaf detritus in the urban landscape - Neely Law, CWP/CBP and Tom Schueler, CSN.

- Nutrient content of stormwater pond sediments - Tom Schueler, CSN.

- Nutrient content of streambank sediments - Bill Stack, CWP/CBP.

- Summary of Tetra Tech Memo (2014b).

Speaker Presentation Summaries:

What we have learned about sediment and nutrient dynamics from urban source area sampling – Dr. Shirley Clark, PSU-Harrisburg

Clark noted that there have been magnitude-level decreases in atmospheric deposition of both N and P species since the National Urban Runoff Program (NURP) studies of the early- and mid-1980s, which should translate into lower runoff loads (U.S. EPA 1983). Clark presented data showing variation in nitrate and ammonia concentrations in the water running off roofs made from different types of material, with the highest concentrations of various nitrogen species associated with wood-based materials and the highest concentration of phosphorus (P) associated with green roofs. Clark presented data from a 2003 study on runoff from various types of roads that showed little difference in its concentration of various N and P species, although sediment concentrations were somewhat variable. The data presented on generalized EMCs from various urban land uses (CWP 2003) showed that higher TN and TP concentrations were associated with lawns in general compared to various impervious land uses. Clark presented data from Garn's 2002 study of lawn nutrient runoff that indicated higher nutrient concentrations were associated with higher levels of fertilization.

What we have learned about sediment and nutrient dynamics from urban stormwater outfall monitoring - Tom Schueler, CSN

Schueler summarized data from the original NSQD, which included data from about 3,800 storm events nationwide, where approximately 35% are located in the Chesapeake Bay watershed (Schueler 2014). More recent data are now available.

For EMCs of TSS, box plots of all the collected data show little difference among the different land use categories - commercial, highway, industrial, institutional, open space, and residential - in median, 25th, and 75th percentile concentrations, although the data were highly variable (Fig.5). Statistics for the institutional category were somewhat weaker, but there was no indication of the number of samples for this category; additionally, industrial land use is not a current category in the CBWM. For EMCs of TP, the residential land use category had a somewhat higher median concentration value than the other land uses, but no significant differences between land uses were detected.

For EMCs of TN (including TKN and nitrate), there were no statistically significant differences among the different land use categories. Since these monitoring results are based on outfall sampling during wet weather events, Schueler noted that the NSQD database does not reflect any information on dry weather nutrient loads which may be altered by various problems with grey infrastructure and could comprise 20% to 50% of total TN loads in some urban watersheds. Schueler also noted data from a CWP study (CWP 2008) that showed elevated median EMCs for TN for outfall samples in Virginia's Coastal Plain region compared to the state as a whole or its Piedmont region. Schueler speculated that this could be due to higher water tables or different nutrient dynamics from septic systems.

Sediment and nutrient concentrations and loads in small urban streams in Fairfax County, Virginia - John Jastram, USGS

Jastram reported preliminary results from a cooperative study of small urban streams and their watersheds in Fairfax County that have up to 10 years of data at some sites (Jastram 2014). Although the researchers saw some major variability in N and P levels in the different watersheds, those discrepancies do not appear to be the result of differences in land use within the watersheds.

One site studied had median TN concentrations of 5 mg/L, which is 2-3 times higher than concentrations seen in other watersheds. The land use in the portion of the watershed draining to this site was primarily large-lot (or estate) residential and primarily on-site septic systems. Two groundwater seeps in the watershed were found to have very high TN concentrations relative to the rest of the stream. Another site had an occasional summer spike in TN concentrations which can be attributed to the high concentrations of TN in the groundwater sources to this stream. The researchers speculated that septic systems may be responsible for the elevated TN levels.

Two sites in the study showed elevated TP concentrations compared to the other sites. These watersheds drain land whose soils rank at the high end of the spectrum for P concentration in soils in the county. Although the researchers are still analyzing the data for correlations, it is likely that underlying soil conditions rather than land use is primarily responsible for the differences seen in TP yields (load/unit area) among the watersheds. In the four most intensively studied watersheds, there were significant differences in suspended sediment loads and yields. However, no correlations were observed between these differences and land use.

Urban nutrient stream data as a function of land cover/land use at various spatial and temporal scales - Claire Welty, UMBC and Baltimore Ecosystem Study LTER (Long Term Environmental Research)

Based on weekly monitoring data collected since 1998 at nine stations (most of which are nested within an urban watershed near Baltimore, but including stations whose drainages are largely forested or agricultural), Welty's data show that nitrate-N concentrations and loads were lowest for the forested sites, highest for the agricultural watershed, and intermediate for the urban ones. The five most urbanized catchments (from 0.7 km^2 to 171 km^2 and percent impervious from 18.6 to 45) exhibited similar nitrate yields. To the extent that runoff from these urbanized watersheds differ in nitrate concentrations, those differences are likely caused by varying inputs from septic or grey infrastructure, and not by differences in runoff from land use.

Major Findings & Recommendations:

FINDINGS:

1. There does not appear to be any major correlation between different types of urban land use and nutrient and sediment concentrations, loads or yields, with the possible exception of higher amounts of TN and TP (total nitrogen and phosphorus, respectively) in the runoff from residential lawns compared to other urban land uses. Two extensive analyses of stormwater outfall monitoring data clearly indicate there is little or no statistical difference in the event mean concentration of TN, TP, and TSS between "generic" impervious cover and its commercial, residential, institutional, and industrial components.

In the last five years, the NSQD (Pitt 2014) has doubled in size from about 3500 storm events to more than 7000. This enabled Tetra Tech (2014b) to analyze a much wider range of land uses and covers, as well as mixes of them together. Figure 2 compares the TN EMCs for different levels of urban impervious cover and shows no discernible trend.

The same uniform pattern was evident when TN EMCs were compared by urban land use category, with nearly all land uses clustering around 2.0 mg/L (Fig. 3). Similar analyses for TP and TSS also showed little or no differentiation based on general land use type (Figs. 4 and 5).

2. Most of the studies cited and much of the data presented in the workshop occurred before the recent changes in lawn fertilization content and practices being driven by new state regulations in the Bay region.

3. A number of other factors may be driving observed differences in nutrient and sediment concentrations, such as N inputs from grey infrastructure and the P content of underlying soils.

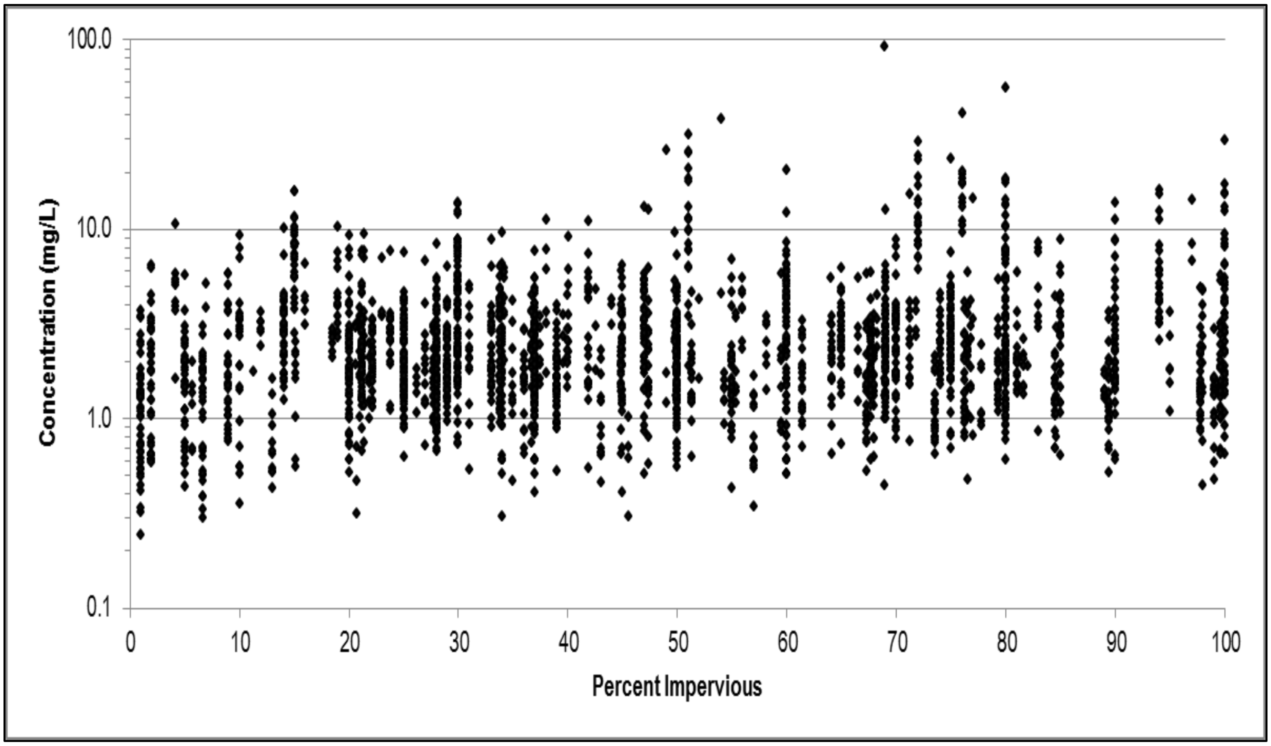

Figure 2. TN storm concentrations as a function of catchment impervious cover (source: Tetra Tech 2014b).

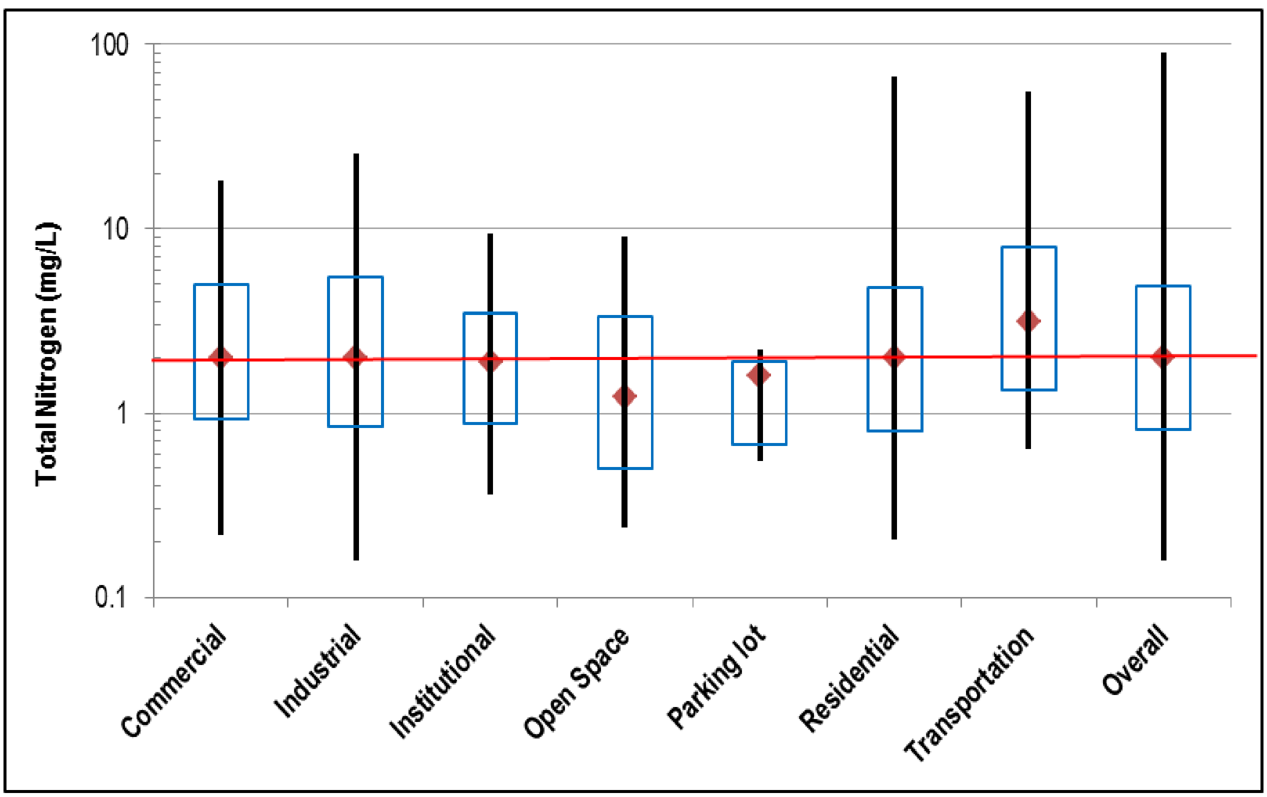

Figure 3. Comparison of TN EMCs on land use categories (source: Tetra Tech 2014b).

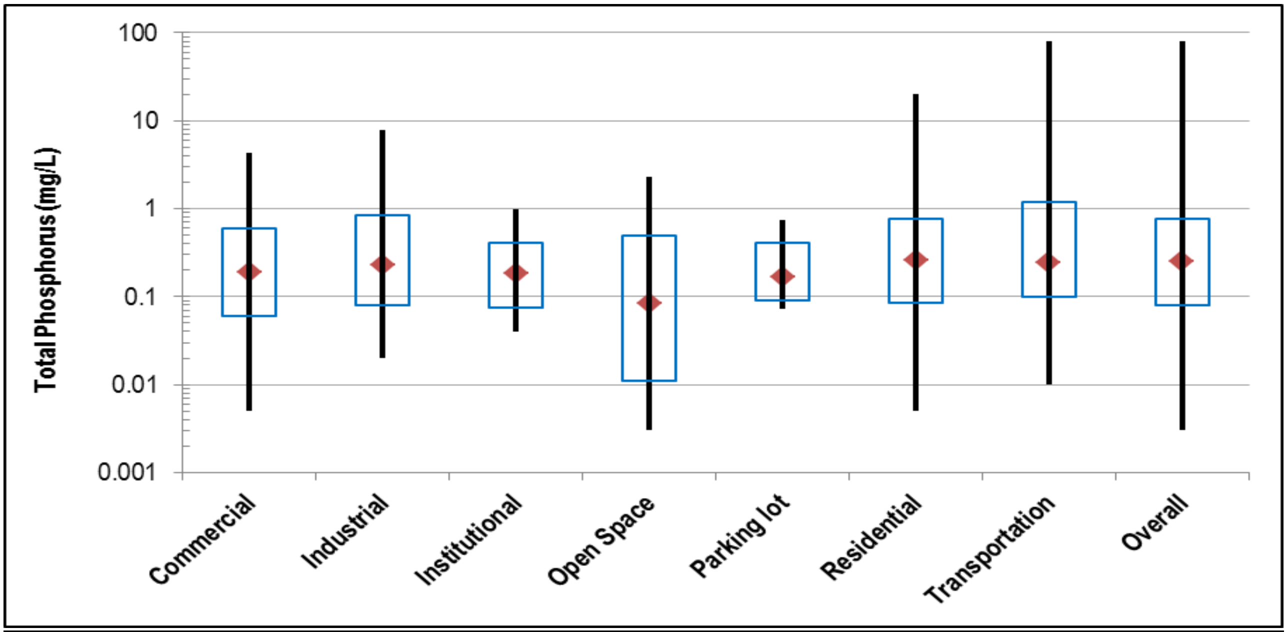

Figure 4. TP concentration statistics from NSQD and literature review for general land uses (source: Tetra Tech 2014b).

4. Another key finding was that outfall TSS concentrations from all urban land uses were at least an order of magnitude lower than what is observed in urban streams, suggesting that other downstream sources are responsible for the urban sediment budget (see Fig. 5). This finding was also reinforced by stream sediment research profiled in Section 4 of this report.

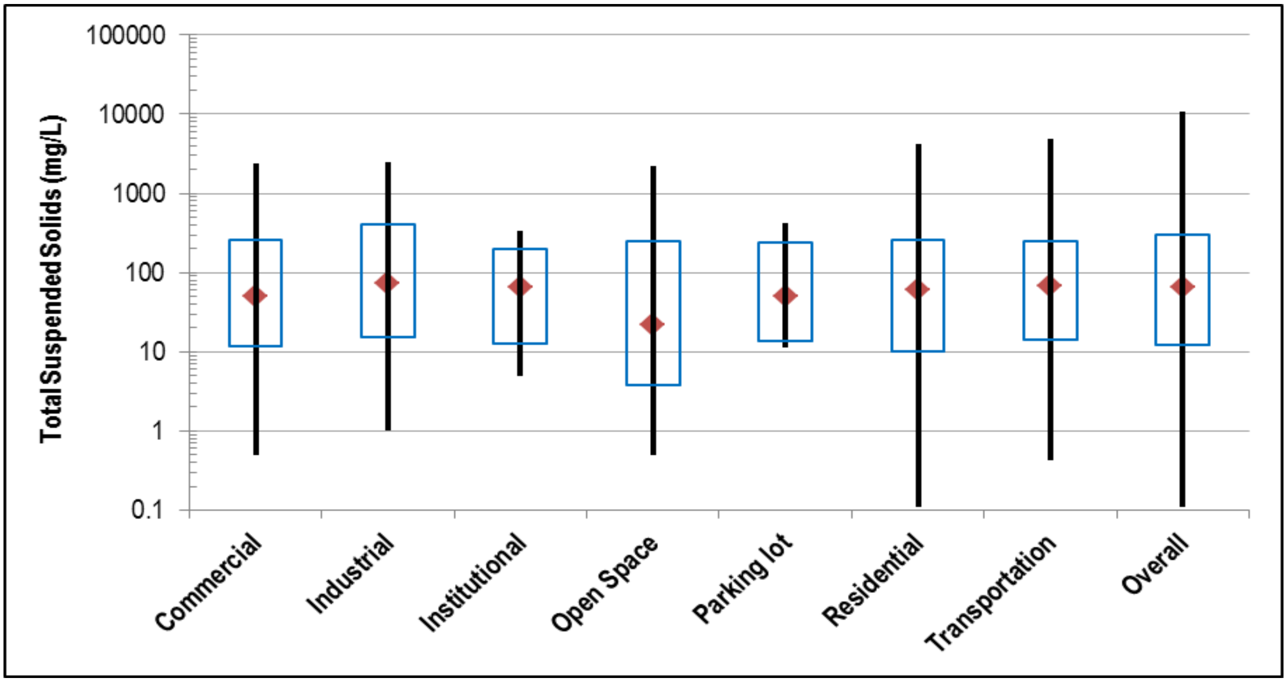

Figure 5. TSS concentration statistics from NSQD and literature review for general land uses (source: Tetra Tech 2014b).

The workshop also included a session that compared the degree of sediment nutrient enrichment in the urban landscape from upland soils, street solids, leaf detritus, catch basin, BMP sediments, and stream bank sediments (Table 3). While these data are not particularly useful for the CBWM simulations, they are useful for defining potential nutrient removal rates for select urban BMPs that either capture or prevent the loss of sediments (e.g., stream restoration, street cleaning).

Table 3. Sediment nutrient enrichment in the urban landscape.

Location	TP (lbs/ton)	TN (lbs/ton)	Location	Reference
Street solids	1.03	2.02	FL	Berretta et al. 2011
	2.07	4.33[1]	MD	DiBlasi 2008
Catch basins	1.10	3.46	FL	Berretta et al. 2011
	1.17	1.56*	MD	Law et al. 2008
	1.27	5.54	MD	MWCOG 1993
	1.96	6.96[1]	MD	Law et al. 2008
BMP sediments	1.17	5.86	Varies	Schueler 1994
	1.29	5.30	FL	Berretta et al. 2011
Outfall net filters	0.90	13.66[2]	MD	Stack et al. 2013
	1.11	16.10[2]*	FL	Rushton 2006
	1.19	7.81	FL	Rushton 2006
Streambank sediments	0.44	--	MD	BDPW 2006
	0.71	1.70	MD	MD SHA n.d.
	1.05	2.28	PA	Walter 2007
	1.43	4.40	PA	Land Studies 2005
	1.78	5.41	MD	Stewart 2012
Upland soils	0.18	3.20	MD	Pouyat et al. 2007
MEAN	**1.17**	**5.60**		

[1]as Total Kjehldahl Nitrogen (TKN)
[2]Majority of material sampled included organic debris mixed with sediment
*Leaves only

RECOMMENDATIONS: The evidence presented at the workshop and the companion Tetra Tech memo (2014b) do not justify the disaggregation of the watershed model's current urban land use classes (pervious and impervious) into further sub-categories, beyond a potential transport land use category.

Section 3: Should there be a lower target load for disconnected impervious cover?

Background:

In the current Phase 5.3.2 watershed model, impervious surface loads vary spatially solely based on differences in atmospheric deposition. No consideration is given to the spatial location of impervious surfaces within a watershed or to the existence of stormwater management infrastructure.

Key Questions:

1. Does current science support the differentiation of impervious surface effects on nutrient and sediment loads to the Bay based on some measure of hydrologic connectivity; and

2. How "pervious" are pervious surfaces and should they be treated similarly to impervious surfaces in some areas?

Key Speakers:

- Interconnections between pervious and impervious areas in urban watersheds - Peter Claggett, USGS.

- Limiting imperviousness to maintain ecological quality: Are threshold-based policies a good idea? - Glenn E. Moglen, VT.

- Hydrologic function in the urban landscape - Stu Schwartz, Center for Urban Environmental Research and Education at the UMBC.

Speaker Presentation Summaries:

Interconnections between pervious and impervious areas in urban watersheds - Peter Claggett, USG.S

Estimates of total impervious surface area in the Chesapeake Bay watershed have varied considerably over the past decade due to different data inputs informing such estimates. For the Phase 5.3.2 model, the CBP estimates of total impervious area increased ~57% over previous estimates by switching from sole reliance on Landsat-derived land cover data to inclusion of ancillary data on roads and housing (Claggett et al. 2013). These new estimates likely still underestimate the total amount of impervious surfaces in the watershed by 5%-20% compared to high-resolution impervious surface data. As the CBP collects more high-resolution local land use and land cover data and the region's population continues to grow, impervious surface area estimates will continue to increase. Therefore, it is important to consider the question of whether all impervious surfaces impact water quality equally.

One means of spatially differentiating the impacts of impervious surface is to assess their relative hydrologic connectivity to streams. Impervious surfaces connected to streams via stormwater conveyance systems or proximity may have disproportionate impacts on flow and water quality compared to impervious surfaces that are hydrologically disconnected. As impervious surfaces increase in a watershed, streams become more "flashy" with higher peak flows and lower low flows. Increased flows can further lead to channel incision and widening.

In the absence of data on storm sewers, spatial proximity, flow path distance, and/or residential densities can be used to differentiate connected from disconnected impervious area. Alternatively, published statistical relationships can be used to estimate directly connected impervious area from total impervious area. Whichever method is used to account for connectivity in the Phase 6 watershed model, the information will have to be incorporated into an urban runoff load adjustment factor within each watershed model segment.

Limiting imperviousness to maintain ecological quality: Are threshold-based policies a good idea? - Glenn E. Moglen, VT

There are ecological impacts from impervious surfaces in aggregate biotic indicators of impairment at high levels (>10%) of impervious surface. However, methods used to estimate impervious surfaces yield results that can vary by as much as an order of magnitude. Three methods for measuring impervious surfaces were compared using the National Land Cover Dataset (NLCD), inference from generalized land use from the Maryland Department of Planning using impervious surface land use coefficients (SCS 1986), and using road network data. The NLCD systematically under-predicted impervious area compared to land use data, with differences greatest at low levels of imperviousness.

Stream flow response to impervious surfaces is dependent on the location of impervious surfaces in a watershed. A model was presented that showed advantages to concentrating impervious surfaces in stream valleys and generally in downstream locations of the watershed if one's goal were to minimize overall imperviousness experienced by the aggregate drainage network. From a hydrologic perspective, impervious surfaces in stream valleys and floodplains have less impact on peak flood flows compared to impervious surfaces in headwater areas due to the relatively low gradients and large contributing areas of floodplains (i.e., they saturate first naturally during a storm event). However, it would be naïve to target new development in floodplains given the importance of these areas for sediment deposition, stream migration, denitrification, and wildlife corridors. In general, concentrating impervious surfaces in a watershed will localize the impacts and facilitate management and control of runoff.

Engineering BMPs designed to mitigate the impacts of impervious surfaces should be tailored to the location of impervious surfaces (e.g., promoting infiltration in headwaters and retention/detention in valleys). Caution should be exercised in the use of thresholds for impervious cover (e.g., 10%) because of uncertainty in data and methods used to measure impervious cover, and because the threshold concepts can give a false sense of security to planners or others trying to protect valued riparian resources.

Peculiarities of pervious: Hydrologic function in the urban landscape - Stu Schwartz, Center for Urban Environmental Research and Education at the UMBC

Urban development decouples form (i.e., land cover and topography) from hydrologic function (i.e., runoff). Pervious surfaces in urban areas do not reliably function as their hydrologic soil group (USDA Soil Survey) or runoff curve numbers (SCS 1986) might suggest. In Baltimore, Maryland, more than half of field sampled residential yards and most vacant lots are at least 10% compacted.

Standard land development practices involve topsoil removal and mass grading coupled with soil compaction (from use of heavy equipment – and by design [i.e., topsoil is valuable and is often sold]). These practices routinely increase bulk density and soil strength and remove organic soils, resulting in dramatically reduced infiltration and plant-available water in the constructed "pervious" landscape. Impacts can be mitigated through active soil decompaction and amendment practices that avoid compaction from heavy equipment and mass grading and maintenance or restoration of deep porous permeable, organic rich, biologically active soil profiles.

Measures of impervious surface connectivity must consider the limited hydrologic function resulting from disturbed compacted soils in the urban "pervious" landscape. Pervious land uses on disturbed compacted soils can quickly saturate, generating surface runoff similar to impervious surfaces. These highly disturbed pervious landscapes can manifest an urban variable source area hydrology, generating significant surface runoff that is not reliably predicted from land use or soil survey data alone.

Major Findings & Recommendations:

1. Impervious surfaces increase the proportion of stream flow related to surface runoff during storm events and thereby increase stream power, erosion, transport of sediment, and associated particulate P. N loads are statistically related to runoff volumes and thereby are also related to impervious surface area.

2. The meaning of hydrologic connectivity must be explicit and clear if it is to be used as a modifier of land use. For the Phase 6 model, hydrologic connectivity has meant the direct conveyance of runoff from the land to streams and infers a corresponding reduction in water residence time (i.e., with fewer opportunities for nutrient retention and transformation), increase in peak flows, and a decrease in baseflow.

   Hydrologic connectivity in this context is both a surface and subsurface phenomena. Flow over roads and rooftops and through open ditches and gutters are examples of surface flow, whereas subsurface flows refer to buried streams, stormwater pipes, infiltration and exfiltration associated with leaky sanitary sewer networks, and preferential subsurface flow through soil macropores.

   Researchers have also used the term to refer to connections between stream channels and floodplains. This infers that connectivity is positively associated with flood flow attenuation, increased sediment deposition and retention, and increased opportunities for nutrient retention and transformation. Both definitions are valid and reflect actual watershed processes, but they have opposite water quality implications.

3. Impervious surface connectivity varies over space due to *in situ* factors affecting surface runoff (e.g., stormwater conveyance systems, soil texture, depth, contributing area, and surface curvature) and subsurface flows (e.g., geology, fragipan, and sanitary sewer infrastructure acting as preferential flowpaths), and over time due to vegetation state (e.g., transpiration following leaf-out), temperature and wind affecting evapotranspiration, and precipitation frequency, duration, and intensity. From an overland flow perspective, impervious surfaces adjacent to streams are "connected" but these areas (floodplains) typically saturate first during a storm event under natural

conditions and therefore paving them may have a smaller incremental impact on peak flows compared to impervious surfaces on well-drained soils.

4. Pervious surfaces may function similarly to impervious surfaces in generating runoff due to removal of topsoil, compaction, grading, and other human interventions. This is particularly the case in large planned subdivisions.

5. Measures of impervious area for large regions are highly variable depending on the resolution and quality of imagery and/or planimetric data used in the analysis. Moderate resolution (30 m cells) Landsat imagery is poor at detecting narrow roads, sidewalks, driveways, small buildings, and structures under tree canopy. The degree of under-detection of impervious surfaces can be particularly high in areas such as rural watersheds with low aggregate levels of impervious surfaces.

6. The hydrologic connectivity of impervious surfaces is correlated to total impervious surface area. Hydrologic connectivity to streams could be estimated from overland flow path analysis, representing relative transit time after accounting for surface and soil storage that may effectively disconnect impervious surfaces within the contributing areas to those storage zones. Surrogate measures of connectivity include a fraction of total impervious area derived from the literature (e.g., 60%), housing density thresholds (e.g., high density = connected, low density = disconnected), or spatial proximity to streams.

FINDINGS: Impervious surfaces, compacted pervious surfaces, and stormwater infrastructure alter the timing, location, and magnitude of runoff in a watershed. Nitrogen, phosphorus, and sediment loads are all impacted by changes in the level and nature of runoff. The level and nature of runoff alteration, however, is also impacted by physical watershed attributes (e.g., dimensions, geology, soils, slope, and vegetation) and resulting impacts to nutrients and sediments are further affected by biogeochemical processes occurring in the soils and stream by historic land use practices (e.g., accumulation of legacy sediment in the floodplain).

Employing an impervious surface area threshold to spatially differentiate the impacts of impervious surfaces on nutrients and sediment is problematic because estimates of impervious surface area are highly variable depending on data resolution, type, and quality. Therefore, the CBP partners should consider developing a continuous modifier of nutrient and sediment loads by small catchment that considers the percent impervious surface and likely compacted pervious area within the drainage area for each catchment.

RECOMMENDATIONS: While there are some land uses that should be expected to experience a high degree of presumed disconnection (e.g., rural highways, large lot developments, open section roads, etc.), each individual disconnection will be subject to a unique hydrologic soil group, infiltration rate, slope, sheet flow path length, and density of vegetative cover. Consequently, it may be impossible to assign a universal load to individual disconnected areas and a site-based engineering survey and/or calibrated hydrologic model may be needed to compute the actual effect of each individual disconnection.

In urban areas, subsurface flows can be significant and warrant further research. Given the complexity and variability of connectivity and considering current research on the topic, there appears be insufficient scientific evidence to make a generalization about the effects of "connected" impervious surface area on nutrients and sediment independent of a measure of total impervious surface area.

Speakers at the workshop also noted that it will be extremely difficult to accurately map the spatial extent of disconnected impervious cover at the scale of the Bay watershed, considering available spatial data and mapping capabilities. Parameterizing the effects of urban land uses by small catchment would also facilitate a more explicit consideration of changes in nutrient and sediment processes from headwaters through higher order streams and provide a framework for disaggregating urban stream corridors.

Section 4: Should there be a new land use to represent the urban stream corridor?

Background:

The goal of this session was to determine the feasibility of breaking the stream corridor out as a separate land use, and following discussion, there was an overall impression of agreement of the potential benefit of separating the stream corridor into a unique land use. There is a need for discussion on the extent of this effort and how this action would impact upland BMPs.

The importance of stream components (banks, riparian zone, and floodplain) varies with stream size, with floodplains potentially providing the most benefit in larger stream systems and riparian areas having differing functions at different scales.

Key Questions:

1. How do stream bank erosion, sewage transmission losses, and other discharges influence nutrient and sediment loading and processing within the urban stream corridor?

2. How does the urban stream corridor itself act to process nutrients and sediments delivered from upland and adjacent land?

3. How should we define and map the urban stream corridor as a unique entity for processing nutrients and sediments?

Key Speakers:

- Sources of sediment and nutrients from the riparian corridor - Lisa Fraley-McNeal, CWP, CBP Stream and Sediment Coordinator

- Stream bank erosion as a sediment source from the Piedmont region - Mitchell Donovan, UMBC

- Sediment and nutrient transport and storage along the stream corridor - Greg Noe, US GS
- Assessment and restoration of riparian processes in urban watersheds - Peter Groffman, Cary Institute and BES.
- N along the urban watershed continuum: Riparian zones to rivers - Sujay Kaushal, University of Maryland
- Potential GIS data for mapping floodplain area in Chesapeake Bay watershed - Daniel Jones, USGS

Speaker Presentation Summaries:

Sources of sediment and nutrients from the riparian corridor - Lisa Fraley-McNeal, CWP, CBP Stream and Sediment Coordinator

Fraley-McNeal summarized the findings from a 2014 literature review (CWP 2014) on the significance of stream channel erosion in the sediment budgets of 38 urban watersheds in PA, MD, and VA. . While there were differences in the geomorphic context and study methods among the monitoring and modeling studies, several key themes emerged. First, the bulk of the research indicated that between 20% and 60% of measured watershed sediment budget was due to stream bed/bank/floodplain erosion in small urban headwater streams. Second, the analysis appeared to reinforce the general relationship between watershed sediment yield and increasing watershed impervious cover developed by Langland and Cronin (2003), although further adjustments may be supported with analysis of monitoring data. Overall, the presentation concluded that there was substantial concurrence between modeling and monitoring data when it comes to sediment contributions from small streams and with some specific refinements, it may be possible to identify specific watershed factors to improve predictive capability.

Stream bank erosion as a sediment source from the Piedmont region - Mitchell Donovan, UMBC

Donovan presented results from an extensive research study to evaluate stream bank erosion as a sediment source in watersheds in the Maryland Piedmont. The long term study focused on 25 streams in Baltimore County, MD, 14 influenced by mill dams and 11 that were not. The study design involved comparing historic topographic maps from the 1960's with Light Detection and Ranging (LIDAR) data taken in 2005 to develop estimates of stream erosion over a 50 year interval. While erosion from streams influenced by mill dams was higher, the effect was generally confined to the immediate downstream reach.

For all streams, erosion rates were greatest along larger streams but these larger streams produced less total sediment load due to their shorter total length in the watershed as a whole. On average, stream channels moved 3% of their channel width per year during the study period, which may allow for prediction of bank erosion rates based on the relative size of each channel in the overall stream network. Donovan noted that 6% to 80% of stream erosion is contributed by legacy sediments, with greater contributions in the larger streams. On a watershed basis, estimated stream sediment yields fell between 100 and 150 $Mg/km^2/yr$, approximating 45% of the total sediment yield for the watershed draining to Loch Raven Reservoir.

Sediment and nutrient transport and storage along the stream corridor - Greg Noe, USGS

Noe described some of the key findings from a long term study in Difficult Run, located in Northern Virginia, which has experienced rapid urbanization over the past five decades. The comprehensive study involved measurements of changes in hydrology, stream bank erosion rates, legacy sediments, and floodplain trapping/retention along a longitudinal gradient from headwater to higher order streams.

Noe analyzed historical storm USGS gauging data and found progressive urbanization in the watershed had greatly increased the magnitude and frequency of peak flow events and reduced baseflows. The higher peak flows produced more stream power which created incising streams in the upper reaches. Increased stream down-cutting through legacy sediment was a major source of delivered sediment.

While most headwater reaches eroded sediment, there was significant sediment deposition in the wider floodplains of the lower reaches. Retention of sediments and nutrients deposited in the floodplain was considerable, creating a lag time of up to 100 to 1000 years for the materials to move further down the river network and reach the Bay. Noe made several management recommendations based on the ongoing research.

First, efforts to increase hydrologic connectivity between rivers and floodplains should be encouraged. Second, efforts to reduce bank erosion will be most effective near headwater streams. Third, floodplains should be managed to be as natural as possible, with minimal infrastructure, to allow flooding and associated deposition to occur (floodplains tend to be quite retentive of sediment and nutrient over time). Lastly, it may be possible to enhance N retention by managing floodplains to promote forest growth rather than open meadow/turf.

Assessment and restoration of riparian processes in urban watersheds - Peter Groffman, Cary Institute of Ecosystem Studies and BES

Groffman presented a summary of BES research conducted in Baltimore City and County that focused on N dynamics within the floodplains and riparian areas of urban watersheds. He noted that the "urban stream syndrome" results in drier soils and lower water tables in the urban riparian areas. These changes reduce anaerobic denitrification processes and are likely linked to higher groundwater nitrate levels in urban riparian zones compared to forested or rural streams.

Groffman also mentioned that many features in urban watersheds, such as aging detention ponds, oxbow wetlands, and some kinds of stream restoration projects can become denitrification "hotspots" if they can satisfy the need for linking carbon and N input sources with hydric soils and anoxic conditions. He concluded by presenting recent mapping research to assess riparian condition at the urban watershed scale, using SSURGO, NWI, and other layers, indicating that the use of these high resolution mapping tools can provide useful spatial data on active biogeochemistry in the urban landscape.

N along the urban watershed continuum: Riparian zones to rivers - Sujay Kaushal, University of Maryland

Land development replaces natural drainage networks with infrastructure networks (e.g., impervious surfaces, curbs, gutters, and storm drains). Hydrologic connectivity, as measured by surface and subsurface flow paths, can alter fluxes, sources, and transformation of N in watersheds. In addition, N sources shift due to weather conditions.

Impervious surfaces serve as conduits of N from atmospheric deposition during storm events and sanitary sewer infrastructure serves as a conduit of N during low flow events (e.g., droughts). Headwater stream burial decreases the connectivity between streams and floodplains and reduces opportunities for N uptake and transformation. In addition to impacting N loads, impervious surfaces also impact stream salinity, temperature, and alkalinity in ways that are deleterious to biotic communities.

Potential GIS data for mapping floodplain area in Chesapeake Bay watershed - Daniel Jones, Eastern Geographic Science Center, USGS

Jones summarized ongoing efforts by his group to develop more effective methods to map floodplains in the Chesapeake Bay, with a special emphasis on urban watersheds. He described the 'pros and cons' of each of the existing Bay-wide data layers (e.g., SSURGO, National Hydrologic Dataset [NHD], Federal Emergency Management Agency [FEMA], and NWI), along with LIDAR data at various resolutions. In initial testing, the best representation of the floodplain was obtained by using a mix of these methods, since each individual layers has their own inherent limitations and coverage issues, especially in urban watersheds.

USGS is currently testing these mapping methods to define floodplains in nine sub-watersheds in the Chesapeake Bay, with plans for an additional 45 in the coming years. The lessons learned from the pilot should be directly applicable to selecting the best floodplain mapping methods across the Chesapeake Bay.

Major Findings & Recommendations:

FINDINGS: The workshop focused on four criteria to determine whether it a stream corridor land use should be proposed for the Phase 6 watershed model.

The first criterion is whether the urban stream corridor is expected to have significantly different loads. Numerous speakers presented research that, based upon conceptual physical models, urban stream channel erosion is a major component of the urban sediment budget, delivering sediment and attached nutrients to the Bay. The magnitude of stream channel erosion in any given urban watershed is strongly influenced by local factors such as watershed impervious cover and the physical properties of the corridor.

The range of total sediment contribution from channel erosion in zero to third order streams varied between a balance of degradation and aggradation, or 0% and 80%, with most studies in the 20% to 60% range. Results from investigations of mill dams seem to show potentially high local contributions of legacy sediments, but no significant trend can be observed when evaluated at the larger watershed scale.

The importance of floodplains for medium to large streams for nutrient processing and sediment storage was highlighted. It was pointed out that the narrower floodplains in individual headwater streams have less influence on the transport and delivery of nutrients and sediments but still remain a major source given the total channel length they represent in any given watershed. In urban areas, nutrient processing in riparian areas tends to be limited due to poor connection of the floodplain to the stream as well as a lowered groundwater table due to stream incision. Nitrification can occur in dry riparian areas causing them to be a source of N rather than a sink, as is “normal” in non-urban streams.

A recent expert panel report (EDND EP 2014) also concluded that unique dry weather nutrient discharges occurring in the urban stream corridor were a significant source of the annual nutrient load. In addition, numerous speakers presented strong evidence of significant N dynamics within the urban stream corridor, either in the hyporheic zone, stream, floodplain, wetlands, or via groundwater migration.

The second criterion is whether the stream corridor can be adequately mapped. Several speakers provided evidence that this was possible if the floodplain was used to represent the stream corridor and several mapping tools were used in combination to define a representative corridor area. The initial consensus was that SSURGO data could be used to define the base floodplain, supplemented with National Wetland Inventory (NWI) data, and possibly additional terrain-based methods to get more local results. Some capability to exclude existing impervious cover within the floodplain may also be needed.

The third criterion relates to whether the pollutant dynamics of the urban stream corridor can be accurately simulated in the context of the CBWM. The consensus was that it could not be done in Phase 5.3.2, but could be used in Phase 6 in a number of different ways.

The last criterion involves whether the urban stream corridor would respond in a unique manner to urban BMPs, and the answer is clearly in the affirmative. Many current urban BMPs are spatially applied within or in close proximity to the urban stream corridor (e.g., riparian reforestation, stream buffers, palustrine wetland restoration, stream restoration, and the elimination of discovered nutrient discharges from grey infrastructure.

RECOMMENDATIONS: Considering the urban stream corridor as a separate land use would require distinguishing between floodplain and channel characteristics with respect to sediment and nutrient transport, processing, and ultimate yield. In addition, the spatial extent of the channel, riparian zone, and floodplain would need to be mapped.

Several tools and methods exist to map riparian area, floodplains, and stream bank erosion; however, work is still needed on these tools to extract pertinent information in order to inform the CBWM. Simplifications may be available to define this stream corridor.

The steering committee recommends that meetings be held in the near term to develop an operational way to allocate sediment and nutrient loads to the urban stream corridor and make corresponding reductions to target loads for impervious and pervious cover.

Section 5: What changes can be expected in future urban nutrient inputs?

Background:

There are many different urban inputs to urban land, and the magnitude of each input can change over time due to a host of factors, such as regulations, market forces, and climate. This session evaluated how five major urban nutrient inputs might change in the future, and how the changes might influence nutrient loading rates, compared to the current baseline. The five nutrient sources include atmospheric deposition, lawn fertilizer applications, construction site fertilizer application, organic matter loadings, and nutrient discharges from grey infrastructure.

Key Questions:

1. Will more stringent air pollution controls reduce the amount of nutrients deposited from the atmosphere over urban land in the future, and if so, how might this reduce nutrient loading from pervious and impervious cover?

2. How will nutrient inputs from lawn fertilizer change in response to new state laws reducing phosphorus content, as well as the industry phase out of phosphorus in fertilizer products?

3. What do we know about the runoff and pollutant generation from construction sites, as they proceed from initial land clearing to final stabilization?

4. How do the sediment and nutrient loads from construction sites respond to the use of traditional or enhanced erosion and sediment control practices?

5. Are the disturbed acres recorded from National Pollution Discharge Elimination System (NPDES) construction permits sufficient to quantify the acres of construction sites in the watershed?

6. How significant is the organic matter nutrient loading derived from tree canopy and/or pervious cover that land on impervious areas? How much of it is actually delivered to the storm drain system into the urban stream corridor?

7. How significant are the nutrient discharged from grey infrastructure to the total urban nutrient budget in the Chesapeake Bay watershed?

Input 1. Long term Bay-wide and regional declines in air deposition loads for N (and to a lesser extent P) over both pervious and impervious land are forecasted due to more stringent air pollution controls.

Key Speakers:

- Estimating loads and trends of the atmospheric N deposition in the Chesapeake watershed - Lewis Linker, EPA-CBPO.

- National atmospheric deposition program - Christopher Lehmann, University of Illinois at Urbana-Champaign.

This session focused on whether long term trends in wet and dry weather atmospheric deposition rates could change the availability for wash-off nutrients on pervious and impervious land.

Long term Bay-wide and regional declines in air deposition loads for N (and to a lesser extent P) over both pervious and impervious land are forecasted due to more stringent air pollution controls. The CBP has developed a strong technical approach to model the changes in nutrient air deposition in the Chesapeake Bay air-shed over time. Based on these tools, the CBP has shown a steady decline in N deposition over the last three decades, in response to more restrictive emission controls due to Clean Air Act (Fig. 6).

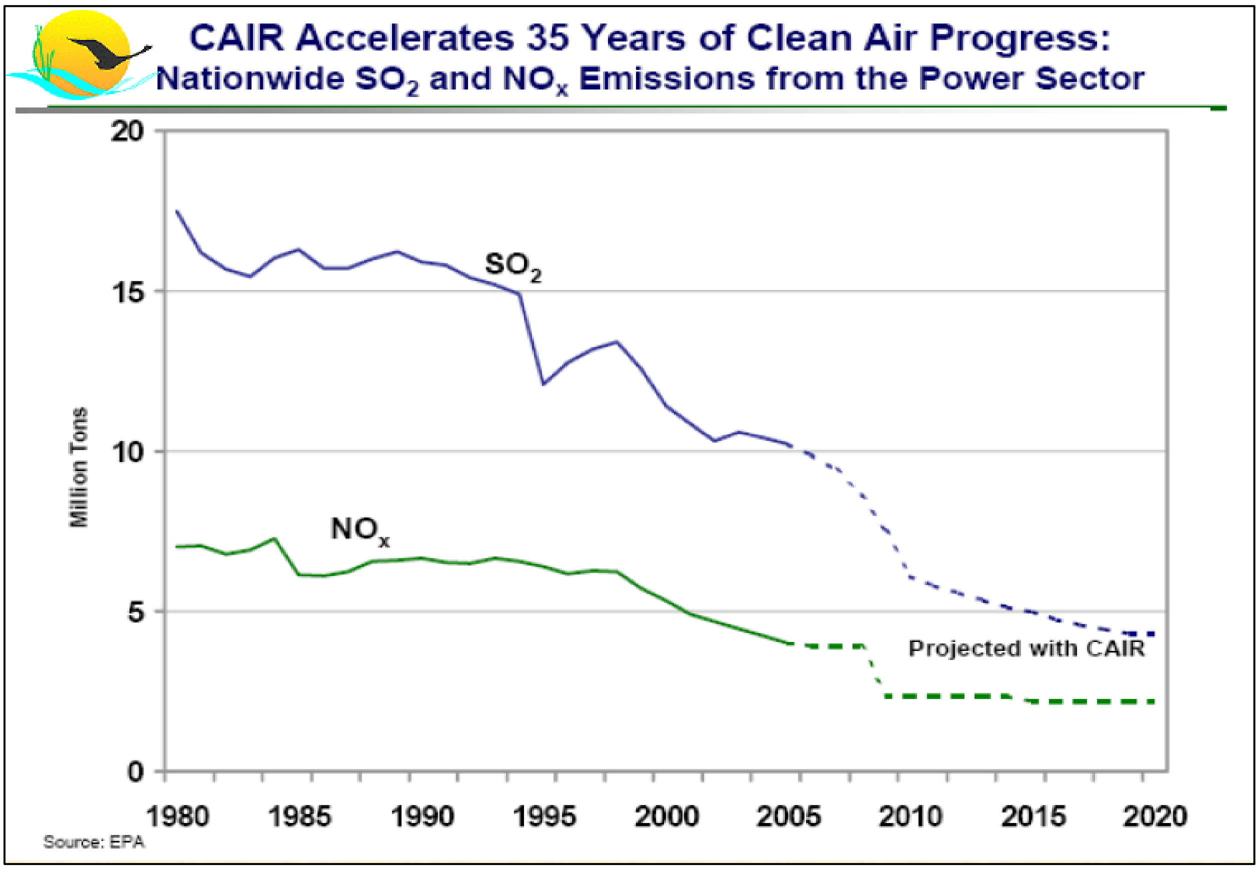

Figure 6. Past trends in N deposition in the Bay Watershed (source: U.S. EPA 2010b).

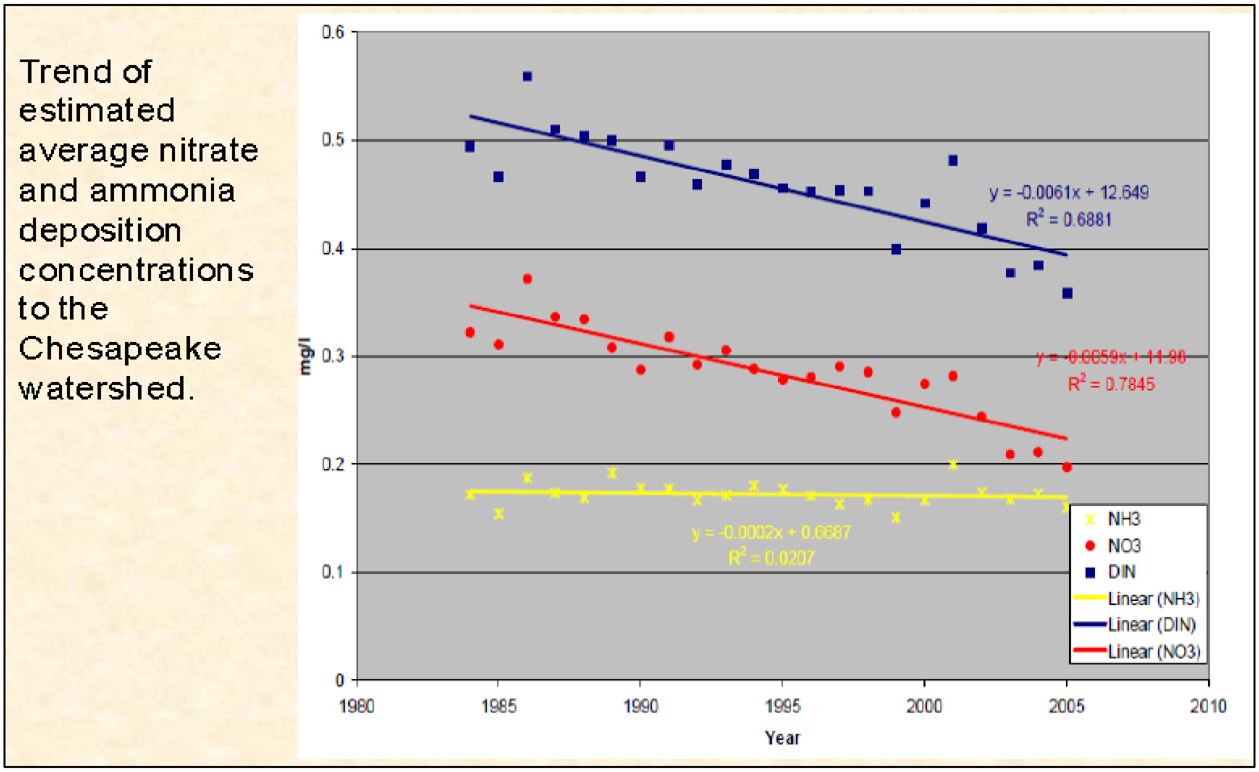

Figure 7. Projected future trends in N deposition in the Bay Watershed (source: Linker 2014).

By 2020, total annual N loads deposited over the Bay watershed are projected to decline to 66 million lbs/yr, which represents a 42% drop from 1990 levels (114 10^6 lbs/yr, Linker et al. 2013). Reductions are expected to level off in future years (Fig. 7). A key dilemma associated with this encouraging drop in N deposition is how will this sharp decline in nutrient inputs affect future N build up and wash-off from pervious and impervious lands (i.e., will the surface runoff loads decline in direct proportion to the reduced inputs, or in some other manner?).

Long term air deposition monitoring conducted at 24 National Atmospheric Deposition Program (NADP) stations in the Bay watershed generally confirms the modeling analysis, with consistent declines in nitrate deposition (although some local clusters of increased ammonia deposition are noted in some rural parts of the watershed). Data analysis shows statistically significant decreases in nitrate deposition and no statistically significant trends in precipitation over time.

It was noted that atmospheric deposition is not a fixed annual value but is episodic across seasons and perhaps this could be factored into the model (i.e., tuning to periods of maximum deposition throughout the year). It was further noted that many of the NADP stations in the watershed have historically avoided urban areas, but several new urban stations have recently been launched.

Input 2. Changes in N and P fertilization rates due to state-wide lawn fertilizer laws and the Bay-wide effect they have had on the nutrient content of fertilizer applied to pervious land.

Key Speakers:

- Summary of key findings on nutrient dynamics and export from lawns - Tom Schueler, CSN.
- Key expert panel recommendations on simulating lawns in the next model - Norm Goulet (NVRC) and Karl Berger (MWCOG).

In recent years, four states (MD, VA, DC, and NY) adopted legislation to sharply reduce the P content (and in some cases N content) of lawn maintenance fertilizer. In anticipation, the fertilizer industry has gradually been phasing out the use of P in most of its DIY home fertilizer formulations. According to the UNM expert panel, this should result in a 55% to 85% reduction in P inputs to fertilized pervious areas, and a much smaller decline in N inputs (Table 4 from UNM EP 2013).

Table 4. Industry reported change in P fertilizer sales in the Bay States, 2006 to 2010[1]

State[2]	2006	2010	Percent reduction
	Millions of Pounds	Millions of Pounds	
Pennsylvania	1.41	0.26	**82%**
Maryland	0.68	0.10	**85%**
Virginia	0.60	0.22	**63%**
Delaware	0.09	0.04	**55%**
West Virginia	0.07	0.02	**71%**
Total	**2.85**	**0.66**	**77%**

[1]Annual sales data reported by SMC (2011) for non-farm fertilizer sales by state. Scott's™ currently has a 60% market share and has committed to a full phase out of P in its fertilizer products by January 1, 2013.
[2]Note that the statistics on P sales are provided for an entire state and NOT the fraction of the state located within the Bay watershed.

The forecasted drop in fertilizer inputs to pervious land is encouraging, although the expert panel cautioned that there are many uncertainties in our understanding of non-farm fertilizer sales and the actual fertilization behaviors of both commercial applicators and homeowners. Therefore, the consensus was that improved urban fertilizer input statistics are critically needed to confirm whether the presumed nutrient reductions are real and sustained in the future.

Input 3. Lower target loads for sediment discharge from active construction sites and incorporation of higher fertilizer applications at construction sites.

Key Speakers:

- Key findings on sediment and nutrient pathways from ESC expert panel - Randy Greer, Delaware Department of Natural Resources and Environmental Control (DNREC).

- Data availability and quality for quantifying construction activities - Matt Johnston, University of Maryland-CBPO

Our best understanding of the nutrient and sediment dynamics at construction sites is contained within the recently approved Erosion and Sediment Control expert panel report (ESC EP 2014). The panel conducted a mass balance analysis to estimate sediment loads discharged from construction sites, using runoff coefficients and sediment EMCs discharged from those sites (Table 5).

Based on this analysis, the panel recommended that the sediment target load decrease from the current 24.4 t/ac/yr in Phase 5.3.2 of the CBWM to around 12 t/ac/yr in Phase 6. In reviewing the panel report, the Water Quality Goal Implementation Team (WQGIT) indicated that a final decision on which target load to use should ultimately be made by the Modeling Workgroup.

The second relevant finding from the expert panel is that the Phase 5.3.2 model does not reflect the considerable fertilizer inputs that are applied to construction sites to rapidly stabilize the exposed soils with grass and other vegetation. As shown in Table 6, recommended fertilization rates are extremely high at 115 lbs/ac/yr and 75 lbs/ac/yr of N and P, respectively. The current version of CBWM assumes no fertilizer inputs from construction sites.

Table 5. Comparative of target sediment loads for construction sites[1]

ESC Scenario	Worst case	Mid-point	Best case	Best estimate
Construction w/o ESC	22.3	8.6	5.1	12.0
Sites operating at level 1	2.5	1.8	1.1	1.8
Sites operating at level 2	1.6	1.0	0.7	1.1
Sites operating at level 3	1.05	0.57	0.31	0.65

[1]All units in t/ac/yr.
Source: ESC EP 2014

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Table 6. Typical fertilization rates at construction sites in Bay States

ESC stabilization recommendations	Formulation (N-P-K)	Application rate lbs/ac	N Rate N lbs/ac	TP rate TP lbs/ac
Temporary stabilization	10-10-10	500-600	50	27
Permanent stabilization	10-20-10	500-1000	65	48
Total fertilizer application	- -	**600 to 1500**	**115**	**75**

Suggested application rate in the absence of a soil test or UNM plan. May be replaced by mulching in the non-growing season.
Source: Adapted from ESC EP 2014.

Input 4. Organic Matter Loading

Key Speakers:

- Nutrient content of urban soils **-** Richard Pouyat and Ian Yesilonis, USFS
- Nutrient content and particle size distribution of street solids **-** Neely Law, CWP
- Magnitude and fate of leaf detritus in the urban landscape **-** Neely Law, CWP and Tom Schueler, CSN

One of the more intriguing, but unresolved, nutrient loading sources discussed at the workshop was the significance of the organic matter subsidy produced by fall leaf drop (and to a lesser degree, pollen and green fall during the growing season). Nowak (2014) provided data for Baltimore, MD to estimate an urban tree canopy biomass nutrient load estimated at 28.8 lbs/ac/yr and 2.95 lbs/ac/yr of N and P, respectively. If a fraction of this load washes off into the stream, leaf drop alone would be a considerable component of CBWM nutrient loadings rates. It should be noted that the understanding of the fate, transport, and processing of leaf litter in urban watersheds is limited, but to date this load has largely not been accounted for in urban nutrient mass balances.

The unresolved issue at this time is how much of the leaf drop moves through the urban landscape and is actually delivered to the urban stream corridor. Some proportion is removed by humans, some is trapped on pervious land, and some fraction reaches the street curbs, storm drain, and catch basin. In addition, the particle size and nutrient content of organic carbon changes over the seasons and in a downstream direction.

At this time, however, there is no consensus on how to define the significance of this loading source to the overall nutrient budget. The SC EP may try to address this issue in its forthcoming report but has also not come to consensus yet (SC EP 2014). Going forward, the steering committee recommends further research on the topic and also suggests that CBPO modelers examine both the organic matter load and the declining atmospheric load when simulating wash-off from impervious surfaces.

Input 5. Nutrient Discharges from Grey Infrastructure

This topic has been extensively covered in a recently released expert panel report (EDND EP 2014). The current version of the CBWM does not explicitly simulate nutrient discharges from grey infrastructure (e.g., illicit discharges to storm drain, sewer exfiltration, and sanitary sewer overflows).

The expert panel concluded that there was conclusive evidence that these discharges increase N and P levels in dry weather urban stream flow and may collectively account for as much as 20% to 40% of the annual nutrient load in urban watersheds, depending on the age and condition of its grey infrastructure (EDND EP 2014). The panel had less data to review re. wet weather discharges but estimated that these nutrient discharges could comprise 1% to 2% of the total urban wet weather load, particularly during intense or extreme storms.

Major Findings & Recommendations:

FINDINGS: Numerous speakers and expert panels provided extensive evidence that nutrient inputs to urban land will change in the future and these changes will need to be explicitly considered in the Phase 6 model. Five expected changes in urban nutrient inputs were discussed:

1. Future declines in N air deposition over pervious and impervious land;

2. Current and future declines due to Bay-wide drop in Phosphorus (P) content of lawn fertilizer;

3. Increased fertilizer application to construction sites;

4. Potential new nutrient inputs due to organic matter deposited from pervious lands; and

5. Potential new dry weather nutrient loads generated by nutrient discharges from grey infrastructure.

RECOMMENDATIONS: The consensus from the workshop was not to propose any specific refinements to the next phase of the CBWM given how difficult it is to simulate the processes that create nutrient discharges from these sources but did agree that the collective nutrient load created by the range of nutrient discharges is probably a substantial part of the load from pervious and impervious land and might be best simulated as a load produced in the urban stream corridor, rather than upland impervious or pervious urban land.

Section 6: Is there merit in subdividing pervious land to reflect fertilization status/wash-off risk?

Background:

This session relied heavily on discussions about the UNM expert panel report (UNM EP 2013). The CBWM currently simulates a unit fertilizer application rate for all pervious land that reflects the fact that approximately half of pervious land in the watershed is fertilized and the other half not. A recurrent question discussed at the workshop is whether it made sense to split pervious land into categories that would reflect either:

1. Fertilization status (fertilized/unfertilized);

2. Export risk status (high risk/low risk, as defined in UNM EP 2013); or

3. Some hybrid of the two?

Major Findings & Recommendations:

FINDINGS: There is some data that could be interpreted to indicate a higher nutrient export signal from pervious land than from other types of urban land use. For example, data through

2003 from the NSQD summarized by Schueler (see above) shows a slightly elevated median EMC for TP from residential land (although a slightly lower EMC for TN) that might be attributable to greater fertilizer use. However, the recent literature review and synthesis (Tetra Tech 2014b) does not show elevated EMCs for residential land uses (data for "turf" are based on too few samples to draw any conclusions) compared to other forms of urban land use.

The results from various studies reviewed by the UNM EP (2013) show that export of either TP or TN can increase significantly at very high levels of fertilization (e.g., in excess of University Extension recommended rates) or in situations of high risk but that export from lower-risk, lower-rate applications may not be significantly different than a no-fertilizer treatment.[1]

Moreover, in recent years, the dynamics of lawn fertilization have changed significantly as a result of both state fertilizer regulation and revised formulations from turfgrass fertilizer manufacturers, reducing or eliminating P in most products, and shifting to more slow-release forms of nitrogen.[2] Thus, runoff data from earlier years may no longer reflect current lawn fertilization practices, although, in the case of phosphorus, such data may still reflect the legacy of over-fertilization from past years. There was also a conversion of agricultural lands to urban lands which may be reflected in time series data.

The steering committee concluded that the risk of higher-than-background nutrient export exists primarily when turf is over-fertilized or when it is fertilized in high-risk ways such as spreading fertilizer on impervious surfaces or too close to waterways (Fig. 8). In theory, pervious urban land could be split between a no fertilization/low-risk fertilization category and an over-fertilization/high-risk category. However, the differences between these categories are highly variable and not well quantified and the CBP partners lack the ability to directly map where these categories occur.

Even separating fertilized from non-fertilized pervious land would require information on individual properties that does not currently exist and would be very difficult to obtain. The UNM EP did identify some potential indicators of fertilizer use, such as household income and lot size that could be used to estimate fertilizer use at a county- or river basin-segment scale. The Bay states are expected to generate more specific fertilizer application data as a result of improved tracking efforts just under way or soon to be initiated.

The 12 risk factors for high fertilizer export defined by the UNM EP (Table 7) present a similar mapping challenge, given the local variability in each of these factors. The steering committee concluded that the CBP partners lack the ability to map all these factors for counties or individual river basin segments across the Bay watershed, although some of the factors, (e.g., steep slopes) could be mapped with current information.
Going forward, it may be possible for individual local governments to map these factors on a more comprehensive basis. Such information could be used to target outreach campaigns for

[1] Some studies even found greater export of TP and sediment occurring from plots with no nitrogen fertilizer compared to those fertilized with nitrogen because of the increased infiltration capacity of the denser turf in the fertilized treatments.
[2] P loading rates to pervious land in Phase 5.3.2 of the watershed model were revised as a result of the UNM EP report; the impact of Maryland's N-based regulation was addressed through a BMP credit.

implementing UNM plans and may lead to a more precise delineation of nutrient export risk in future versions of the watershed model.

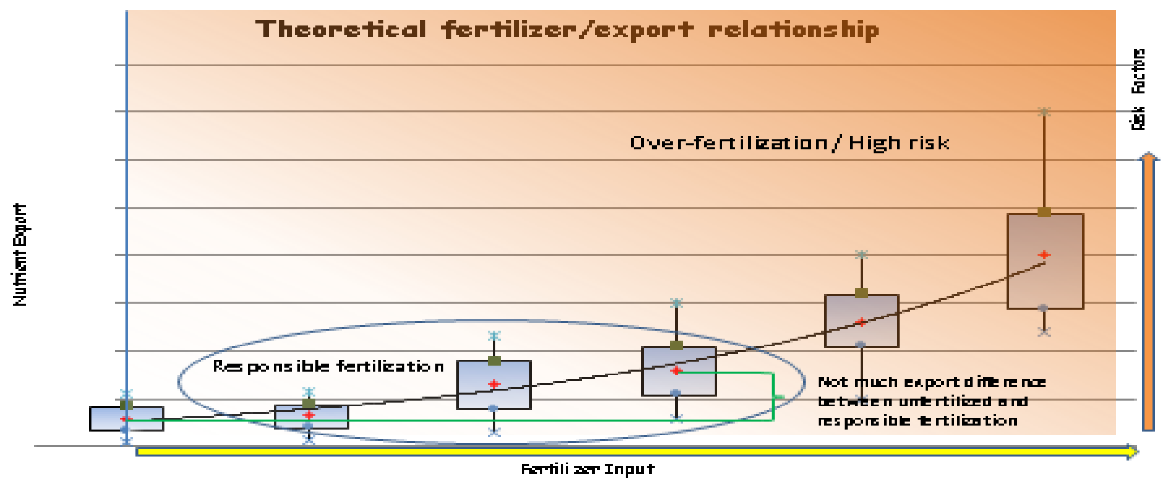

Figure 8. Theoretical fertilizer/export relationship (source: Berger 2014).

Table 7. High-Risk Factors for Nutrient Export from Lawns (CBP UNM EP 2013)

1. Owners are currently over-fertilizing beyond state or Extension recommendations
2. P-saturated soils as determined by a soil analysis
3. Newly established turf
4. Steep slopes (more than 15%)
5. Exposed soil (more than 5% for managed turf and 15% for unmanaged turf)
6. High water table (within three feet of surface)
7. Over-irrigated lawns
8. Soils that are shallow, compacted, or low water holding capacity
9. High use areas (e.g., athletic fields, golf courses)
10. Sandy soils (infiltration rate more than 2 in/hr)
11. Adjacent to stream, river, or Bay (within 300 ft)
12. Karst terrain

Following an UNM plan is one way of ensuring that lawn fertilization occurs as a responsible, low-risk practice. The modest credits available for urban nutrient management under the revisions outlined in the expert panel report reflect the likelihood that existing fertilization practice on many lawns already fits into the low-risk category. As the Bay states hopefully improve the ability to track lawn fertilizer sales data, and as the capability to map fertilization status improves in the future, the watershed model's credits for this BMP (its application rates for lawn fertilizer and the extent of the land uses to which fertilizer is applied) should be re-examined by a future expert panel.

It also should be noted that the workshop did not consider specialized subsets of the urban pervious land use categories, such as golf courses or roadway medians. The impact of fertilization practices on these land uses, and whether it varies significantly from the overall urban pervious category, remains unexamined.

RECOMMENDATIONS: The steering committee concluded that the current pervious land use category in the watershed model should not be disaggregated on the basis of fertilization status.

The clear workshop consensus was the largest improvement to pervious land in Phase 6 would be to acquire more accurate statistics on non-farm N and P fertilizer sales data. It was repeatedly noted during the workshop that the quality of existing non-farm fertilizer sales statistics is inadequate to define current or future N and P fertilizer inputs to pervious land.

Section 7: How should tree canopy and forest fragments be handled on pervious land?

Background:

Forest cover and tree canopy tend to be quite variable in urban areas in the Bay watershed. This session evaluated how forests influence stormwater runoff and nutrient loadings from urban land, and how this data might be factored into the next phase of the watershed model.

Key Questions:

1. How do urban trees/canopy treat stormwater as compared to urban turf? Compared to forest?
2. What is the water budget of urban tree canopy: How much is evaporated? Transpired? Infiltrated?
3. Are there discrete groupings of urban trees that make a substantial difference in water quality (e.g., conifer vs. deciduous or open-grown vs. part of a forest, etc.)?
4. How do urban trees process nutrients and sediments delivered from adjacent urban land?
5. What amount of nutrients is lost and to what degree is deciduous leaf litter an issue?

Key Speakers:

- Effect of woody vegetation and soils on urban hydrology - Dave Nowak, USFS
- Proposed modeling of stormwater organic matter fluxes and dynamics - Ken Belt, UMBC
- Impact of canopy cover and impervious surfaces on urban streams - Susan Day, VT

- Chesapeake water quality and urban trees: Perspective and needs - Sally Claggett, USFS.

Speaker Presentations Summaries:

Effect of woody vegetation on urban hydrology/proposed modeling of stormwater organic matter fluxes - Dave Nowak, USFS and Ken Belt, USFS

Nowak was unable to attend the workshop so Belt presented information on the i-Tree Hydro model which quantifies the joint effect of impervious and tree cover on urban hydrology and water quality. The model was calibrated against stream flow data for five urban watersheds in the mid-Atlantic and Northeast. The modeling results suggest that the tree canopy reduces stormwater volumes, particularly as percent impervious cover increases in an urban watershed. Based on these reductions in urban flow, the i-Tree model also simulates a modest nutrient reduction for urban watersheds based on EMC data. The current version of the model, however, does not explicitly account for any nutrient loading caused by leaf drop or green fall.

Belt also discussed the dynamics of organic matter from trees and other vegetation in urban watersheds. Organic matter loading to streams is greatly subsidized via gutter transport from across the watershed continuum (as leaf fall, animal waste, lawn clippings, sewage, etc.). It is an important food source and habitat for biota and affects many biogeochemical reactions. The various forms of organic matter (course and fine particulate, dissolved) can influence water quality by increasing N and P loads, driving microbial processes (e.g., denitrification, biochemical oxygen demand [BOD] loads, binding to heavy metals, etc.). It is a key driver of biological processes, both in the terrestrial and aquatic realms. Schueler and Law also presented a review of the current science on the influence of organic matter loads from pervious areas on stream nutrient loads based on the deliberations of the street sweeping expert panel.

Trees and soils: How much do they alter urban hydrology? - Susan Day, VT

Day provided a more micro-scale presentation on her experiments with how site factors and forestry practices affect the hydrologic performance of individual trees or tree clusters. It was noted that underlying soil quality affects the size, growth rate, and survival rate of the tree canopy. Day also presented evidence that the surface cover and grade around individual trees can influence runoff infiltration around trees. Subsurface transmission/storage of runoff is then influenced by tree root distribution, soil depth, and soil characteristics. Day noted that unpaved soil surface area was a key variable in ultimate tree canopy, but other site variables were also important. Perhaps most importantly, the amount of perviousness of a treed site is strongly affected by site-level management.

Chesapeake water quality and urban trees: Perspectives and needs - Sally Claggett, USFS Chesapeake Liaison

Claggett provided a holistic vision of the potential nutrient and sediment benefits attributable to trees within the urban environment. In particular, interception, ET, and soil condition are the driving factors for benefits. Looking at a cross-section of literature, urban tree evapotranspiration specifically accounts for a wide range (15%-60%) of runoff reduction.

Claggett also presented on the direction of the Tree Canopy Expert Panel (TC EP) that is reviewing the credit given in the CBWM to this practice. Of the many factors considered by the panel (e.g., do certain species, or spacing patterns, provide distinct benefits to runoff reduction?), the extent of tree canopy in comparison to impervious surface and available soil is most significant.

Major Findings & Recommendations:

FINDINGS: The Phase 5.3.2 CBWM does not distinguish tree canopy in developed areas (often referred to as urban tree canopy) from other pervious areas. This is despite the fact that tools and data are available to accurately map tree canopy at the county scale and often at a finer resolution given the abundance of local data. The purpose of this section of the workshop was to further the discussion of whether tree canopy has a unique pollutant loading and what that might be. During an informal vote at the end of the workshop, most participants thought that tree canopy should be a unique land use layer.

When a jurisdiction reports the expansion of tree canopy, credit is given in the model as a land use conversion (from pervious urban to forest). An expert panel is being formed to review this credit and their work will help inform modelers how much loading a tree canopy layer would receive.

How is tree canopy distinct from other pervious land uses?

The urban tree canopy consists of individual trees and forest remnants that occur on developed land. Forests remnants are generally less than an acre; if larger, they act more like true forests and can be mapped and provided credits. Tree canopy is known to reduce stormwater through canopy interception of precipitation, increased evapotranspiration (ET) and infiltration, and reduced nutrient export due to enhanced soil biological processes. The extent of these stormwater benefits is based on leaf area index or biomass so larger and denser canopy provides more benefits. Ample research was presented to distinguish the hydrologic functions that tree canopy (and everything below) provides vs. other pervious land uses.

How much does urban tree canopy reduce runoff?

The extent to which trees reduce stormwater volume is key to determining how tree canopy land use would be uniquely loaded for nutrient and sediment since few studies are available that directly address nutrient and sediment fluxes. Most water quality information is aggregate in nature and incorporates the effects of multiple land uses on EMC, so contributions from forests at this scale may be difficult to assign.

Research was presented on applications of the i-Tree Hydro model which estimates the joint effect of impervious and forest cover on urban hydrology and water quality, allowing the urban forest to be assessed separately from other urban sources. The i-Tree Hydro model was calibrated and run in five urban watersheds in the mid-Atlantic and Northeast, including Rock Creek, in Washington, DC, and Gwynn Falls, Baltimore, MD. The modeling results suggest that forest canopy reduces runoff volumes, particularly as percent impervious tree cover increases.

The i-Tree Hydro model also predicts a modest nutrient reduction for urban watersheds with high canopy coverage. Continued research should incrementally improve these algorithms to account for leaf detritus in storm systems. However, in its present form, i-Tree Hydro can be used to recommend a tentative loading rate for a tree canopy land use.

Several researchers evaluated the water balance of urban trees and found significant runoff reduction attributable to interception and particularly to ET. In general, the rate of forest ET tends to exceed that of grass as demonstrated at the Coweeta Experimental Forest (Burt and Swank 1992). With higher leaf biomass and deeper roots to access more water, trees use sunlight energy for transpiration. In general, higher biomass, abundant water, and warmer climates will result in increased ET values.

Some data were presented indicating that organic matter from trees in urban areas can wash into storm conveyance systems and be discharged to streams, adding a potentially significant source of nutrients. However, this characterization ignores the benefits that organic material provides in natural systems and its contribution to instream processing of nutrients. This issue was previously discussed in Section 5 (organic matter loading). There is an absence of published literature on the topic of leaves in storm/road systems so it continues to be an area in need of research.

What is the role of soil under the tree canopy?

The volume and quality of soil in which an urban tree grows affects its size and growth rate and the overall effectiveness of the tree canopy. Susan Day (VT) presented evidence that the surface cover and grade around individual trees can influence runoff infiltration around trees. Once infiltrated, subsurface flow is influenced by tree root distribution, soil depth, aeration, and other soil characteristics. Day noted that soil surface area was a key variable in ultimate tree canopy, but other site variables were also important. This is supported by a program in Minnesota that developed a stormwater credit for ET that is tied to canopy size. The credit is based on the anticipated mature size of the canopy if a tree is planted with sufficient soil (2 ft^3 soil per 1 ft^2 canopy is specified).

It is interesting to note that much of a city's tree canopy may not have been planted. For instance, one study showed this to be the case for 2/3 of the trees in Baltimore (Nowak 2014). These areas are not likely to have the same degree of disturbed, hard pan soils common to some urban landscapes. Enhanced biophysical processes in treed urban soil can contribute to stormwater reduction and denitrification in the following ways:

- More organic matter/surface roughness to slow flow;
- Macropores from large roots;
- Rich organic carbon needed for denitrification;
- Loose soil for more infiltration; and

- Fungi and microbes (contribute to ET and denitrification).

RECOMMENDATION: The general workshop consensus was that urban tree canopy should be considered as either (a) a unique category of pervious land, (b) a pervious land use overlay, or (c) treated as an urban BMP, depending on the science available. More work is needed from the FWG (Forestry Work Group) and LUWG in the coming months to make a consensus recommendation. An expert panel is also being formed to evaluate urban tree canopy as an urban BMP.

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Appendix A: Workshop Agenda

Scientific and Technical Advisory Committee
April 22-23, 2014
Workshop Agenda
Location: Sheraton Annapolis Hotel
173 Jennifer Road – Annapolis, MD 21401
Workshop Webpage: http://www.chesapeake.org/stac/workshop.php?activity_id=230

The Peculiarities of Perviousness:
A workshop to define, measure, and model the nutrient dynamics
from the mosaic of land cover known as pervious land

Workshop Objective: The objective of this workshop is to characterize the key source areas and pervious cover types that generate nutrients and sediments, and/or reduce runoff in the urban landscape and determine whether it is feasible to utilize them in Phase 6 of the Chesapeake Bay Watershed Model (CBWM), by answering the following questions:

5. Does the source or cover type depart in a meaningful way from the average nutrient loading for generic pervious land?

6. If so, are their existing or future mapping tools that can accurately measure the source or cover type at the scale of a county and the entire Bay watershed?

7. If so, can the pollutant dynamics of the source or cover type be accurately simulated in the context of existing or future versions of the CBWM?

8. If so, would the source or cover type respond in a unique manner to the application of a new or existing urban BMP type?

Based on the answers to the preceding questions, the outcome of the workshop would be to analyze current research and recommend the best process to create a scientifically sound pervious land sub-classification system for the purposes of simulating and managing nutrient loads in the Bay watershed.

AGENDA AT A GLANCE		
Day One: April 22, 2014		
9:00 to 10:00	T-1: Setting the Stage	
10:00 to 12:00	T-2: Review of Urban Wet and Dry Weather Monitoring	
1:00 to 3:00	T-3: Changes in Urban Fertilizer and Atmospheric Inputs	T-4: Nutrient Enrichment of Sediments in Urban Landscape
3:15 to 4:15	Day 1 Synthesis	
Day Two: April 23, 2014		
9:00 to 11:45	T-5: Urban Stream Corridor as a Land Use	T-6: Pervious/Impervious Connections
1:00 to 3:00	T-7: Effect of Tree Canopy on Pervious/Impervious Cover	
3:15 to 4:45	T-8: Synthesis Session/Next Steps	

DETAILED AGENDA
DAY 1

Webinar Website:
https://chesapeakeresearch.webex.com/chesapeakeresearch/j.php?MTID=m9a5af6baefe64cda31728cb10f4d04e5
Password: pervious
Toll-Free Number: 1-877-668-4493
Access Code: 730-750-434

Track 1: Setting the Stage
Track Organizer: Tom Schueler, CSN
Track Recorder: Jeremy Hanson, CRC
Track Length: 1 hour

Objectives and Products to be Developed from the Workshop: Speaker: David Sample, VT (10 minutes)
http://www.chesapeake.org/stac/presentations/230_Track%201%20Sample.pdf

The CBWM and Pervious Land: How does the current CBWM simulate pervious and impervious land? What are the current categories and how do we differentiate the loading? Speaker: Gary Shenk, EPA-CBPO (20 minutes)
http://www.chesapeake.org/stac/presentations/230_Track%201%20Shenk.pdf

Land Use Data for Watershed Modeling: Why is it important to improve the land use data informing the CBP models? What are the criteria for adding new land uses to the CBP models? How do the CBP Partners propose to improve the land use data? Speaker: Karl Berger, Co-Chair LUWG/MWCOG (15 minutes)
http://www.chesapeake.org/stac/presentations/230_Track%201%20Berger%20Claggett.pdf

Proposed Phase 6 Land Uses: What developed land uses are proposed for use in the Phase 6 model? How will those land uses be mapped and parameterized? Speaker: Peter Claggett, USGS-CBPO (15 minutes)
(See above link)

Track 2: Review of Dry and Wet Weather Urban Water Quality Monitoring Data
Track Organizers: David Sample, VT and Karl Berger, MWCOG
Track Recorder: Emma Giese, CRC
Track Length: 2 hours

Urban Stormwater and Baseflow: What have we learned about pollutant concentrations from mixed urban land over the past three decades, and how does that knowledge inform how we manage pervious and impervious land?

Speakers:

1. What We Have Learned About Sediment and Nutrient Dynamics From Urban Source Area Sampling – Dr. Shirley Clark, PSU-Harrisburg
http://www.chesapeake.org/stac/presentations/230_Track%202%20Clark.pdf
2. What We Have Learned About Sediment and Nutrient Dynamics From Urban Stormwater Outfall Monitoring - Tom Schueler, CSN

http://www.chesapeake.org/stac/presentations/230_Track%202%20Schueler.pdf

3. Sediment and Nutrient Concentrations and Loads in Small Urban Streams in Fairfax County, Virginia - John Jastram, USGS
http://www.chesapeake.org/stac/presentations/230_Track%202%20Jastram.pdf
4. Urban Nutrient Stream Data as a Function of Land Cover/Land Use at Various Spatial and Temporal Scales - Claire Welty, UMBC and Baltimore Ecosystem Study LTER
http://www.chesapeake.org/stac/presentations/230_Track%202%20Welty%20v%202.pdf

Track 3: The Impact of Changes in Fertilizer and Atmospheric Deposition Inputs on Urban Lands

Track Organizers: Tom Schueler, CSN and Norm Goulet, NOVA Regional Commission
Track Recorder: Cameron Bell, VT
Track Length: 2 hours

How many types of turf cover should be simulated? Should turf cover be sub-divided into different types based on nutrient risk, fertilizer application rate or other factors? If so, can these factors be measured at the local or Bay watershed scale?

Speakers (40 minutes):

- Summary of key findings on nutrient dynamics and export from lawns - Tom Schueler, CSN
http://www.chesapeake.org/stac/presentations/230_Track%203%20Schueler.pdf
- Key expert panel recommendations on simulating lawns in the next model - Norm Goulet, NOVA Regional Commission and Karl Berger, MWCOG
http://www.chesapeake.org/stac/presentations/230_Track%203%20Berger.pdf
- Prospects for estimating fertilizer inputs – Karl Berger, MWCOG
(See above link)

*Construction sites as an urban source area***:** What do we really know about runoff and pollutant generation from the many different stages associated with construction from land clearing to final stabilization? How are sediment and nutrient loads influenced by the use of traditional or enhanced erosion and sediment control practices? Are the disturbed acreages recorded on NDPES permits sufficient for quantifying "construction" acres in the Phase 6 model?

Speakers: (30 minutes)

- Key findings on sediment and nutrient pathways from ESC expert panel - Randy Greer, DEDNREC
- Data availability and quality for quantifying construction activities - Matt Johnston, UMD-CBPO
http://www.chesapeake.org/stac/presentations/230_Track%203%20Greer%20Johnston.pdf

Past and Future Trends in Air Deposition of Nutrient Inputs for Impervious and Pervious Land: How will trends in wet and dry weather atmospheric deposition rates change the availability for wash-off of nutrient inputs on pervious and impervious land?

Speakers: (50 minutes)

- Estimating Loads and Trends of Atmospheric Nitrogen Deposition in the Chesapeake Watershed and Tidal Waters - Lewis Linker, EPA-CBPO
http://www.chesapeake.org/stac/presentations/230_Track%203%20Linker.pdf
- National Atmospheric Deposition Program - Christopher Lehmann, University of Illinois at Urbana-Champaign

http://www.chesapeake.org/stac/presentations/230_Track%203%20Lehmann.pdf

Track 4: Urban Nutrient Enrichment in the Urban Landscape: Is it a Predictive Tool for Loading or Urban BMPs?

Track Organizer: Norm Goulet, NOVA Regional Commission and Cecilia Lane, CSN
Track Recorder: Matt Ellis, CRC
Track Length: 2 hours

Nutrient Enrichment in the Urban Landscape: Can different levels of nutrient enrichment in urban soils, street solids, BMP sediments, bank sediments, and vegetative detritus be used to define or predict nutrient loading in the urban landscape? Or help predict the impact of certain BMPs?

Speakers (100 minutes):

- Nutrient content of urban soils- Richard Pouyat and Ian Yesilonis, USFS
- Nutrient content and particle size distribution of street solids - Neely Law, CWP http://www.chesapeake.org/stac/presentations/230_Track%204%20Law.pdf
- Magnitude and fate of leaf detritus in the urban landscape - Neely Law, CWP and Tom Schueler, CSN http://www.chesapeake.org/stac/presentations/230_Track%204%20Law-Schueler%20Detrius.pdf
- Nutrient content of stormwater pond sediments – Tom Schueler, CSN http://www.chesapeake.org/stac/presentations/230_Track%204%20Schueler.pdf
- Nutrient content of streambank sediments - Bill Stack, CWP http://www.chesapeake.org/stac/presentations/230_Track%204%20Stack.pdf

Facilitated Discussion (20 minutes)

Break (15 minutes)
Joint Discussion - Day 1 Synthesis (60 minutes)

DAY TWO AGENDA

Webinar Website:
https://chesapeakeresearch.webex.com/chesapeakeresearch/j.php?MTID=m9374fb2004f30c16221c059c8a96e3ad
Password: pervious
Toll-Free Number: 1-877-668-4493
Access Code: 731-546-557

Track 5: The Urban Stream Corridor as its Own Land Cover Type

Track Organizer: Bill Stack, CWP, and other CWP Staff
Track Recorder: Reid Christianson, CWP
Track Length: 165 minutes

How does stream bank erosion, sewage transmission losses and other discharges influence nutrient and sediment loading and processing within the stream corridor? How does the stream corridor itself act to process nutrients and sediments delivered from upland and adjacent urban land? How should we define and map the stream corridor as unique entity for processing nutrients and sediments?

Introduction: Why the urban stream corridor should be a separate land cover type. Description of how the model represents streams and how riparian systems fit the criteria for being considered a separate land cover and what the definition of the stream corridor should include (e.g., ditches, storm drains ephemeral streams) - Bill Stack, CWP (15 minutes)
http://www.chesapeake.org/stac/presentations/230_Track%205%20Stack.pdf

Sources, sinks, and transport of sediment and nutrients in the stream corridor: This includes a comparison of nested in-stream vs. upland monitoring studies where loadings originating from streams can be categorized as a separate source of contaminants from the watershed including stream bank erosion, water and sanitary infrastructure and gross stormwater solids from the riparian corridor. This also includes a description of stream sediment fingerprinting studies conducted by the USGS that can apportion loadings by land cover as well as a description of sediment and nutrient sinks and transport phenomena within the stream corridor.

Speakers:

- Sources of sediment and nutrients from the riparian corridor - Lisa Fraley-McNeal, CWP (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%205%20Fraley-McNeal.pdf
- Stream bank erosion as a sediment source from the Piedmont region– Mitchell Donovan, UMBC (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%205%20Donovan.pdf
- Sediment and nutrient transport and storage along the stream corridor - Greg Noe, USGS (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%205%20Noe.pdf

Processing of nutrient inputs in the stream corridor: This talk describes the role that the stream corridor plays in transforming and processing nutrients from in-stream and upland sources including urban pervious and impervious loadings as well as "point sources" from illicit discharges.

Speaker:

- Assessment and restoration of riparian processes in urban watersheds - Peter Groffman, BES (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%205%20Groffman.pdf

Floodplain mapping potential in the Chesapeake Bay Watershed: This talk describes possible scenarios for using GIS to map the stream corridor focusing on a case study of Difficult Run in Fairfax, County Virginia. One of the requirements for consideration of the stream corridor as a land use is the ability to accurately map the source or cover type at the scale of a county and the entire Bay watershed.

Speaker:

- Potential GIS data for mapping floodplain area in Chesapeake Bay watershed – Daniel Jones, USGS (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%205%20Jones.pdf

Track 6: Interconnections Between Pervious and Impervious Areas in Urban Watersheds

Track Organizer: Peter Claggett, USGS
Track Recorder: Matt Ellis, CRC
Track Length: 165 minutes

Pervious and Impervious Interconnections: Are different runoff volumes or nutrient loads produced by impervious areas that are connected to pervious areas as compared to those that are directly connected to stream corridors via proximity or storm drains? How pervious are pervious surfaces?

Introduction: What is meant by impervious/pervious surface connectivity? Why is it being considered for inclusion in the Phase 6 model? How has it been measured? How might it be treated in the Phase 6 model? – Peter Claggett, USGS (30 min)
http://www.chesapeake.org/stac/presentations/230_Track%206%20Claggett.pdf

Speakers (90 minutes):

- Limiting imperviousness to maintain ecological quality: Are threshold-based policies a good idea? - Glenn Moglen, Virginia Tech (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%206%20Moglen.pdf
- Nitrogen Along the Watershed Continuum: Riparian Zones to Rivers- Sujay Kaushal, University of Maryland (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%206%20Kaushal.pdf
- Hydrologic Function of the Pervious Landscape - Stuart Schwartz, University of Maryland, Baltimore County (30 minutes)
  http://www.chesapeake.org/stac/presentations/230_Track%206%20Schwartz.pdf

Facilitated Discussion (45 minutes)

Track 7: The Effect of Tree Canopy on Urban Land

Track Organizers: Sally Claggett, USFS and David Sample, VT
Track Recorder: Jeremy Hanson, CRC
Track Length: 2 hours

How do urban trees/canopy treat stormwater as compared to urban turf? Compared to forest? What is the water budget of urban tree canopy—how much is evaporated? Transpired? Infiltrated? Are there discrete groupings of urban trees that make a substantial difference in water quality (e.g., conifer vs. deciduous or open-grown vs. part of a forest, etc.)? How do urban trees process nutrients and sediments delivered from adjacent urban land? What amount of nutrients is lost and to what degree is deciduous leaf litter an issue?

Speakers: (30 minutes each including Q&A)

- Hydrologic modeling of tree cover effects and proposed modeling of stormwater organic matter fluxes and dynamics - Ken Belt, USFS and Dave Nowak, USFS
  http://www.chesapeake.org/stac/presentations/230_Track%207%20Nowak.pdf
- Impact of canopy cover and impervious surfaces on urban streams – Susan Day, VT
  http://www.chesapeake.org/stac/presentations/230_Track%207%20Day%201.pdf
- Chesapeake water quality and urban trees: perspective and needs - Sally Claggett, USFS
  http://www.chesapeake.org/stac/presentations/230_Track%207%20Claggett.pdf

Facilitated Discussion (30 minutes) - David Sample, VT

Break (15 minutes)

Track 8: Synthesis Session: What Does the Data Tell Us Where to Go
Track Facilitator: Tom Schueler, CSN
Track Recorder: Natalie Gardner, CRC
Track Length: 1.5 hours

Track Report Out: Each of the Track Organizers (or Recorders) for Tracks 2 through 7 would provide a 5 minute summary of key points of synthesis relative to the four technical criteria, with 30 minutes for audience discussion

Next Steps in the Process for Defining Pervious Land in the CBWM: The final interactive session would feature a facilitated discussion to identify critical research needs and define a draft charge for a future expert panel. The goal is to make consensus recommendations on land use categories to CBPO modelers by the end of 2014.

Appendix B: Workshop Participants

Peculiarities of Perviousness Workshop Participants - April 22-23, 2014

Name	Affiliation	Email
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