PTAPP Meeting
May 19, 2015

Quantifying Nutrient Reductions for Structural Stormwater (SW) Controls

EPA Region 1
Mark Voorhees
Topics for Discussion

- Background/Context & Accounting Principles
- Goals and approach for nutrient source load characterization
- Goals and approach for estimating long-term cumulative nutrient load reductions for structural SW controls
Historical Perspective

How & Why

- Lower Charles River P TMDL, 2007
- Residual Designation Petition, ~2008
- SW Control Performance Analyses ~2010
- Stormwater Management Optimization Analysis, 2011
- Draft Residual Designation Permit, ~2010
- Draft NH & MA MS4 Permits with TMDL Reductions 2013 (NH) MA (~2014)
- Accounting System Phosphorus Source Loads & Reduction Credits ~2010-14
- Additional BMP Performance Analyses ~2013
- Sustainable Funding Study & EPA Updated Optimization Analysis, 2011
- Accounting for Nitrogen Source Loads & Reduction Credits ~2013-15
- Spreadsheet based Stormwater Management Optimization Tool ("Opti-Tool"), 2013-2015
Accounting Principles

• The Accounting methodology must:
  • Be based on credible information for quantifying sources and reduction credits for various control practices;
  • Allow for accounting across jurisdictional and sub-watershed boundaries within the watershed of interest;
  • Be re-visited from time to time to update information and incorporate new information
Goals of Nutrient Source Characterization and Quantification

- Characterize sources in appropriate units to reflect water quality impacts (e.g., kg/ha/yr)
  - Eutrophication is tied to long-term nutrient loading (average annual loads are appropriate)
- Export rates should reflect regional hydrology and precipitation patterns
- Export rates should reflect regional SW quality conditions and pollutants of concern
Approach for Nutrient Source Load Characterization

- Regional precipitation patterns
- Regional SW nutrient quality data
- Separate impervious and pervious sources
- Account for build-up and wash-off processes
New England Region
Precipitation Patterns
Relevant Points

• Most rain events are small in size;
• Occur regularly (average about once every three days)
• The total volume and event size distribution are relatively consistent across New England Region
Percentage of Total Number of Rainfall Events Based on Size of Rain Events - Boston, MA (1948-2004)

- 0.0 - 0.2 inches: 55%
- 0.2-0.6 inches: 27%
- 0.6-1.0 inches: 10%
- 1.0-1.5 inches: 5%
- 1.5-2.0 inches: 2%
- 2.0 inches and above: 1%
New England rainfall is approximately 43 inches/year spread over 100 storms, note the large number of small storms contribute substantial flow volume.
Stormwater Phosphorus & Nitrogen

**Phosphorus**
- Highly associated with very fine particles ~ 40 microns
- Fine particles readily washed from impervious surfaces with small amounts of rainfall
- Stormwater controls must have filtration component to be effective

**Nitrogen**
- N Oxides are readily washed off in early portion of rain events
- Organic nitrogen can be a significant part of N load
- High removals of SW nitrogen may require de-nitrification
Hydrologic Response Modeling Analysis

- Continuous hydrologic model simulations to estimate long-term average annual runoff yields for several watershed surface types – (e.g., impervious and pervious with varying soil conditions and vegetative cover)
  - Stormwater Management Model (SWMM)
  - P8 – Curve Number Method
- Representative of our climate conditions (e.g., hourly precipitation and daily temperature)
Importance of Impervious Area (IA) in SW Pollutant Loading

- Impervious area (IA) generates much greater runoff volume than pervious areas, therefore IA is typically the most significant contributor of overall SW pollutant loading.

### Calculated annual phosphorus load export rates (PLE) based on various hydrologic conditions for a range of stormwater total phosphorus (TP) concentrations

<table>
<thead>
<tr>
<th>Watershed surface</th>
<th>Description</th>
<th>Annual Runoff Yield, MG/ha/yr</th>
<th>Flow weighted SW TP conc., mg/L</th>
<th>Annual Phosphorus Load Export (PLE), kg/ha/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.10</td>
<td>0.20</td>
</tr>
<tr>
<td>Impervious surface</td>
<td>impervious surface</td>
<td>2.59</td>
<td>0.98</td>
<td>1.96</td>
</tr>
<tr>
<td>Pervious area HSG A</td>
<td>well drained soils</td>
<td>0.07</td>
<td>0.03</td>
<td>0.05</td>
</tr>
<tr>
<td>Pervious area HSG B</td>
<td>moderately drained soils</td>
<td>0.21</td>
<td>0.08</td>
<td>0.16</td>
</tr>
<tr>
<td>Pervious area HSG C</td>
<td>limited permeability</td>
<td>0.41</td>
<td>0.15</td>
<td>0.31</td>
</tr>
<tr>
<td>Pervious area HSG D</td>
<td>poorly drained soils</td>
<td>0.69</td>
<td>0.26</td>
<td>0.52</td>
</tr>
</tbody>
</table>

Typical range of urban SW TP concentrations

Annual Runoff yield by SWMM for hourly rainfall - Boston MA (1998-2002). Flow-weighted SW TN conc. = total annual N load divided by total annual runoff volume. HSG = Hydrologic Soil Group, MG= million gallons, ha = hectare (1 ha = 2.47 acres).
Nutrient Source Characterization and Quantification

- **Phosphorus**: EPA Region 1 has developed phosphorus load export rates for various source categories
  - Memorandum documenting approach, 2014

- **Nitrogen**: EPA Region 1 is presently using the nitrogen load export rates that are largely based on the results of the WISE modelling conducted by Geosyntec Inc. for the Lower Exeter River watershed.
<table>
<thead>
<tr>
<th>Phosphorus Source Category by Land Use</th>
<th>Land Surface Cover</th>
<th>Phosphorus Load Export Rate, Kg/ha/yr</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial (Com) and Industrial (Ind)</td>
<td>Directly connected impervious</td>
<td>2.0</td>
<td>Derived using a combination of the Lower Charles USGS Loads study and NSWQ dataset. This PLER is approximately 75% of the HDR PLER and reflects the difference in the distributions of SW TP EMCs between Commercial/Industrial and Residential.</td>
</tr>
<tr>
<td>Pervious</td>
<td>See* DevPERV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-Family (MFR) and High-Density Residential (HDR)</td>
<td>Directly connected impervious</td>
<td>2.6</td>
<td>Largely based on loading information from Charles USGS loads, SWMM HRU modeling, and NSWQ data set</td>
</tr>
<tr>
<td>Pervious</td>
<td>See* DevPERV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medium -Density Residential (MDR)</td>
<td>Directly connected impervious</td>
<td>2.2</td>
<td>Largely based on loading information from Charles USGS loads, SWMM HRU modeling, and NSWQ data set</td>
</tr>
<tr>
<td>Pervious</td>
<td>See* DevPERV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Density Residential (LDR) - &quot;Rural&quot;</td>
<td>Directly connected impervious</td>
<td>1.7</td>
<td>Derived in part from Mattson Issac, HRU modeling, lawn runoff TP quality information from Chesapeake Bay and subsequent modeling to estimate PLER for DCIA (Table 14) to approximate literature reported composite rate 0.3 kg/ha/yr.</td>
</tr>
<tr>
<td>Pervious</td>
<td>See* DevPERV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Highway (HWY)</td>
<td>Directly connected impervious</td>
<td>1.5</td>
<td>Largely based on USGS highway runoff data, HRU modeling, information from Shaver et al and subsequent modeling to estimate PLER for DCIA for literature reported composite rate 0.9 kg/ha/yr.</td>
</tr>
<tr>
<td>Pervious</td>
<td>See* DevPERV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Forest (For)</td>
<td>Directly connected impervious</td>
<td>1.7</td>
<td>Derived from Mattson &amp; Issac and subsequent modeling to estimate PLER for DCIA that corresponds with the literature reported composite rate of 0.13 kg/ha/yr (Table 14)</td>
</tr>
<tr>
<td>Pervious</td>
<td>0.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open Land (Open)</td>
<td>Directly connected impervious</td>
<td>1.7</td>
<td>Derived in part from Mattson Issac, HRU modeling, lawn runoff TP quality information from Chesapeake Bay and subsequent modeling to estimate PLER for DCIA (Table 14) to approximate literature reported composite rate 0.3 kg/ha/yr.</td>
</tr>
<tr>
<td>Pervious</td>
<td>See* DevPERV</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agriculture (Ag)</td>
<td>Directly connected impervious</td>
<td>1.7</td>
<td>Derived from Budd, L.F. and D.W. Meals and subsequent modeling to estimate PLER for DCIA to approximate reported composite PLER of 0.5 kg/ha/yr.</td>
</tr>
<tr>
<td>Pervious</td>
<td>0.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV)- Hydrologic Soil Group A</td>
<td>Pervious</td>
<td>0.03</td>
<td></td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV)- Hydrologic Soil Group B</td>
<td>Pervious</td>
<td>0.13</td>
<td></td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV) - Hydrologic Soil Group C</td>
<td>Pervious</td>
<td>0.24</td>
<td>Derived from SWMM and P8 - Curve Number continuous simulation HRU modeling with assumed TP concentration of 0.2 mg/L for pervious runoff from developed lands. TP of 0.2 mg/L is based on TB-9 (CSN, 2011), and other PLER literature and assumes unfertilized condition due to the upcoming MA phosphorus fertilizer control legislation.</td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV) - Hydrologic Soil Group C/D</td>
<td>Pervious</td>
<td>0.33</td>
<td></td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV) - Hydrologic Soil Group D</td>
<td>Pervious</td>
<td>0.41</td>
<td></td>
</tr>
</tbody>
</table>
## Proposed Average Annual Nitrogen Pollutant Load Export Rates for calibration of default HRU Time-series for use in Opti-Tool

<table>
<thead>
<tr>
<th>Nitrogen Source Category by Land Use</th>
<th>Land Surface Cover</th>
<th>Runoff Nitrogen Load Rate, Kg/ha/yr</th>
<th>Export Rates</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial (Com) Industrial (Ind) &amp; Institutional</td>
<td>Directly connected impervious</td>
<td>16.9</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. Avg of NLER for rooftops and other impervious surfaces for commercial and industrial</td>
</tr>
<tr>
<td>Multi-Family (MFR) and High-Density Residential (HDR)</td>
<td>Directly connected impervious</td>
<td>15.8</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. Avg of NLERs for rooftops and other impervious surfaces for residential</td>
</tr>
<tr>
<td>Medium-Density Residential (MDR)</td>
<td>Directly connected impervious</td>
<td>15.8</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. Avg of NLERs for rooftops and other impervious surfaces for residential</td>
</tr>
<tr>
<td>Low Density Residential (LDR) - &quot;Rural&quot;</td>
<td>Directly connected impervious</td>
<td>15.8</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. Avg of NLERs for rooftops and other impervious surfaces for residential</td>
</tr>
<tr>
<td>Highway (HWY)</td>
<td>Directly connected impervious</td>
<td>11.4</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. Avg of NLERs for roadways and freeway impervious surfaces</td>
</tr>
<tr>
<td>Forest (For)</td>
<td>Directly connected impervious</td>
<td>12.7</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. NLER for roadways</td>
</tr>
<tr>
<td>Open Land (Open)</td>
<td>Directly connected impervious</td>
<td>12.7</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. NLER for roadways</td>
</tr>
<tr>
<td>Agriculture (Ag)</td>
<td>Directly connected impervious</td>
<td>12.7</td>
<td></td>
<td>WISE modeling by Geosyntec for the Squamscot River IMP, 2014. NLER for roadways</td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV) - Hydrologic Soil Group A</td>
<td>Pervious</td>
<td>2.9</td>
<td></td>
<td>Derived from SWMM and P8 - Curve Number continuous simulation HRU modeling with assumed TN concentration of 2.5 mg/L for pervious runoff from agriculture lands. Median TN conc of 2.5 mg/l by (Budd and Meals, 1994)</td>
</tr>
<tr>
<td>*Developed Land Pervious (DevPERV) - Hydrologic Soil Group B</td>
<td>Pervious</td>
<td>0.3</td>
<td></td>
<td>Derived from SWMM and P8 - Curve Number continuous simulation HRU modeling with assumed TN concentration of 2.0 mg/L for pervious runoff from developed lands. TN of 2.0 mg/L is based on TB-9 (CSN, 2011), and other PLER literature and assumes 50% of unfertilized and 50% fertilized conditions.</td>
</tr>
</tbody>
</table>
Goals for Stormwater Control

Nutrient Load Reduction Assessments

- Identify structural and non-structural control practices worthy of reducing nutrient loads
- Quantify load reductions based on expected long-term cumulative performance
  - Cumulative effectiveness for all rain events not just “design storms”
  - Estimate cumulative effectiveness of various structural controls with varying capacities (small to large)
    *Important for Retrofitting considerations*
- Base on credible data and information
Reduction Credits for Structural Controls

Develop estimates of long-term cumulative performance using regional performance and climate data

Stormwater Best Management Practices Performance Analysis by Tetra Tech Inc.

- Develop and calibrate models to UNHSWC performance data
- Simulate long term performance varying the capacity of controls

Validate results with literature review
BMP Performance Curve Concept

Size SW Control from established curves developed from calibrated models and detailed performance data

Provides long-term cumulative performance estimates based on control’s design capacity

Eliminates the need for detailed modeling and evaluation in individual applications (improves consistency)
Scheme for BMP Performance Curve Development

Precipitation

Land simulation (SWMM)
Surface runoff generation and pollutant Build-up/wash-off

Model Calibration to Data

BMP simulation (SUSTAIN/BMPDSS)
BMP Treatment

BMP Performance Curve: Gravel Wetland
Land Use: Commercial

Pollutant Removal

Depth of Runoff Treated (inches)

TSS  TP  Zn
Land Simulation: SWMM Model Representations

- Surface runoff hydrology
- Water quality process:
  - Build-up: \( B = C_1 (1 - e^{-C_2 t}) \)
    where \( B \) = pollutant buildup, \( C_1 \) = max buildup, \( C_2 \) = buildup rate coefficient
  - Wash-off: \( W = C_1 q^{C_2} B \)
    where \( W \) = washoff load, \( C_1 \) = washoff coefficient, \( C_2 \) = washoff exponent, and \( B \) = pollutant buildup
SW Control Simulation: SUSTAIN/BMPDSS

- Includes numerous SW control types
- Simulates controls long-term cumulative performances
Calibration: UNHSWC Data

- Surface runoff and quality (TP, TSS and Zn)
- SW Control performance
  - Gravel Wetland
  - Wet Pond
  - Bioretention
  - Porous Asphalt
  - Swale
  - Infiltration System
  - Enhanced Biofiltration with Internal Storage Reservoir (for denitrification) (also calibrated for TN)
SW Control Calibration Process

- Generate inflow hydrology and water quality time series
  - Hydrology Calibrate SWMM to the UNHSC data
- Match outflow: hydrology
- Match outflow: event mean concentration
- Perform long term simulations and compare to independently reported long term performance estimates by UNHSWC

<table>
<thead>
<tr>
<th>Total pollutant load</th>
<th>TSS (lbs)</th>
<th>TP (lbs)</th>
<th>Zn (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inflow</td>
<td>279.29</td>
<td>2.81</td>
<td>0.45</td>
</tr>
<tr>
<td>Outflow</td>
<td>4.21</td>
<td>0.48</td>
<td>0.01</td>
</tr>
<tr>
<td>Cumulative pollutant removal (2004-2006)</td>
<td>98%</td>
<td>83%</td>
<td>98%</td>
</tr>
<tr>
<td>UNH report percentage (2004-2006)</td>
<td>99%</td>
<td>81%</td>
<td>99%</td>
</tr>
</tbody>
</table>
SW Control Long-term Cumulative Performance Curve Concept

BMP Performance Curves
Surface Infiltration Practices
rain gardens, swales, basins, etc.
(Saturated Soil Infiltration Rate 0.52 in/hr)

Cumulative Performance Curve Concept

Runoff Volume Reduction
Cumulative Phosphorus Load Removal

Physical Storage Design Capacity, Impervious Surface Runoff

TP
Volume

Small Rain Garden http://www.flickr.com/photos/cdwilliams1/2915660835/
Larger Stormwater Basin http://www.flickr.com/photos/leonizzy/6232922661/
Generation of BMP Performance Curves for New England Region

**BMPs**

**Surface Infiltration** (6 infiltration rates)

**Infiltration trenches** (6 infiltration rates)

**Bio-filtration** (non-infiltration)

**Porous pavement with underdrain**

**Gravel wetland**

**Dry Ponds**

**Conveyance swales**

**Enhanced Bio-retention***

* Optimized for N and P removal
  – Curves not yet final
EPA Region 1’s On-going Work Related to SW Nutrient Load Reductions

- Developed performance curves for:
  - Enhanced bio-filtration systems (optimized for TP & TN);
  - rooftop storage disconnection;
  - impervious area disconnections; and
  - removal of impervious area

- Following work in the Chesapeake Bay Region

- Developing long-term cumulative performance curves for TN for several SW controls using UNHSC performance data (2015)
Supporting Studies for Permit Process


- Optimal Stormwater Management Plan Alternatives: A Demonstration Project in Three Upper Charles River Communities, 2009
  http://www.epa.gov/region1/topics/water/pdfs/OptimalSWMngtPlanAlternativesUpperCharlesPilotStudy.pdf

- Sustainable Stormwater Funding Evaluation for the Upper Charles River Communities of Bellingham, Franklin, and Milford, MA
Supporting Studies for Permit Process (continued)

- Additional Stormwater Best Management Practice (BMP) Performance Analysis, 2013 for: (1) rooftop storage/IC disconnection; (2) IC disconnection; (3) IC removal.  

- Spreadsheet Based Stormwater Management Optimization Tool (on-going 2013-2015)

- Funding of BMP performance monitoring with emphasis on Nitrogen (UNH SWC 2014-15)

- Develop Regional BMP Performance Curves for Nitrogen and calibrated model input parameters for Opti-Tool (2015)

Questions ?

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Thank you