Appendix S3. SEJ protocol document.
AquaBase Structured Expert Judgment Protocol
Effectiveness of Best Management Practices in
Reducing Nitrogen Export as an Intermediate Ecosystem Service

Purpose:
We have invited you to participate in this survey because of your expertise in the area of urban stormwater management. This “expert elicitation” will solicit input from you on specific data needs related to best management practices (BMPs) and nitrogen management in urban waterways. Scientific understanding of BMP performance and nitrogen removal is far from complete; therefore subject experts like you are critical sources of information. Using readily available for actual Chesapeake Bay sub-watersheds, this structured expert judgment will be used to generate data on: (1) nitrogen loading to and export from Chesapeake Bay sub-watersheds; (2) ranges in BMP performance related to nitrogen-removal effectiveness for different BMPs; (3) sources of variability in BMP performance; and, (4) the relative contributions of different sources to variability in BMP performance. Although we draw on data and watershed scenarios from catchments in the Chesapeake Bay to generate expert estimates, the resulting data will address a larger research need for managing excess nitrogen in an urbanizing watershed context.

Background:
Managing for nitrogen removal as an ecosystem service requires an ecosystem-based approach that relies on multiple forms of data describing the performance of BMPs. In urbanizing areas, many aquatic ecosystems are degraded, land cover may be highly impervious, and the space available for implementing land-based management options and restoration is often limited. Often natural resource managers are unable to meet prescribed water quality targets and other ecosystem service needs. Given the rapid rate of urbanization, managers must often quickly make decisions on where, which, and how many BMPs to implement within a catchment while simultaneously considering both the costs and the prospects for providing a variety of different ecosystem goods and services. Yet there is a lack of empirical data that can be used to inform decisions about the types and optimal placement of BMPs, and water quality and quantity continue to be problematic in urbanized areas such as the Chesapeake Bay.

In the context of this study, and many urban stormwater management efforts, BMP performance refers to the ability of a given BMP to permanently or temporarily remove nitrogen from downstream export. BMP performance is also often reported as a N-removal “effectiveness” or “efficiency”. Any such “nitrogen removal” is accomplished through two main pathways: (1) through uptake by plants or microbes within BMPs, and, (2) through the conversion of reactive nitrogen (i.e., NOx, NH3, N2O) to an inert form (N2) through denitrification. BMPs are designed and located to enhance the microbial and plant communities responsible for N removal.

Performance may also depend on the BMP itself. BMP features include: the type of BMP (e.g., stormwater detention ponds, created wetlands, etc.), BMP size, age, hydrologic conditions, intensity of a given rain event, position in the watershed, and soil characteristics, to name a few. Consequently, it is difficult for scientists and managers to disentangle the unique contribution and relative importance of features in contributing to variability in BMP performance. Thus it is difficult to assign single, robust values of “performance” for certain BMP types. Furthermore, high levels of uncertainty associated with the effectiveness of BMPs in N-removal makes it difficult to make decisions about their deployment.
Quantifying the uncertainty associated with BMP performance and identifying the factors that may be driving that uncertainty should help managers make more informed decisions. Thus we are asking experts such as yourself to estimate and comment on: (1) ranges in BMP performance related to nitrogen-removal effectiveness for different BMPs; (2) sources of variability in BMP performance; and, (3) the relative contributions of different sources to variability in BMP performance.

**Methods:**
We will ask you to predict ranges in incoming and outgoing TN loads for two urbanizing sub-watershed scenarios, across a range of hydrologic (rain) events. It is not our intention to seek a group consensus, but rather to generate distributions of BMP performance that faithfully reflect the range of expert opinions. The results of this elicitation will be summarized and shared with all participants as well as the broader community of scientists and managers that study and implement stormwater BMPs.

**Format:**
The questions here follow the same format and are based on real sub-watersheds in Maryland: one located in the Coastal Plain physiographic province, and one in the Piedmont physiographic province. We present the available data on watershed features for specific BMPs (wet and dry detention ponds, and constructed wetlands), discharge and precipitation collected at either the level of the individual BMP (Coastal Plain scenario) or at the watershed outlet (Piedmont scenario).

The estimation you will be asked to provide will be related to incoming and outgoing total nitrogen loads load only. We focus exclusively on this commonly used metric, which is typically measured in units of mass (e.g., kg or lbs of TN). TN load at a given point in a watershed is the product of TN concentration (e.g., kg TN L\(^{-1}\)), discharge (e.g., L min\(^{-1}\)), and the length of time elapsed (e.g., the duration of elevated flows during a rain event; units = minutes).

We will ask you to estimate TN load at specific locations in the watershed: at the watershed outlet (“watershed-level estimates”) and into and out of a specific BMP (“BMP-level estimates”). You are asked to estimate the uncertainty for each location by giving the median along with the 5\(^{th}\) and 95\(^{th}\) percentiles of the distribution that you expect would best describe the TN load under the specified conditions.
Example #1: Watershed-level TN loads

To begin with, let’s consider TN loads for the urbanizing sub-watershed in the Piedmont physiographic province. Assuming you have reviewed the provided data (i.e., watershed description, discharge and precipitation), here is how you might interpret a watershed-level question and generate a response:

Given a description of a watershed in the Piedmont including watershed size and discharge and precipitation records for a specific rain event, what is the **outgoing** total nitrogen load (kg of TN) measured at the outlet?

*I would say there is …*

only a 5% chance is a 50% chance is a 95% chance
the TN load is below ___kg the TN load is below ___kg the TN load is below ____kg

Presumably the number you have in mind is uncertain. Considering the available watershed information, you might make calculations to estimate this value and fill in:

<table>
<thead>
<tr>
<th>5%</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>0.5</td>
</tr>
<tr>
<td>95%</td>
<td>0.9</td>
</tr>
</tbody>
</table>

Here your response communicates that you believe that there is a 5% chance that the actual efficiency is below 0.1 kg, a 50-50 chance that it’s below 0.5 kg, and a 95% chance that it is below 0.9 kg.

The actual value for this BMP is **0.43 kg TN**. Because this value is within the 90% confidence band you specified, you would not be surprised by the real answer. If the actual value were 0kg or 2kg, you would be surprised because these values are outside of your 90% confidence band.

An expert’s probabilistic assessments are *statistically accurate* if half of the actual values fall on either side of the median (the 50th percentile) and if the actual values fall outside the 90% confidence band only 10% of the time.

If your response had been:

<table>
<thead>
<tr>
<th>5%</th>
<th>0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>50%</td>
<td>0.9</td>
</tr>
<tr>
<td>95%</td>
<td>1.7</td>
</tr>
</tbody>
</table>

you would be equally unsurprised by the observed value of 0.43kg but your answer would be less informative because the range in your percentiles is greater.
Example #2: BMP-level TN loads

We now consider the Coastal Plain sub-watershed. Considering the available information provided for a specific rain event and BMP (i.e., drainage area, BMP description, discharge, precipitation, land use), here is how you might interpret a BMP-level question and generate a response:

What is the incoming total nitrogen load (kg of TN) from BMP A, a dry detention pond for a given rain event?

I would say there is …

only a 5% chance is a 50% chance is a 95% chance
the TN load is below ___ kg the TN load is below ___ kg the TN load is below ___ kg

Presumably, the number you have in mind is uncertain. Considering the watershed information that includes BMP information, discharge, land use, etc., you might fill in:

| 5% | 3  | 50% | 6  | 95% | 7.5 |

This response means that you believe that there is a 5% chance that the actual efficiency is below 3 kg, a 50-50 chance that it’s below 6 kg, and a 95% chance that it is below 7.5 kg.

The actual value for this BMP is 5 kg TN. Because this value is within the 90% confidence band you specified, you would not be surprised by the real answer. If the actual value were 1 kg or 10 kg, you would be surprised because these values are outside of your 90% confidence band.

An expert’s probabilistic assessments are statistically accurate if half of the actual values fall on either side of the median (the 50th percentile) and if the actual values fall outside the 90% confidence band only 10% of the time.

If your response had been:

| 5% | 0.1 | 50% | 4  | 95% | 20 |

you would be equally unsurprised by the observed value of 5 kg but your answer would be less informative because the range in your percentiles is greater.
“Calibration” Questions
Since expert judgment is inherently subjective, it can most effectively be put to use in science-based decision making when the resulting combination of expert uncertainty distributions are validated relative to empirical data. Thus, 10 “calibration variables” are distributed throughout this protocol. The true answers to those 10 questions are known, but are not yet available in the scientific literature. By accounting for each expert’s performance relative to the calibration variables, we can greatly improve the overall combination of expert judgments (Aspinall 2010) which will enable more accurate group-level estimates of BMP efficiency and uncertainty.

Expert Names
Expert names and affiliations will be included in publications for this research to meet the demands of scientific reproducibility and transparency. Association between expert names and individual answers will never be shared in the public realm. Association between names and assessments will be preserved only in unpublished records of the research.
Preparing for the elicitation

This particular elicitation is technical in nature. Please prepare accordingly as you may need a few days to formulate your answers. Experts consulted in trial runs provided several suggestions that may be helpful in your preparation.

- Allow yourself several days to work through the questions and related readings (~ 2-3 days)
- Read through the protocol in its entirety first, and perhaps several times over, to understand the scenarios and get a sense of the questions being asked, and information needed to calculate your estimates.
- You may consult outside sources available to you, and even work with other colleagues to prepare your estimates but it is you that will be interviewed and your name that will be cited in the list of participating experts.
- We encourage you to use a spreadsheet to keep track of your calculations and/or answers. This will enable you to reproduce calculations quickly, avoid conversion errors, and will help inform our understanding of how you arrived at your answers.
- Feel free to write your answers in this booklet, and have any spreadsheets you have prepared available for the elicitation. Keep track of your work and calculations. In providing your answer, much of our discussion will focus on your rationale and assumptions made when formulating your answer.

Resource package

You are free to use any sources of information you wish in formulating your answers to the questions below. We have compiled a “resource package” containing some relevant publications, reports, data sources, and further readings on the structured expert judgment process. We particularly encourage you to read the short (2 page) article by Aspinall (2010), which provides a succinct and readable overview of the structured expert judgment process. All materials in the resource package are listed below and are available for download at: https://www.dropbox.com/sh/e2kr83r83fy5jr7/jZlP3fKqpE

Sub-folder 1: Structured Expert Judgment
- Aspinall 2010 More tractable expert advice_Nature
- Cognitive heuristics primer EPA
- Cooke 2013 Quantifying uncertainty on thin ice_NatureCC

Sub-folder 2: Regional Nitrogen Data
- Ator et al. 2011 Sources, fate, & transport of N & P_USGSreport2011-5167
- Regional N data summary

Sub-folder 3: Selected Nitrogen Loading & Stormwater Literature
- CSN 2012 CBP stormwater performance standards
- CSN 2012 CBP urban stormwater retrofit removal rates
- Davis et al. 2012 Hydrol perf of bioret SW control measures_ASCE
- Filoso & Palmer 2011 Stream restoration & nitrogen export_EcolApps
- Kaushal et al. 2011 Source of N in nonpoint polluted streams_ES&T
- Koch et al. BMP Meta-analysis_InReview
- Mayer et al. 2007 Meta-analysis of N removal in riparian buffers_JEnvQual
- Passeport et al. 2013 Ecological engineering to reduce excess N_EnvironMgmt
**ALSO: Please double-check units!**

USGS gage data reports discharge as cubic feet per second, and BMP specifications are sized for precipitation events measured in inches (not in SI units). The Piedmont scenario relies on USGS discharge data measured at 15 minute intervals. In the Coastal Plain scenario, discharge data were collected at varying time intervals (varied between 15 min and 1 hr). We have tried to remain consistent where possible, and are relying on the best available data and as accurate as possible.

As a reminder, common conversions in this protocol include:

<table>
<thead>
<tr>
<th>Category</th>
<th>Conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>1 inch (in) = 25.4 millimeters (mm)</td>
</tr>
<tr>
<td><strong>Volume</strong></td>
<td>1 cubic meter (m³) = 1000 liters (L)</td>
</tr>
<tr>
<td></td>
<td>1 cubic foot (ft³) = 28.317 liters (L) = 0.028317 cubic meters (m³)</td>
</tr>
<tr>
<td></td>
<td>1 (US) gallon (gal) = 3.7854 liter (L)</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>1 pound (lb) = 0.454 kilogram (kg)</td>
</tr>
<tr>
<td></td>
<td>1 kilogram (kg) = 10⁶ milligrams (mg)</td>
</tr>
<tr>
<td><strong>Area</strong></td>
<td>1 square mile (mi) = 2.589 square kilometer (km²) = 258.9 hectares (ha) = 640 acres (ac)</td>
</tr>
<tr>
<td></td>
<td>1 square kilometer (km²) = 10⁶ square meters (m²) = 100 hectares (ha) = 247.1 acres (ac)</td>
</tr>
<tr>
<td></td>
<td>1 hectare (ha) = 10,000 square meters (m²) = 0.01 square kilometers (km²) = 2.471 acres (ac)</td>
</tr>
<tr>
<td><strong>Flow</strong></td>
<td>1 cubic foot per second (ft³ s⁻¹) = 28.317 liter per second (L s⁻¹)</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>1 hour (h) = 3600 seconds (s)</td>
</tr>
</tbody>
</table>
CHESAPEAKE BAY SUB-WATERSHEDS

The Chesapeake Bay watershed measures over 64,000 square miles and extends across six states, from Virginia to New York and the entire District of Columbia (D.C.). Over 17 million people live within the boundaries of this watershed, interacting with more than 150 major rivers and large streams. Here our analysis focuses on the dynamics between urban stormwater management and changes in hydrologic conditions experienced within the sub-watersheds. Rapid rates of development in the past 50 years have been met with efforts to improve degraded freshwater quality fisheries in the Bay. Common to urbanized regions around the globe, stormwater infrastructure is employed to help mitigate the transport of pollutants, namely sediment, nitrogen, and phosphorus into downstream waters such as the Chesapeake Bay estuary.

As described above, all of the questions will ask you to estimate incoming and outgoing TN loads across a range of hydrologic contexts specific to two urbanizing sub-watersheds in the D.C. region, both in the state of Maryland. We present the best available data for two scenarios: one in the Piedmont physiographic province, one in the Coastal Plain physiographic province. For each scenario, we will ask you to consider watershed context (i.e., size, land use), precipitation and discharge data for several independent rain events. Note that rain events will vary in terms of timing, season, antecedent conditions and intensity. For each rain event, you will be asked to provide estimates for nitrogen export (as kg of total nitrogen), measured at the catchment outlet. For a subset of the storms, we will also ask you to estimate TN export at specific BMPs at different locations throughout a sub-watershed (i.e., at the outlet, or at the individual BMP). For all BMP-level questions, assume that the structures are operating optimally, and that maintenance schedules have been adhered to. Assume that the data provided are the best and only data available for the site. You are welcome to consider outside sources of information to formulate your answers.

Examples of available regional summaries of N deposition, concentrations, and loading rates to streams in the Chesapeake Bay area are included in the resource package provided at the URL given above.
**Part 1: Piedmont Scenario**

This sub-watershed also lies just north of the Washington DC metro area, in the Piedmont physiographic province with crystalline bedrock consisting of phyllite and slate. The drainage area is 3.5 km². Previous land cover was agricultural but underwent significant residential and commercial development in the 1990s. This sub-watershed now consists of 85% urban land cover with 39% of the total watershed covered by impervious surfaces (e.g. roads, rooftops, parking lots). Forest cover makes up 15% of the total land cover.

Stormwater BMP implementation in this watershed relies largely on treatment by ponds and wetlands located within the stream channel or directly adjacent to the stream. As shown in Figure 1, BMPs include wet and dry ponds, constructed wetlands, oil & grit separators, bioretention/swales and infiltration trenches. Contemporary low-impact development (LIDs) are not widely implemented with the exception of a few bioretention cells that treat a small set of townhouses. Ponds and wetlands in the urban watershed vary in size, age, and design goals. Land cover draining to the constructed wetlands & wet ponds (e.g., BMPs B & C) consist of single family homes and streets. BMP A, a dry pond, is located in-stream whereas BMP C (among others) are off-channel. Stormwater runoff from impervious surface is collected and transported by curbs and gutters to a network of underground pipes. Detention ponds were designed initially for hydraulic detention and not designed for infiltration so excavated material used in the construction were used to line the ponds. Riparian zones between BMPs consist of trees and urban grasses. Wastewater is transported via sanitary sewer pipes outside of the watershed for treatment and septic tanks are not believed to be present in the watershed. All impervious cover-generated runoff is assumed to receive treatment from a BMP before exiting the catchment.

Continuous hydrologic data were collected from 2010 to 2012. These include instantaneous discharge (15-minute intervals) and precipitation, as well as total nitrogen, all measured at the catchment outlet (indicated as a star in Figure 1). Discharge, precipitation and nitrogen loads for seven independent rain events were gathered during this time period.

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**Question Synopsis for Part 1**

Questions #1 to 4 ask you to estimate TN loads out of the catchment for a range of independent rain events between 2010 and 2012. The rain events are:

I: October 27, 2010
II: April 16, 2011
III: May 18, 2011
IV: September 18, 2012

The next set of questions (#5 to 32) will ask you to estimate TN loads out of the catchment, and into and out of individual BMPs in response to independent rain events:

V: September 12, 2010 (Questions #5 to 11)
VI: October 2, 2012 (Questions #12 to 18)
VII: Tropical Storm Lee, September 8, 2011 (Questions #19 to 25)
VII: Tropical Storm Lee preceded by a hypothetical storm (Questions #26 to 32).

Assume that the watershed characteristics as described above remain the same while only the hydrologic and seasonal context will change (i.e., storm intensity, duration, and timing) for each set of questions.
Figure 1. Map of urban Piedmont watershed with stormwater BMPs and USGS stream gauge located at the watershed outlet. Discharge (runoff), precipitation and TN data are collected at the outlet of the watershed, indicated by the star (USGS Gaging station). Yellow boxed letters denote specific BMPs (A, B and C) analyzed in this expert elicitation.

Figure 2. General land cover map of urban Piedmont watershed.
Photo 1. BMP A: A dry detention pond (“dry pond”) with extended detention capacity for the 2-year event and storage capacity for up to the 100-year event. See Table 1 for additional information.
Photo 2. BMP B: A wet detention pond ("wet pond") with permanent pool for water quality treatment and storage capacity for up to the 100-year event. Note that this BMP begins at the headwater and additional information can be found in Table 1.
Photo 3. BMP C: A wet pond/wetland with wetland used for water quality treatment. Designed detention capacity for >10 to 100-year event. Additional information is found in Table 1.
Table 1. Description of stormwater BMPs indicated in Figure 1 & Photos 1-3.

<table>
<thead>
<tr>
<th>BMP</th>
<th>Type</th>
<th>Location</th>
<th>Approximate Construction Date</th>
<th>Baseflow Depth (ft)</th>
<th>100-year Event Depth (ft)</th>
<th>Drainage area (km²)</th>
<th>Maintenance Schedule</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Dry Pond</td>
<td>Instream</td>
<td>1994</td>
<td>≈0</td>
<td>15</td>
<td>1.4</td>
<td>Triennial</td>
</tr>
<tr>
<td>B</td>
<td>Wet Pond</td>
<td>Headwater</td>
<td>1990</td>
<td>5</td>
<td>12</td>
<td>0.2</td>
<td>Triennial</td>
</tr>
<tr>
<td>C</td>
<td>Wet Pond/wetland</td>
<td>Adjacent to Stream</td>
<td>1998</td>
<td>≈0</td>
<td>11</td>
<td>0.2</td>
<td>Triennial</td>
</tr>
</tbody>
</table>

Table 2. Total discharge and precipitation for rain events I - VIII

<table>
<thead>
<tr>
<th>Rain event</th>
<th>Date</th>
<th>Total discharge (ft³)</th>
<th>Total precipitation (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>October 27, 2010</td>
<td>6.51E+05</td>
<td>1.2</td>
</tr>
<tr>
<td>II</td>
<td>April 16, 2011</td>
<td>1.40E+06</td>
<td>1.3</td>
</tr>
<tr>
<td>III</td>
<td>May 18, 2011</td>
<td>2.33E+05</td>
<td>0.4</td>
</tr>
<tr>
<td>IV</td>
<td>September 18, 2012</td>
<td>5.15E+05</td>
<td>1.1</td>
</tr>
<tr>
<td>V</td>
<td>September 12, 2010</td>
<td>9.90E+04</td>
<td>0.5</td>
</tr>
<tr>
<td>VI</td>
<td>October 2, 2012</td>
<td>2.46E+06</td>
<td>3.1</td>
</tr>
<tr>
<td>VII &amp; VIII</td>
<td>September 8, 2011</td>
<td>2.03E+07</td>
<td>9.7</td>
</tr>
</tbody>
</table>
Figure 3. Instantaneous stream discharge measured every 15 minutes at the outlet of the urbanized sub-watershed in the Piedmont physiographic province from 2010 to 2012 (outlet is indicated as a star in Figure 1). Total annual discharge for 2010, 2011 and 2012 are provided in the plot. Shaded in grey are individual rain events that will be referred to in subsequent questions (see Table 2).
Figure 4. Daily precipitation measured at the outlet of the urbanized sub-watershed in the Piedmont physiographic province from 2010 to 2012 (outlet is indicated as a star in Figure 1). Total precipitation levels for 2010, 2011 and 2012 are provided in the plot. Shaded in grey are individual rain events that will be referred to in subsequent questions (see Table 2).
Rain event I: Typical fall storm (October 27, 2010)

Consider the available hydrograph and precipitation record for a typical fall storm:

![Graph showing discharge and precipitation records for a fall storm](image)

**Figure 5.** Magnified views of discharge and precipitation records for an individual fall storm at the Piedmont catchment. Grey shading denotes the duration of this rain event (rain event I). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(1) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event I?

5%___________ 50%___________ 95%___________
Rain event II: Early spring storm (April 16-17, 2011)

Consider the available hydrograph and precipitation record for an early spring storm:

Figure 6. Magnified views of discharge and precipitation records for an individual fall storm at the Piedmont sub-watershed. Grey shading denotes the duration of this rain event (rain event II). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(2) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event II?

5% __________ 50% __________ 95% __________
Rain event III: Late, small spring storm (May 18, 2011)

Consider the available hydrograph and precipitation record for a late, small spring storm:

Figure 7. Magnified views of discharge and precipitation records for an individual fall storm at the Piedmont sub-watershed. Grey shading denotes the duration of this rain event (Rain event III). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(3) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event III?

5%________________  50%________________  95%________________
Rain event IV: Typical fall storm (September 18, 2012)

Consider the available hydrograph and precipitation record for a typical fall storm:

Figure 8. Magnified views of discharge and precipitation records for an individual fall storm at the Piedmont sub-watershed. Grey shading denotes the duration of this rain event (Rain event IV). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(4) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event IV?

5%________________  50%________________  95%________________
Rain event V: Small fall storm (September 12, 2010)

Consider the available hydrograph and precipitation record for a small fall storm:

![Graph showing discharge and precipitation records for an individual fall storm at the Piedmont sub-watershed. Grey shading denotes the duration of this rain event (rain event V). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.]

**Figure 9.** Magnified views of discharge and precipitation records for an individual fall storm at the Piedmont sub-watershed. Grey shading denotes the duration of this rain event (rain event V). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

**Watershed-level question:**

(5) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event V?

5%_________________ 50%_________________ 95%_________________
**BMP-level questions (see Figure 1 for locations of individual BMPs):**

What is the nitrogen load (kg TN) at the following locations:

(6) **Incoming** TN load to BMP A:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(7) **Outgoing** TN load from BMP A:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(8) **Incoming** TN load to BMP B:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(9) **Outgoing** TN load from BMP B:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(10) **Incoming** TN load to BMP C:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(11) **Outgoing** TN load from BMP C:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]
Rain event VI: Large fall storm (October 2, 2010)

Consider the available hydrograph and precipitation record for a fall storm:

Figure 10. Magnified views of discharge and precipitation records for an individual fall storm at the Piedmont sub-watershed. Grey shading denotes the duration of this rain event (rain event VI). Discharge (measured every 15 minutes) and precipitation measurements were taken at the outlet, indicated as a star in Figure 1. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(12) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event VI?

5%______________ 50%______________ 95%______________
BMP-level questions (see Figure 1 for locations of individual BMPs):

What is the nitrogen load (kg TN) at the following locations:

13) **Incoming** TN load to BMP A:
   
   5%__________ 50%__________ 95%__________

14) **Outgoing** TN load from BMP A:
   
   5%__________ 50%__________ 95%__________

15) **Incoming** TN load to BMP B:
   
   5%__________ 50%__________ 95%__________

16) **Outgoing** TN load from BMP B:
   
   5%__________ 50%__________ 95%__________

17) **Incoming** TN load to BMP C:
   
   5%__________ 50%__________ 95%__________

18) **Outgoing** TN load from BMP C:
   
   5%__________ 50%__________ 95%__________
Rain event VII: Tropical Storm Lee (September 7-9, 2011)

Consider the available hydrograph and precipitation record for Tropical Storm Lee, a 1 in 1000 year rain event:

![Graph](image)

**Figure 11.** Hourly precipitation and instantaneous stream discharge (measured every 15 minutes) for several weeks preceding Tropical Storm Lee. Note that stream discharge data are presented on a logarithmic scale. Grey shading indicates the duration of sampling for rain event VII that occurred on September 8, 2011 (Tropical Storm Lee).
Figure 12. Magnified view of precipitation and discharge for rain event VII on September 8, 2011, as shown in Figure 11. Grey shading denotes the duration of rain event VII referenced in the questions below. Refer to Figures 3 and 4 to compare this rain event with annual discharge and precipitation patterns, respectively. Cumulative totals for sampling time, discharge and precipitation are provided within the plot. Discharge was measured every 15 minutes.

Watershed-level question:

(19) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event VI?

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

BMP-level questions (see Figure 1 for locations of individual BMPs):

What is the nitrogen load (kg TN) at the following locations:

(20) **Incoming** TN load to BMP A:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]
(21) **Outgoing** TN load from BMP A:

<table>
<thead>
<tr>
<th></th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
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</table>

(22) **Incoming** TN load to BMP B:

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<tr>
<th></th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
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</table>

(23) **Outgoing** TN load from BMP B:

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<tr>
<th></th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
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(24) **Incoming** TN load to BMP C:

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<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
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(25) **Outgoing** TN load from BMP C:

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<tr>
<th></th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
</thead>
</table>
Rain event VIII: Tropical Storm Lee (September 7-9, 2011)

We now ask you to consider the same tropical rain event and this *hypothetical* hydrograph record. Again considering Tropical Storm Lee, consider that a tropical storm of equal magnitude occurred just one month prior:

![Graph showing hypothetical stream discharge](image)

**Figure 13.** Hypothetical instantaneous stream discharge (at 15 minute intervals) for the Piedmont scenario from 2010 to 2012. Consider that Tropical Storm Lee (September 18, 2011, rain event VIII, shaded in grey) was preceded by a rain event of equal magnitude just one month prior. Total precipitation amount in 2011 remains the same for this hypothetical example.
Figure 14. Magnified views of hydrograph and precipitation records for Tropical Storm Lee at the Piedmont scenario described above (these are the same data as presented in Figure 12). Grey shading denotes the duration of rain event VIII referenced in the questions below. Cumulative totals for sampling time, discharge and precipitation are provided within the plot. Discharge data is at 15 minute intervals.

Watershed-level question:

(26) What is the outgoing total nitrogen load (kg TN) from the sub-watershed over the entire duration of rain event VI?

5%______________  50%______________  95%______________

BMP-level questions (see Figure 1 for locations of individual BMPs):

What is the nitrogen load (kg TN) at the following locations:

(27) **Incoming** TN load to BMP A:

5%______________  50%______________  95%______________
(28) **Outgoing** TN load from BMP A:

5%__________ 50%__________ 95%__________

(29) **Incoming** TN load to BMP B:

5%__________ 50%__________ 95%__________

(30) **Outgoing** TN load from BMP B:

5%__________ 50%__________ 95%__________

(31) **Incoming** TN load to BMP C:

5%__________ 50%__________ 95%__________

(32) **Outgoing** TN load from BMP C:

5%__________ 50%__________ 95%__________
Part 2: Coastal Plain scenario

The sub-watershed described in this scenario is located in the Coastal Plain physiographic province and is part of a highly urban and sub-urban catchment. The drainage area is 1.5 km². This catchment drains to a tributary of the Chesapeake Bay on the western shore and sites described below are located 0.5-1.5 km above the tidal boundary. The sub-watershed is substantially developed (approximately 88% urban, 53% impervious, 11% forest), serviced with a combination of public sewer treatment and private septic systems. Recently several stormwater BMPs have been retrofitted to new designs in order to increase infiltration (reduce sediment and nutrient export).

The purpose of this particular scenario is to better understand specific BMP-to-BMP variation in nitrogen removal performance under identical watershed contexts and hydrologic conditions. Similar to Part 1, we will ask questions about watershed-level and BMP-level nitrogen export under varying storm conditions. All questions will follow the same format as in previous questions: you will be asked to estimate total nitrogen (TN) loads (in kg TN) into or out of BMP sites, out of the sub-watershed over the duration of particular rain events.

In this scenario, note that some of the questions below ask how two different BMP sites would perform. For one BMP site in particular, we ask you to consider the same site under identical flow conditions assuming either pre- or post-retrofit design specifications. We provide as much information on the design and retrofit as is available.

Also note that the available data may be presented differently than in Part 1. In particular, general gaps in data indicate that no data were collected for the time period, and instantaneous discharge was sampled at varying intervals (e.g., every 15 min, 45 min or 1 hr). The sampling interval is specified in each figure caption.
Figure 15. Map of the Coastal Plain suburban watershed (delineated by the purple line) showing stream channels (blue), stormwater BMPs (pink squares), and the location of discharge measurements (green star) presented below. Orange lines denote stormwater pipes and culverts. Yellow boxed letters denote specific BMPs (Q and R) analyzed in this expert elicitation.
Stormwater BMP Descriptions at Sites Q and R

Site Q – Parking lot with grass swale

Stormwater treatment at Site Q consists of a 177 m$^2$ vegetated, grassy area in the center of the parking lot and a 1600 m$^2$ grassy depression surrounding the parking lot (see Figure 15). Runoff from the impervious surfaces in this drainage area run downhill towards a single drainage outlet (red circle in Figure 16), which channels runoff into a headwater stream via a culvert (blue ephemeral stream channel in Figure 16). Neither of the monitored vegetated areas have underdrains or perimeter sand filters. Together, these vegetated areas collect runoff from a commuter parking lot and the surrounding area (drainage area: 0.0263 km$^2$). Soil type in the drainage area includes Type B (8100 m$^2$): silt loam or loam, moderately well drained with moderate infiltration rate and Type D (18200 m$^2$): clay loam, silty clay loam, sandy clay loam, sandy clay or clay with very low infiltration rates.

Figure 16. Site Q: A drainage area (purple) containing a grass swale (green). Red dot indicates the downstream drainage location of the drainage area. The grassy, vegetated areas receiving most of the runoff are outlined in green. Yellow arrow indicates direction of flow.
Site R – Dry detention pond

The BMP at Site R is a dry detention pond (“dry pond”), with an area of 1800 m². The dry pond is located behind a shopping center and drains 0.226 km² in a largely residential area. Soil type in the drainage area includes Type B (0.124 km²): silt loam or loam, moderately well drained with moderate infiltration rate; Type C (0.0283 km²): sandy clay loam, low infiltration rates; and Type D (0.0732 km²): clay loam, silty clay loam, sandy clay loam, sandy clay or clay with very low infiltration rates. Runoff from this pond is transported via pipes to downstream sewer networks.

Figure 17. Site R: A drainage area (purple) containing a dry detention pond BMP (green). Green oval indicates the location of the dry detention pond. The drainage area is outlined in purple. Yellow arrows indicate direction of flow.
Table 3. Characteristics of the BMPs described in the Coastal Plain watershed shown in Figures 16 and 17.

<table>
<thead>
<tr>
<th>Site</th>
<th>BMP type</th>
<th>BMP Drainage area</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total (km²)</td>
</tr>
<tr>
<td>Q</td>
<td>grass swale with no underdrain</td>
<td>0.03</td>
</tr>
<tr>
<td>R</td>
<td>dry detention pond</td>
<td>0.23</td>
</tr>
</tbody>
</table>

Watershed area: 1.5 km²

Question Synopsis for Part 2

Questions #33 to 36 will ask for estimates TN loads out of the catchment for a range of independent rain events between 2008 and 2010. The rain events are:

IX: July 4, 2008
X: July 23, 2008
XI: March 22, 2010
XII: April 13, 2010

The next set of questions (#37 to 52) will ask you to estimate TN loads out of the catchment, into and out of individual BMPs – pre- and post-retrofit – In response to independent rain events:

XIII: June 1-2, 2012 (Questions #37 to 42)
XI: Revisit April 13, 2010 rain event (Questions #43 to 47)
XIV: September 30-October 1, 2010 (Questions #48 to 52)
XV: September 30-October 1, 2010 event preceded by a hypothetical storm of equal magnitude one month prior (Questions #53 to 57)

Annual discharge and precipitation data are not available for this scenario. Take note of the sampling interval for discharge measurements (i.e., 30, 45 or 60 minute intervals) and specific site conditions (pre- vs. post-retrofit) when formulating your answers. Otherwise assume that the watershed characteristics and surrounding land use remain the same for all questions.
Rain event IX: Summer storm (July 4, 2008)

Consider the following precipitation record and hydrograph for a summer rain event:

![Hydrograph and precipitation record](image)

**Figure 18.** Hydrograph and precipitation record over several days in summer 2008 including rain event IX (shaded in grey). 30-minute instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event IX, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 19.
Figure 19. Magnified view of precipitation and discharge for rain event IX on July 4-5, 2008 shown in Figure 18. Grey shading denotes the duration of rain event IX referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(33) What is the **outgoing** total nitrogen load (kg TN) from the watershed outlet (indicated by a star in Figure 15) over the entire duration of this storm?

5%______________ 50%______________ 95%______________
Rain event X: Summer storm (July 23, 2008)

Consider the available precipitation record and hydrograph for the following rain event:

![Hydrograph and precipitation record](image)

**Figure 20.** Hydrograph and precipitation record over several days in summer 2008 including rain event X (shaded in grey). 30-minute instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event X, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 21.
Figure 21. Magnified view of precipitation and discharge for rain event X on July 23-24, 2008 shown in Figure 20. Grey shading denotes the duration of rain event X referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(34) What is the outgoing total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

5%_________   50%_________   95%_________
Rain event XI: Spring storm (March 22, 2010)

Consider the available precipitation record and hydrograph for the following rain event:

![Graph showing hourly precipitation and discharge over several days in spring 2010.](image)

**Figure 22.** Hydrograph and precipitation record over several days in spring 2010 including rain event XI (shaded in grey). *60-minute* instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event XI, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 23.
Figure 23. Magnified view of precipitation and discharge for rain event XI on March 22, 2010 shown in Figure 22. Grey shading denotes the duration of rain event XI referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(35) What is the **outgoing** total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

5%__________ 50%__________ 95%__________
Storm XII: Spring storm (April 13, 2010)

Consider the following precipitation record and hydrograph for a spring rain event:

Figure 24. Hydrograph and precipitation record over several days in spring 2010 including rain event XII (shaded in grey). 45-minute instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event XII, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 25.
Figure 25. Magnified view of precipitation and discharge for rain event XII on April 13, 2010 shown in Figure 24. Grey shading denotes the duration of rain event XII referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(36) What is the **outgoing** total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

<table>
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<tr>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
</thead>
</table>

Coastal Plain BMP Retrofits in 2011 & 2012

In 2011 and early 2012, BMPs at sites Q and R were retrofitted in an effort to improve sediment and nutrient retention. Below are the available descriptions of those retrofits. Note that Questions #37 to 43 ask you to estimate TN loads – at the watershed-scale, and for each of the two BMP sites - after the retrofits were completed. Questions #44 to 50 ask you to estimate incoming and outgoing TN loads for the BMPs at these sites assuming both pre-retrofit or post-retrofit conditions.

Site Q – parking lot with linked bioretention structures with underdrain

The grassy, vegetated areas at Site Q were recently converted into two, linked bioretention structures with underdrains. As before, this bioretention structure treats runoff from a commuter parking lot and the surrounding area. Soil type in the drainage area includes Type B (0.0081 km²): silt loam or loam, moderately well drained with moderate infiltration rate and Type D (0.0182 km²): clay loam, silty clay loam, sandy clay loam, sandy clay or clay with very low infiltration rates. The bioretention structure at Site Q was designed according to the Maryland Stormwater Manual as follows:

- The combined bioretention structure is sized to manage the water quality volume (WQV) associated with a 1-inch storm.
- Both the small and large areas of the bioretention structure are equipped with underdrains due to predominantly poorly draining soils.
- Both structures have a perimeter sand filter, a gravel diaphragm, and a 5-8 cm mulch layer.
- The smaller bioretention structure located in the center of the parking lot and is 177 m² in area. The larger structure is 720 m² in area.
- Underdrains connect the two structures and combined filtered flow is conveyed under the road through a modified culvert to a dry swale.
Figure 26. Site Q: A drainage area (purple) containing retrofitted linked bioretention retention with underdrains. Red dot indicates the downstream drainage location of the drainage area. The grassy, vegetated areas receiving most of the runoff are outlined in green. Yellow arrow indicates direction of flow.
Figure 27. Close-up view of construction plan for the bioretention structure at Site Q.

Photo 4. Photographs of the larger of the two bioretention structures at Site Q. Image on the left shows the bioretention structure shortly after construction in summer 2011 and the culverts that drain excess runoff. The parking lot is in the foreground. The image on the right shows the structure while full of storm water.
Site R

The dry pond at Site R was recently retrofitted as a regenerative step-pool-conveyance structure. Soil type in the drainage area includes Type B (0.124 km$^2$): silt loam or loam, moderately well drained with moderate infiltration rate; Type C (0.0283 km$^2$): sandy clay loam, low infiltration rates; and Type D (0.0732 km$^2$): clay loam, silty clay loam, sandy clay loam, sandy clay or clay with very low infiltration rates. The step-pool conveyance retrofit uses a series of shallow pools, riffle grade controls, native vegetation, and an underlying sand and compost filter to treat, detain, and convey runoff. It was designed according to the Maryland Stormwater Manual as follows:

- The step-pool conveyance is sized to manage peak discharge from a 100-year storm, which is approximately 217 cfs (6150 L sec$^{-1}$).
- The filtration bed (344 m$^2$) is sized to manage the water quality volume associated with a 1 inch storm.
- The entire structure is approximately 200 m long consisting of 8 pools and 8 riffles, each 12 m long. Elevation drop along the length is 2.2 m. Riffle width is 9 m and riffle depth is 0.76 m.
- Filtered flow from the structure enters the storm sewer system via an ephemeral channel.
Figure 28. Photo and schematic of retrofit at Site R. Green oval indicates the location of the regenerative step-pool conveyance structure. Yellow arrows indicate direction of flow.
Figure 29. Close-up view of construction plan for the regenerative step-pool conveyance structure at Site R.

Photo 5. Photographs of the regenerative step-pool conveyance structure at Site R. The image on the left shows the final ponding basin (looking downstream). The image on the right (also looking downstream) shows the regenerative step-pool conveyance structure during Hurricane Sandy (2012).
### Table 4. Characteristics of the BMP retrofits described in the Coastal Plain scenario.

<table>
<thead>
<tr>
<th>Site</th>
<th>BMP type</th>
<th>BMP Drainage area</th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total (km²)</td>
<td>Impervious cover (%)</td>
<td>BMP area (m²)</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>grass swale with no underdrain</td>
<td>0.026</td>
<td>58.5</td>
<td>1795</td>
<td></td>
</tr>
<tr>
<td>Q</td>
<td>bioretention with underdrain</td>
<td>0.026</td>
<td>58.5</td>
<td>897</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>dry pond</td>
<td>0.23</td>
<td>43</td>
<td>1784</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>regenerative step-pool conveyance structure</td>
<td>0.23</td>
<td>43</td>
<td>1784</td>
<td></td>
</tr>
</tbody>
</table>
Storm XIII: Late spring storm (June 2, 2012) with post-retrofit Sites

Consider the following precipitation record and hydrograph for a summer rain event:

![Hydrograph and precipitation record](image)

**Figure 30.** Hydrograph and precipitation record over several days in summer 2012 including rain event XIII (shaded in grey). 60-minute instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event XIII, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 31.
Figure 31. Magnified view of precipitation and discharge for rain event XIII on June 1-2, 2012 shown in Figure 30. Grey shading denotes the duration of rain event XIII referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(37) What is the **outgoing** total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

5% ___________ 50% ___________ 95% ___________

BMP-level questions either pre- or post-retrofit (See above for BMP retrofit description, see Figure 15 for locations of BMP sites):

What is the nitrogen load (kg TN) at the following locations:

(38) **Incoming** TN load to bioretention structure at Site Q:

5% ___________ 50% ___________ 95% ___________
(39) **Outgoing** TN load from bioretention structure at Site Q (i.e., **post**-retrofit):

5%__________  50%__________  95%__________

(40) **Incoming** TN load to regenerative step-pool conveyance structure at Site R:

5%__________  50%__________  95%__________

(41) **Outgoing** TN load from the dry pond at Site R (i.e., **pre**-retrofit):

5%__________  50%__________  95%__________

(42) **Outgoing** TN load from regenerative step-pool conveyance structure at Site R (i.e., **post**-retrofit):

5%__________  50%__________  95%__________
Consider again Storm XII: Spring storm (April 13, 2010) with post-retrofit Sites

The following precipitation record and hydrograph for this spring rain event are shown again for your convenience:

Figure 32. Hydrograph and precipitation record over several days in spring 2010 including rain event XII (shaded in grey). 45-minute instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event XII, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 33.
Figure 33. Magnified view of precipitation and discharge for rain event XII on April 13, 2010 shown in Figure 32. Grey shading denotes the duration of rain event XII referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

**Watershed-level question:**

(43) What is the outgoing total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

5% __________  50% __________  95% __________

**BMP-level questions either pre- or post- retrofit (See above for BMP retrofit description, see Figure 15 for locations of BMP sites):**

What is the nitrogen load (kg TN) at the following locations:

(44) **Incoming** TN load to bioretention structure at Site Q:

5% __________  50% __________  95% __________
(45) **Outgoing** TN load from bioretention structure at Site Q (i.e., *post*-retrofit):

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<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
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(46) **Incoming** TN load to regenerative step-pool conveyance structure at Site R:

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<th></th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
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(47) **Outgoing** TN load from the dry pond at Site R (i.e., *pre*-retrofit):

<table>
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<th></th>
<th>5%</th>
<th>50%</th>
<th>95%</th>
</tr>
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</table>

(48) **Outgoing** TN load from regenerative step-pool conveyance structure at Site R (i.e., *post*-retrofit):

|           | 5%           | 50%          | 95%          |
Rain event XIV: Tropical Storm Nicole (September 30 – October 1, 2010)

On September 30 to October 1, 2011, a 1 in 100 year storm (Tropical Storm Nicole) hit the region. Consider the precipitation record and hydrograph for this sub-watershed:

Figure 34. Hydrograph and precipitation record over several days in summer 2012 including rain event XIV (shaded in grey). 60-minute instantaneous discharge measurements were taken at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Gaps in the precipitation record reflect missing data. Magnified views of hydrograph and precipitation records for rain event XIV, including cumulative totals for sampling time, discharge and precipitation are shown in Figure 35.
Figure 35. Magnified view of precipitation and discharge for rain event XIV on September 29 – October 1, 2010 shown in Figure 34. Grey shading denotes the duration of rain event XIV referenced in the questions below. Discharge was measured at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data were collected at a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(49) What is the outgoing total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

5% 50% 95%

BMP-level questions either pre- or post- retrofit (See above for BMP retrofit description):

What is the nitrogen load (kg TN) at the following locations:

(50) **Incoming** TN load to bioretention structure at Site Q:

5% 50% 95%
(51) **Outgoing** TN load from bioretention structure at Site Q (i.e., **post**-retrofit):

5%______________ 50%______________ 95%______________

(52) **Incoming** TN load to the dry pond at Site R:

5%______________ 50%______________ 95%______________

(53) **Outgoing** TN load from the dry pond at Site R (i.e., **pre**-retrofit):

5%______________ 50%______________ 95%______________

(54) **Outgoing** TN load from the regenerative step-pool conveyance structure at Site R (i.e., **post**-retrofit):

5%______________ 50%______________ 95%______________
**Rain event XV: Hypothetical back-to-back extreme events**

We now ask you to consider the same tropical rain event and this *hypothetical* hydrograph record. Again considering the extreme storm on September 30 – October 1, 2010 (Tropical Storm Nicole), consider that an extreme storm of equal magnitude occurred just one month prior:

![Graph of precipitation and hydrograph](image)

**Figure 36.** Precipitation record and hydrograph over several weeks for the Coastal Plain sub-watershed. Two consecutive extreme storms (1 in 100 years) occur one month apart. Total precipitation amount for 2010 remains the same for this hypothetical example. Instantaneous discharge is at 60-minute intervals at the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data are for a sampling station 15 km to the northwest.
Figure 37. Magnified view of precipitation and discharge for rain event XV on September 30 and October 1, 2010 shown in Figure 36. Grey shading denotes the duration of rain event XV referenced in the questions below. Discharge is for the sub-watershed outlet, indicated as a star in Figure 15. Precipitation data is for a sampling station 15 km to the northwest. Cumulative totals for sampling time, discharge and precipitation are provided within the plot.

Watershed-level question:

(55) What is the outgoing total nitrogen load (kg TN) from the watershed outlet over the entire duration of this storm?

5%______________     50%______________     95%______________

BMP-level questions either pre- or post- retrofit (See above for BMP retrofit description):

What is the nitrogen load (kg TN) at the following locations:

(56) Incoming TN load to bioretention structure at Site Q:

5%______________     50%______________     95%______________
(57) **Outgoing** TN load from bioretention structure at Site Q (i.e., **post**-retrofit):

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(58) **Incoming** TN load to the dry pond at Site R:

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(59) **Outgoing** TN load from the dry pond at Site R (i.e., **pre**-retrofit):

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]

(60) **Outgoing** TN load from the regenerative step-pool conveyance structure at Site R (i.e., **post**-retrofit):

\[
\begin{array}{ccc}
5\% & 50\% & 95\% \\
\end{array}
\]