Final Report on Measurement of Phosphorus Loads at Alewife Brook

Grantor: Tufts Community Research Council  
Award to Mystic River Watershed Association  
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Abstract

The Mystic River Watershed Association (MyRWA) engaged in a pilot project, in partnership with Professor John Durant and Masters student Kate Munson, to perform an initial study on the measurement of phosphorus loads at Alewife Brook. To quantify the load of phosphorus carried by Alewife Brook, the team measured the concentration of total phosphorus, orthophosphate, total Kjeldahl nitrogen and turbidity during multiple storm events. An ISCO 6712 autosampler was installed on Alewife Brook within a locked cabinet. Data was gathered during five storms between April and August 2014 – with event mean concentrations calculated on four of the storms to date. The team developed R code to compile and analyze the precipitation events and water quality data from all storms. Ms. Munson began study on advanced regression tools (ESTIMATOR MODEL) and SWIMM that will be used to model phosphorus loads and allow for analysis of climate change scenarios. MyRWA applied to grants from the Massachusetts Department of Environmental Protection – 604B and 319 programs for additional study on phosphorus loads in the watershed. MyRWA will continue to collaborate with Ms. Munson through the end of 2014 to reach the goal of studying 8-10 storm events.
Background on Phosphorus Pollution

In freshwater ecosystems, phosphorus is referred to as a 'limiting nutrient' because the abundance of this nutrient is the determinant of growth (nitrogen is the limiting nutrient in marine systems). Phosphorus can emerge from many locations in the urban environment including nonpoint-source pollution (stormwater runoff), leaking municipal infrastructure, sewage treatment facilities and sewer and combined sewer overflows. However, MyRWA has completed an initial analysis that estimates that 80% of phosphorus load to the Mystic River is the result of nonpoint-source pollution. This non-point source pollution refers to stormwater transporting the nutrients on fertilized lawns, driveways and impervious surfaces. To understand the quantity of phosphorus that the system can absorb before impairments are evident, the careful calculation of loads and modeling of response variables (e.g. dissolved oxygen) must be performed.

Policy and Regulatory Environment

In Massachusetts, the Department of Environmental Protection (MA-DEP) regulates nutrient pollution through development of ‘Total Maximum Daily Loads’ (TMDL). As every water body has a different capacity to absorb nutrients before an impairment emerges – a study specific to each water body is required to determine what amount of phosphorus can be absorbed by the water body. While the Mystic River and many tributaries in the watershed are listed as requiring a TMDL for phosphorus, the state has not conducted a study or begun work to make progress toward this goal. The Mystic River has not been a priority for the MA-DEP. In the neighboring Charles River Watershed, two TMDL studies were conducted during the past decade that is setting targets for phosphorus reduction. In watersheds without a TMDL, there are only minimum requirements to address phosphorus inputs contained in the draft 2014 MS4 NPDES permit. The development of a TMDL for the Mystic and eventual reduction of phosphorus inputs will likely require the initiation of a study outside of MA-DEPs efforts. The initiation of the study in Alewife Brook is an important step forward toward regulation of phosphorus and addressing eutrophication in the watershed.

Research approach

The research deliverables that were originally proposed included testing of sampling strategies in the literature, collection of water quality samples from nine storms, development of event mean concentrations (EMCs) for each storm, calculation of P load for a typical year and a predictive analysis of P loading as impacted by climate change scenarios. As typically occurs during research efforts, the study was modified as a result of changes in available resources and progress within the timeframe of grant cycle. A number of the deliverables have been altered and a number of the proposed deliverables will be delayed until the last few months of the year.
The following table highlights the deliverables of the project and status of completion:

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Status</th>
<th>Expected Date of Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Testing of sampling strategies in literature</td>
<td>Discontinued</td>
<td></td>
</tr>
<tr>
<td>2. Revision of existing Quality Assurance Project Plan</td>
<td>Completed</td>
<td>July 1, 2014</td>
</tr>
<tr>
<td>3. Collection of water quality samples from nine storms</td>
<td>Five (5) storms have been sampled to date.</td>
<td>Dec. 1, 2014</td>
</tr>
<tr>
<td>4. Development of EMC’s for each storm</td>
<td>EMCs calculated for each of first four storms – awaiting data for fifth storm</td>
<td>Dec. 1, 2014</td>
</tr>
<tr>
<td>5. Predicted analysis of P loading impacted by climate change scenarios</td>
<td>Masters student currently receiving training on SWMM modelling and LOADEST</td>
<td>Feb. 1, 2015</td>
</tr>
<tr>
<td>6. Approach funders to support work beyond pilot project</td>
<td>Applications submitted to MA-DEP CWA 319 and 604B funding to support further stormwater work</td>
<td>June 1, 2014</td>
</tr>
</tbody>
</table>

1. **Testing of sampling strategies in literature**

Project partners intended to examine three variables in the sampling literature: minimum threshold trigger, discrete versus composited samples and flow-weighted versus time-dependent sampling. The minimum threshold trigger refers to the increase in flow or stream height that triggers an automated sampling event. To test the discrete versus composite analysis approach, the team intended to use the first six storms to analyze sample results from six bottles collected during the storm (discrete) and a single composited sample for the storm. It was expected that the project would provide estimates of accuracy and error within the two approaches and recommendations for cost-effective analysis on other reaches. Finally, the team intended to evaluate the merits of flow-weighted and time-dependent sampling in the context of the hydraulics of Alewife Brook.

A project change was initiated however due to the inability to receive accurate flow data during storm events. The project intended to receive a data feed directly from the flow gauge managed by the United States Geologic Survey (USGS) on Alewife Brook. In early 2014, the USGS informed MyRWA that the gauge was of such age that it would not be able to provide the data feed to MyRWA without installation of an updated datalogger at a $35,000 cost.

MyRWA investigated the opportunity to install a bubble tube to detect height in stream and detect flow rates. Further investigation determined that the back water effects from operation of the Amelia Earhart Dam would not allow development of a rating curve for the river. As shown in Fig. 1 below, the gauge height data demonstrates a distinctive “saw-tooth” pattern associated with the tidal cycle below the dam and schedule releases of water from the river. The right panel shows that discharge is not correlated with gage height.
Fig. 1 Gauge height and discharge at Alewife Brook

3. Collection of water quality samples from nine storms
4. Development of EMCs associated with each storm

To quantify the load of phosphorus carried by Alewife Brook, the team decided that the only option available was to perform discrete sampling. A significant number of samples were collected during each storm to confirm the ability to calculate EMCs. The following table compiles number of samples collected for each storm:

<table>
<thead>
<tr>
<th>Date</th>
<th>Samples</th>
<th>Flow (m³)</th>
<th>TP EMC (mg/l)</th>
<th>TP Load (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TP</td>
<td>PO₄</td>
<td>Turb</td>
<td>TKN</td>
</tr>
<tr>
<td>April 15, 2014</td>
<td>24</td>
<td>24</td>
<td>24</td>
<td>0</td>
</tr>
<tr>
<td>May 17, 2014</td>
<td>17</td>
<td>17</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>June 25, 2014</td>
<td>14</td>
<td>14</td>
<td>14</td>
<td>0</td>
</tr>
<tr>
<td>July 27, 2014</td>
<td>11</td>
<td>0</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Aug 13, 2014</td>
<td>7</td>
<td>7</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Aug 31, 2014</td>
<td>8</td>
<td>0</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Sep 06, 2014</td>
<td>9</td>
<td>0</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Oct 16, 2014</td>
<td>9</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>
Sampling yielded a predictable behavior of first flush associated with storms. Results from April 2014 Storm is representative of the pattern of results from other storms:

**Fig. 2 Flow and concentration of Total Phosphorus**

![Flow and concentration of Total Phosphorus](image)

The Mystic River Watershed Association has developed code to quickly summarize results of these storms as they become updated as well. As an example of the summary graphics that are produced to track outcome of the analysis, Fig 3 shows the concentrations of Orthophosphate, Total Kjeldahl Nitrogen, Total Phosphorus and Mill Brook during each of the four storm events with data. A full snapshot of coding output is provided at end of report.
Fig 3. Example summary of parameter concentration during storm events developed using R code

5. Predicted analysis of P loading impacted by climate change scenarios

Student Kate Munson is in the middle stages of training herself and applying the ESTIMATOR Model on questions regarding climate change.

The idea that climate variability may have a significant impact on the water cycle and nutrient losses is widely accepted by modern scientists (Jeppeson et al. 2009). The Intergovernmental Panel on Climate Change (IPCC) predicts that changes in winter rainfall are expected to enhance phosphorus loading to freshwaters in the temperate zone (IPCC, 2007). It is a complex endeavor to analyze climate change impacts on diffuse phosphorus losses in river catchments because they are influenced by multiple biogeochemical processes. However, increases in streamflow during the winter months will likely affect interactions between streams and their riparian areas, producing new patterns in runoff.

The ESTIMATOR model calculates concentrations of nutrients carried by rivers (Cohn et al, 1992). This model was chosen because it employs a statistical regression model in which the constituent concentrations are estimated based on easily acquired data, such as flow rate and Julian date.
ESTIMATOR is a 7-parameter, log-linear regression model that uses stream discharge, time, and season to predict in-stream constituent concentrations using the following general equation:

\[
\ln[\text{concentration}] = \beta_0 + \beta_1 \times \ln(Q) + \beta_2 \times \ln\left(\frac{Q}{Q_c}\right) + \beta_3 \times \left\{\ln\left(\frac{Q}{Q_c}\right)\right\}^2 + \beta_4 \times \ln(Q_t_{-1}) + \beta_5 \times \\
\sin\left(\frac{2\pi J}{365}\right) + \beta_6 \times \cos\left(\frac{2\pi J}{365}\right) + \epsilon
\]

where \(Q\) is the discharge at the time of the sample, \(Q_t_{-1}\) represents the previous day’s discharge, \(Q_c\) is a flow centering term to remove multicollinearity, \(J\) is Julian day, and \(\epsilon\) accounts for error.

A second model used, which is based off of the ESTIMATOR model, follows a similar equation:

\[
\ln[\text{concentration}] = \beta_0 + \beta_1 \times \ln\left(\frac{Q}{Q_c}\right) + \beta_2 \times \left\{\ln\left(\frac{Q}{Q_c}\right)\right\}^2 + \beta_3 \times [J - J_c] + \beta_4 \times [J - J_c]^2 + \beta_5 \times \\
\sin[2\pi J] + \beta_6 \times \cos[2\pi J] + \epsilon
\]

where \(J_c\) is a time centering variable similar to \(Q_c\).

Early work has included application of both models on individual storms. Both models 1 and 2 performed very well, producing fairly high R-squared values and very low p-values. The following figures demonstrate how well both models fit the true total phosphorus measurements. Figure 4 shows that both models perform fairly well at predicting natural logged total phosphorus concentrations except for at the lowest peaks of data. It is also apparent that model 2 performs slightly better than model 1 in regions where observed phosphorus concentration follows a somewhat quadratic pattern. Figure 5 clearly demonstrates that both models adequately predict total phosphorus concentrations generally, but often overestimates or underestimates concentrations at the peaks. Again, model 2 appears to perform better than model 1.
Figure 4. Observed vs. Modeled Natural Log of Total Phosphorus Concentration

Figure 5. Observed vs. Modeled Total Phosphorus Concentration
Attempts are being made to improve the efficiency and results of this model. Using the model to predict total phosphorus loads, instead of concentrations, is likely to produce more finely tuned results, because loads more closely relate to discharge. As we come closer to modeling each storm more accurately, projected climate scenarios will be built into the model. As mentioned before, the IPCC predicts that variations in temperature and storm frequency are likely to arise as a result of shifts in global temperature.

Two scenarios will be examined to use the ESTIMATOR model to predict future climate change outcomes. First, a temperature variable will be added to the model. Once temperature changes are quantified and applied to the observed data, IPCC reports containing future temperature projections can be used to model what phosphorus concentrations and loads will look like given an increase in temperature. Second, a method to quantify increases in flow rate given more frequent winter rainstorms is being developed. Once rain event data has been acquired for the colder months at Alewife Brook, a predictive model will be developed. Once the model has been developed, changes in flow rate can be quantified within the predictive model to determine how total phosphorus concentrations will change given higher flow rates.

Projections will be developed which model climate scenarios 10 years from now, 50 years from now, and 100 years from now. Although the data being model applies to a small stream within the Mystic River watershed, even a small change in phosphorus loading could produce significant outcomes for residents within the watershed. Projections of this nature may be a useful tool to show regulators what could happen to river conditions if the phosphorus pollution problem is left unchecked.

In addition to the ESTIMATOR model, the EPA Stormwater Management Model (SWMM) will be calibrated to provide additional insight into phosphorus loading in Alewife Brook. SWMM is used for single event or continuous simulation of runoff quantity and quality. The runoff component of SWMM operates on a collection of subcatchment areas that receive precipitation and generate runoff and pollutant loads. For calibration purposes, three subcatchments will be modeled to provide a means for determining differences in pollutant loading given different land uses, levels of imperviousness, and stream hydraulic features. The model will help to determine spatial variability between locations and estimate production of pollutant loads associated with stormwater runoff. SWMM may also be useful in locating likely sources of phosphorus pollution.

Much like the ESTIMATOR model, SWMM will be used to assess possible future climate scenarios. Because the ESTIMATOR model is statistics-based and the SWMM model is a mechanistic model, the two models will be compared to provide insight into model differences pertaining to climate change projections. SWMM has been used previously to predict hydrological responses to climate and land cover change. However, SWMM modeling literature relating to the effects of climate change on nutrient pollution is fairly sparse. A study of this nature has the potential to be published in scientific literature because it applies well-known modeling techniques to the not so well known nature of nutrient loading under climate change.
6. Approach funders to support work beyond pilot project

The Mystic River Watershed Association applied for significant funding from two funding opportunities managed by the Massachusetts Department of Environmental Protection. The first program is the 604(b) Water Quality Management Planning Grant program. Rules stipulate that only planning agencies and municipalities may apply for these funds. Our organization approached the City of Medford to act as an official recipient to these funds and received affirmation of their willingness to serve in this role. We were expecting to receive notification during June 2014 but no official announcement has been made.

The Mystic River Watershed Association applied for a much larger, significant source of funds from the 319 Nonpoint Source Competitive Grant Program. We learned on September 4, 2014 that we were declined for funding. The Mystic River Watershed Association will continue to seek funding but the likelihood is that sources of funding will be smaller and specific to tasks within a larger project scope.

Partnership Development

The funding provided by TCRC has rekindled a collaborative partnership between Professor Durant and the Mystic River Watershed Association. The involvement of Dr. Durant in Mystic River water quality issues is extremely important to MyRWA as there is no other who has engaged the water quality and sediment issues in the watershed at such a consistent and high level. Funding available in previous years allowed Dr. Durant to assay sediment contaminants with the USGS, assess phosphorus flux in Spy Pond and create real-time assessments of recreation safety. This modest funding project allowed a renewal of work between Dr. Durant and MyRWA. MyRWA has submitted a small proposal to continue our work together on bacteria/recreation assessments and are optimistic of funding opportunities. We also see additional opportunity to work on nutrient pollution with Dr. Durant.

We have had a wonderful relationship with Tufts University - this award only further confirms our view of Tufts as a committed and valuable partner in the community. The funding allowed our organization to complete a pilot study on phosphorus loads in the Alewife Brook, develop strong working relationships with Professor Durant and student Kate Munson and seek additional funding.

Conclusion

TCRC funding has resulted in a number of favorable outcomes for the research efforts of the Mystic River Watershed Association. The most important aspect of this funding has been the opportunity to work closely with Professor John Durant and student Kate Munson. TCRC provided necessary funding to assist in establishing the research site – mostly in supporting the field time that Kate Munson dedicated to the project. Time that Kate Munson invested in the project allowed us to learn to optimize the sampling scheme and improve hardware setup. The results are also providing the first glimpse of nutrient dynamics in the watershed. The completed work puts the organization in a strong position to seek additional funding in the future. The Mystic River Watershed Association is extremely grateful to the support provided by TCRC.