Restoration Research Award Program

Final Report Narrative Questions

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Complete the final report narrative questions below. After completing your narrative questions, save this document on your computer and then submit the document via your Chesapeake Bay Trust Online System account. You can access your account using this link https://www.GrantRequest.com/SID_1520.

1. Awardee Information

Organization Name: Exponent, Inc.
Project Leader: William Goodfellow
Award Number: 16925
Date: 08/31/2020

2. Project Summary

a. Describe the project results achieved. Provide a before and after photo of the project, if applicable.

Exponent has completed all five phases of the project resulting in:

- Compiled and quality-controlled datasets of MS4 and USGS water quality monitoring,
- Annual estimates of pollutant loads, yields, and concentrations, for sediment, nitrogen, and phosphorus,
- Spatial analyses of best management practices (BMPs) implemented in watershed for which monitoring was conducted,
- Statistical analyses of the impact of BMPs on pollutant load, yield, and concentration reductions,
- Simulations of annual load estimation error for six different frequency sampling methods (monthly, weekly, weekly + storm, seven-hour, flow-paced, and MS4) from high-frequency (15-minute) USGS data,
- Regression models predicting load estimation error for each sampling method based on watershed characteristics (watershed size, discharge, baseflow index, flashiness index, % developed low-intensity, high-intensity and open space, % impervious surface, and & woody wetlands),
- BMP Evaluation Software that allows users to predict load estimation error for different sampling frequencies based on watershed characteristics, sampling cost, and expected load reduction, to interactively determine whether that load reduction can be detected using each sampling, given the inputted watershed characteristics,
- Collection of stakeholder feedback on the BMP Evaluation Software, implemented in the delivered version of the software,
- Collection of additional stakeholder-requested analyses, research questions, and further software development suggestions to further this research and these Tools,
- Web-accessible Shinyapps.io version of the Tools created for the CBT and stakeholders, as well as all code used to develop this app stored in a GitHub account created for the CBT from which future modelers, coders, and developers can further advance this research and these Tools.

3. Restoration Research Award Program Narrative Questions

a. What was/were your key restoration research question(s)?

This project addressed two major research questions:

1. What are the cumulative effects of watershed restoration activities within a watershed?

2. What degree of representative sampling is required to determine levels of pollutant discharge at a county scale?

To answer these questions, the hypotheses tested were:

1. An increase in BMP treated area by 0.6% of a watershed area reduces pollutant export by 5%.

2. Stream water sampling at seven-hour frequencies using an automated sampler is sufficient to reduce maximum load estimate error rates to 15%.

3. The uncertainty of pollutant loads estimated at different sampling frequencies significantly differs with watershed size, land use, area of impervious surface, rainfall, and hydrology.

b. What are the results for your research question(s)?

Hypothesis 1 was rejected since a 0.6% increase in BMP implementation by watershed area resulted in a $\leq$1% change in pollutant levels at MS4 monitored watersheds, and variable changes in MS4 and USGS watersheds combined, almost none of which were statistically significant.

Based on the input data used in this analysis, there is no obvious pattern between BMP implementation and pollutant reduction.

There may be several reasons for that, including:

- There may be other confounding variables that were not considered in the analysis.
- There is uncertainty in BMP accounting in each watershed.
- There are limitations of sampling methods that result in large uncertainty in annual pollutant estimates.

The second half of the project, evaluating Hypotheses 2 and 3, looked closer at the potential magnitude and effects of this sampling uncertainty.

Hypothesis 2 was rejected because seven-hour sampling produces load estimates with up to 60% error, so the suggestion that error is at maximum 15% is refuted.

Hypothesis 3 was not rejected since the uncertainty of load estimates does differ significantly with watershed characteristics and therefore can be predicted by watershed size, land use, area of impervious surface, rainfall, and hydrology.

c. List and describe the regulatory presentations and trainings provided.

The results of this research were presented at:

- the June 9, 2020 Pooled Monitoring Forum (https://cbtrust.org/wp-content/uploads/Lana.pdf),
- a webinar to solicit stakeholder feedback on July 30, 2020.

d. How can the findings be used for the regulatory community, for practitioners, for researchers, and others?

The regulated community, practitioners, researchers and others can use these findings to understand that:

- Re-purposing data for causal analyses is challenging – there are confounding issues of data quality, comparable monitoring methods, and unknown exogenous variables.

- Having large amounts of data from a number of monitoring sites is not equivalent to a before-after-control-impact (BACI) monitoring design.
- Accuracy and precision of annual sediment, phosphorus, and nitrogen pollution estimates are not only affected by sampling frequency but also the type of watershed in which sampling methods are applied.
- The right sampling methods need to be applied to make monitoring restoration projects worthwhile.

What do I take from this if I am a practitioner:

- The smaller the pollutant reductions from a project, the larger the investment needed in a high-resolution monitoring program that is able to detect the expected water quality benefits.
- Using tools such as the decision support tool developed in this project can be beneficial when deciding whether monitoring will be a worthwhile component of a project.

What do I take from this if I am a regulator:

- Temporally coarse monitoring will likely be ineffective at evaluating a restoration program's success. The financial burden of a scientifically weak monitoring program outweighs the benefits of the information gained.
- Evolving from broader regulatory monitoring to hypothesis-driven monitoring, with greater coordination between researchers, practitioners, state, and local agencies, will help maximize the scientific value of monitoring dollars and better audit implementation dollars.

Stakeholders noted that for some combinations of watershed characteristics and small expected load reductions as a result of BMP implementation, no sampling method was able to detect such small changes. This is incredibly useful information for an MS4 monitoring manager, and these kinds of insights are, in fact, part of the purpose of the type of Tool developed: to help decision makers understand the precision with which water quality monitoring in different kinds of watersheds is able to detect small changes in annual pollutant load. Because of the error inherent in these types of sampling methods, in concert with some variability-inducing characteristics of watersheds, there may be a bottom threshold beyond which load reductions are undetectable.

Overall, this project created incredibly useful insight as to the measurement of BMP impact using water quality monitoring data in a variety of types of watersheds across the Chesapeake region and the role of sampling uncertainty in that process. The developed BMP Evaluation Software toolkit enables stakeholders to interact directly with those results, inform management decisions, and sets the stage for directed future investigation and Tool improvement.

e. What future research is needed?

Suggestions for BMP Evaluation Software expansion, future model modifications, and follow-up research questions include:

- Amending the Tool to allow users to compare custom sampling methods beyond the current six sampling methods compared
- Predicting load estimation error from other types of watershed characteristics that may be easier to calculate than baseflow index and flashiness index, or develop defaults or in-Tool calculation methods for these inputs based on more straightforward watershed characteristics
- Widening the ranges of values of watershed characteristics to which the Tool applies, by fitting models to a broader dataset (e.g., including watershed with greater than 8% developed high intensity land cover)
- Amending the Tool to calculate regression coefficients specific to a user's selected watershed dataset, rather than using built-in regressions fit to a broader dataset
- Incorporating calculation of how long a particular monitoring plan needs to be in place in order to detect expected or desired load reductions as a function of BMP implementation (current Tool predicts results for an average year of monitoring)

- Calculating expected load reduction as a result of BMP implementation, taking into account sampling method error (current Management Tool does not model impacts of BMP implementation, just load estimation error for a particular set of watershed characteristics and sampling method, assuming constant BMP implementation)
- Inputting watershed characteristics for specific watersheds with BMPs implemented to determine whether MS4 monitoring within these watersheds was capable of detecting load reductions due to BMP installation

f. How and when did you provide the data for this project to the Chesapeake Bay Trust?

All data for this project have been uploaded to the CBT Grants webpage.

g. Provide the citation for the scientific paper in the peer-reviewed literature that was submitted.

There was no publication requirement as part of the deliverables of this project. Regardless, Josh Thompson and co-authors plan to submit scientific papers describing this research to the peer-reviewed literature and the Chesapeake Bay Trust will be informed upon acceptance and publication of these papers.

4. Project Evaluation and Lessons Learned

a. Discuss the project's goal(s) and evaluation(s). Include how the project measured success to meet the goal(s) and to report the outcome(s).

This project focused on evaluating two vital research questions: Understanding and quantifying, if possible,
(1) cumulative effects of watershed-scale restoration efforts, and
(2) frequency/type of sampling required to determine county-scale pollutant discharge levels.
This project measured success by establishing testable hypotheses and collecting data and developing models to quantitatively be able to reject or not reject these hypotheses, while also identifying data gaps and uncertainties. As such, the goals established in this project were met.

b. Discuss the greatest successes.

This project was most successful in directly and systematically quantifying annual load estimation error resulting from different sampling methods by simulating many iterations of six different methods from "true" high-frequency data, and helping practitioners and regulators clearly visualize the magnitude of such error attributable only to sampling method and sample size, in a way that is difficult, if not impossible, to do when evaluating only MS4 and other lower frequency sampling data results. This project truly helped elucidate how much information is missing, and the practical implications of that missing information on ability to detect desired and expected pollutant load reductions. The developed software, now available for CBT to distribute and share, as needed, will continue to help users evaluate these impacts of sampling uncertainty on the direct endpoints they care about (i.e., ability to detect pollutant load reduction), in the context of different watershed characteristics, making complicated models immediately and interactively accessible.

c. Discuss the greatest challenges, including the lessons learned, and potential roadblocks to future progress.

A challenge in testing Hypothesis 1 was informed by the analyses conducted to test Hypotheses 2 and 3, learning that the MS4 sampling method produces inaccurate load estimates with very large error estimates, which may explain why we did not observe significant relationships between BMP implementation and annual loads in Phase II of this project. Phase III analysis has confirmed that more frequent sampling is required to accurately predict annual loads with less error. This has important implications for assessing the cumulative effects of BMP implementation in watersheds draining to the Chesapeake Bay. A potential roadblock may be the political challenges associated with implementation of monitoring requirements that may not be able to answer the questions the monitoring was implemented to address.

d. Based on the results of the project, how would you refine and improve your project or approach in the future?

After examining some of the challenges associated with using low frequency monitoring observational data, to better be able to quantify and understand relationships between BMP implementation and pollutant load reduction, a well-designed, quasi-experimental BACI study may be able to more specifically answer such causal and practically applicable questions. If collecting fresh data is prohibitive, existing monitoring data may be used for such an approach, if sites are more carefully selected to be matched on watershed characteristics, and if data is available both before and after BMP implementation.

e. What advice would you give someone considering a similar project?

Such a project developing quantitative relationships and useful, interactive software tools could benefit from solicitation of stakeholder feedback after the planning and data analysis phase, but before software development, to incorporate feedback on software use in the software design *a priori*.

5. Final Project Deliverables

a. Provide all final products (e.g., final report, data, scientific paper, fact sheets, presentation, etc.) and any additional deliverables required per the approved award.

All deliverables for this project have been uploaded to the CBT Grants webpage.

Notes to awardees: 1) products may be externally reviewed and this may lead to revisions that should be factored into the budget and timeline and 2) for questions about your final report, contact the Trust program manager at 410-974-2941.

Additional guidance and resources are available online at https://cbtrust.org/forms-policies/.

Directions to submit your final report online:

1. Sign into your account using this link *https://www.GrantRequest.com/SID_1520* and the same username and password as when you applied.
2. Once signed in click on the Requirements tab.
3. If you do not see your requirement, use the dropdown on the right and in the middle of the page to shift between “Show: New” and “Show: In Progress.”
4. You should see below the yellow bar your Final Report link.
5. Click on the Final Report link and follow the instructions.
6. Once complete, click Submit & Review and make sure you have uploaded and entered all of the necessary information.
7. If so, click Submit.

To confirm your requirement was successfully submitted use the dropdown to shift between “Show: In Progress” and “Show: Submitted Requirements.”

Photos: Upload any photos, digital images, newsletter articles, or press clippings to supplement your written description. These supplemental files can be uploaded into your final report submission under “additional attachments,” located on your Chesapeake Bay Trust Online System account.

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