Development of an Efficient Optimization Framework for Improving Water Quality in the Chesapeake Bay Watershed

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In this study, we developed a framework for selecting and allocating the most cost-effective sets of Best Management Practices (BMPs) within the Chesapeake Bay Watershed to simultaneously reduce nitrogen, phosphorus, and sediment delivery to water bodies. This framework was built upon the Interior Point Optimizer nonlinear programming algorithm, designed to find local solutions to constrained optimization problems. To speed up the search process, we incorporated an approach based on Pareto optimality to reduce the dimensionality of the optimization problem and considered explicit acreage limits for BMPs allocation. The optimization algorithm was linked to the Chesapeake Assessment Scenario Tool (CAST) to simulate the effects of BMPs on surface water quality. The mathematical formulation of CAST allowed us to analytically derive gradient information (i.e., Jacobian and Hessian matrices) to boost the algorithm’s performance.

The framework was embedded into a web-based environment to set up and run various BMP optimization scenarios efficiently. Since BMP availabilities depend on the area of interest and source of funding, the user can indicate in the web application which BMPs to include or exclude during the optimization process. In addition, acreage limits for BMP placement can be defined depending on the spatial setting, funding agency, and load source. Other options include the maximum allowable BMP investment cost and load reduction targets, which are handled as optimization constraints. It is worth noting that the optimization process can account for the existing BMP implementation plan, then no duplication occurs due to the proposed optimization scenario. When the existing BMPs are of structural nature, they are considered as fixed and cannot be changed or removed during the optimization process. Currently, the framework and web-based application only consider efficiency BMPs, which are modeled as a reduction factor applied to outcoming pollutant loads from a land unit.

We compared our framework, written in C++, against an existing framework written in Python without dimensionality reduction or user-provided gradient information. Results revealed a substantial improvement in convergence, computation time, and the number of function evaluations when using the newly developed framework. Furthermore, optimized solutions showed lower implementation costs and pollutant loads compared to current watershed implementation plan scenarios. These improvements represent an opportunity to analyze different watershed management scenarios. In addition, launching the new framework within a web-based decision support tool facilitates dialogue among stakeholders, which will ultimately improve water quality in the Chesapeake Bay Watershed.