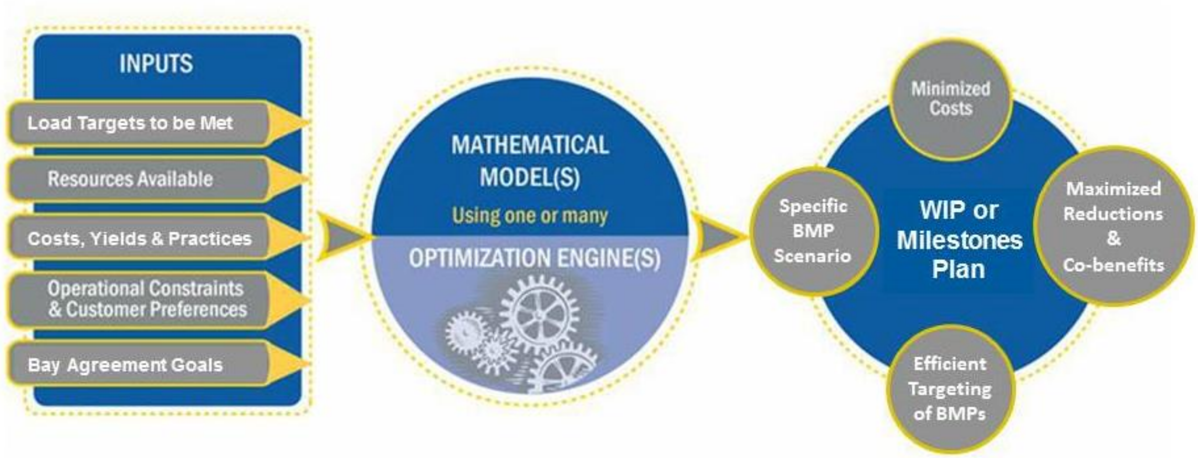
“Cracking the WIP”

Designing an Optimization Engine to Guide Efficient Bay Implementation



STAC Workshop Report
February 17-18, 2016
Annapolis, MD

STAC Publication 17-004

About the Scientific and Technical Advisory Committee

The Scientific and Technical Advisory Committee (STAC) provides scientific and technical guidance to the Chesapeake Bay Program (CBP) on measures to restore and protect the Chesapeake Bay. Since its creation in December 1984, STAC has worked to enhance scientific communication and outreach throughout the Chesapeake Bay Watershed and beyond. STAC provides scientific and technical advice in various ways, including (1) technical reports and papers, (2) discussion groups, (3) assistance in organizing merit reviews of CBP programs and projects, (4) technical workshops, and (5) interaction between STAC members and the CBP. Through professional and academic contacts and organizational networks of its members, STAC ensures close cooperation among and between the various research institutions and management agencies represented in the Watershed. For additional information about STAC, please visit the STAC website at www.chesapeake.org/stac.

Publication Date: July 6, 2017

Publication Number: 17-004

Suggested Citation:

Davis-Martin, J., O. Devereux, R. Batiuk, B. Hobbs, L. Wainger, R. Dixon. 2017. Cracking the WIP: Designing an Optimization Engine to Guide Efficient Bay Implementation. STAC Publication Number 17-004, Edgewater, MD. 36 pp.

Cover graphic derived from: IBM: Understanding Optimization
http://www-01.ibm.com/software/websphere/products/optimization/key-benefits/

The enclosed material represents the professional recommendations and expert opinion of individuals undertaking a workshop, review, forum, conference, or other activity on a topic or theme that STAC considered an important issue to the goals of the CBP. The content therefore reflects the views of the experts convened through the STAC-sponsored or co-sponsored activity.

STAC Administrative Support Provided by:

Chesapeake Research Consortium, Inc.
645 Contees Wharf Road
Edgewater, MD 21037
Telephone: 410-798-1283
Fax: 410-798-0816
http://www.chesapeake.org

Workshop Steering Committee:

James Davis-Martin (Virginia Department of Environmental Quality)
Olivia Devereux (Devereux Environmental Consulting, Inc.)
Rich Batiuk (US Environmental Protection Agency / Chesapeake Bay Program Office)
Ben Hobbs (Johns Hopkins University)
Lisa Wainger (University of Maryland Center for Environmental Science)

Acknowledgements:

STAC and the workshop steering committee would like to thank the following individuals for providing support during and after the workshop:

Workshop Presenters and Facilitators
Rich Batiuk
Mark Bennett
Darrell Bosch
James Davis-Martin
Olivia Devereux
Zach Easton
Ben Hobbs
Lew Linker
Tim Paris
Gary Shenk
Guy Stevens
George Van Houtven

Chesapeake Research Consortium Support Staff
Rachel Dixon
Renee Kelly

Table of Contents

Executive Summary

Developing an implementation plan that would accomplish the load reduction goals of the Chesapeake Bay TMDL appears relatively easy with our current suite of Chesapeake Bay Program (CBP) partnership tools. This can be accomplished by increasing the implementation levels of various best management practices (BMPs) until the desired load is achieved. However, developing an implementation plan that is equitable, minimizes costs, and takes advantage of opportunities to advance broad *Chesapeake Bay Watershed Agreement* goals and other potential co-benefits is not possible with existing tools. Further, nonlinear interactions of BMPs and the spatial variability of watersheds create challenges that are not fully addressed by our current methods of accounting for BMP effects. Models that can identify potential strategies for efficiently addressing multiple objectives of Bay management are needed.

These challenges need to be addressed to guide future planning for the Partnership's 2017 Mid-point Assessment, the Phase III Watershed Implementation Plan (WIP) development and 2018-2019 milestone planning and related goals. Optimization may provide a decision guidance methodology that guides solutions that helps decision makers achieve multiple goals while considering the complexities of a given watershed.

This report describes outcomes of a workshop with the purposes of 1) reviewing the state of optimization modeling approaches, 2) examining cases where optimization had been used in a water quality context, and 3) examining the capacity to integrate an optimization engine with existing tools developed by the CBP to guide WIP development. In exploring the strengths and weaknesses of optimization modeling approaches and some real world applications, it became clear that cost minimization was a key goal for the partners, but other goals and constraints were also important. These included:

1. Maximizing co-benefits, particularly those supporting *Chesapeake Bay Watershed Agreement* goals
2. Maximizing load reduction reliability
3. Equitable distribution of effort among jurisdictions
4. Equitable distribution of effort among source sectors
5. Limits on retirement of agricultural land
6. Ability to use the tool at various scales

Ultimately, the workshop participants defined the Bay optimization problem as follows:

Objectives:

- **Primary Objective:** Minimize total costs (capital, installation, opportunity and maintenance)
- **Secondary/Alternative Objective:** Maximize co-benefits

- **Tertiary Objective:** Maximize load reduction reliability (could also be implemented as a constraint)

Decision Variables:

- Implementation levels of all BMPs within a land-river segment (about 2200)
- Implementation levels of waste water facilities within a land-river segment (0-several)
- The sum of the above multiplied by the number of land-river segments for an optimization run. A county averages 10 land-river segments.

Constraints:

- Achieve user identified nitrogen, phosphorus and/or sediment load targets (by area, by sector, or both)
- User defined scale of scenario, and scale at which optimization would be run (county, multi-county, segmentshed, state-basin, basin, state, baywide, basinwide)
- User defined source(s) (agriculture, developed, septic, wastewater, natural, or any combination of these)
- User defined limits on BMP implementation levels (individually and by sector)
- Land use limits on BMP implementation levels
- User defined limits on agricultural land retirement

For a large scale, basinwide, optimization across all source sectors, this represents a multi-objective optimization with perhaps 40 million variables, many with non-linear response characteristics. At the smallest scale, a county, looking at only one source sector, the multi-objective optimization could be reduced to thousands of variables, but likely to still have some non-linear response.

The workshop participants identified the likely primary users for the system as:

- Local and county planning/public works agencies staff and managers
- State environmental, natural resources, and planning agencies staff and managers
- Regional planning/conservation districts
- Non-governmental organizations/environmental advocates
- Source sector interests
- Federal facility managers and staff

Participants agreed that the development of a Bay Optimization System should be on a timeline compatible with the Phase III WIP development process. Additionally, participants agreed that the development of a Bay Optimization System should be incorporated into the Partnership's on-line Chesapeake Assessment and Scenario Tool (CAST).

Recognizing the challenges of completing the full system capabilities in the proposed timeline, the participants suggested a stepwise approach to developing the Bay Optimization System. The goal is to complete steps 1-5 so that the tools and information are available to the Partnership as they begin development of the Phase III WIPs:

1. Take the collective feedback, discussions, and presentation from the workshop to develop an operational scope of work and set of requirements for system development.

   UPDATE: CBPO staff completed.

2. Convene and financially retain the services of a team of recognized optimization experts to continue to provide their expert input during the development of the CAST-based optimization tool.

   UPDATE: CBPO managers completed. Contract awarded to Chesapeake Research Consortium. Team of regionally and nationally recognized optimization experts convened and working.

3. Screen BMPs to identify dominant practices based on cost-effectiveness and co-benefits. Integrate tabular data regarding BMP cost effectiveness and BMP co-benefits into CAST. This will provide users additional insights for development of scenarios and exposure to some of the underlying data that will drive the optimization solution when the system is complete.

   UPDATE: Cost per BMP had previously been incorporated into CAST. Output provides the cost per scenario based on the level of BMP implementation. Additional information is provided on the cost per pound reduced for the progress and WIP scenarios. A project supported by the CBP's Water Quality Goal Implementation Team (WQGIT) to score BMP co-benefits has been completed by Tetra Tech and is available from CAST. However, the co-benefits are for each BMP and may not be summed for a scenario-wide score.

4. Establish a limited suite of optimized scenarios that cover common situations in the Bay watershed. These can serve as templates upon which users can build implementation scenarios that are informed by optimization prior to full deployment of the Bay Optimization System.
5. Deploy single-objective optimization system to minimize costs of achieving nitrogen, phosphorus, and sediment target loads using a select set of cost effective BMPs for which the pollution response is linear or well understood.
6. Apply co-benefits scoring building on results of single objective optimization
7. Deploy iteration of cost optimization system with additional constraints related to achieving specified level of co-benefits.
8. Expand understanding of BMP reduction reliability. Integrate tabular data regarding BMP reduction reliability into CAST.
9. Expand understanding of co-benefit quantification, monetization or benefit relevant indicators.

UPDATE: STAC Workshop *Quantifying Ecosystem Services and Co-Benefits of Nutrient and Sediment Pollutant Reducing BMPs* held March 29-30, 2017.

10. Continue driving towards true multiple objective optimization to maximize co-benefits and reduction reliability while minimizing costs, showing the tradeoffs that result when emphasizing different sets of objectives. By accounting for uncertain performance (reliability) of alternative strategies, the system could help guide adaptive management in future milestones.

The workshop included participants that were modeling/optimization experts as well as policy focused users of the modeling tools. Concurrent breakout sessions allowed for focused brainstorming and detailed discussions appropriate to each of the groups. Plenary sessions served to align ideas from the groups toward consensus. While this approach is resource intensive, requiring multiple facilitators and note takers, as executed in this workshop, the approach helped maximize participant involvement.

Introduction

This report summarizes a two-day STAC workshop held on February 17-18, 2016. The workshop explored alternative optimization techniques for use in potential decision-support tools to develop optimized implementation plans. Participants assessed common optimization objectives, decision variables and constraints for applicability to the Chesapeake Bay TMDL and the broader *Chesapeake Bay Watershed Agreement* goals. Finally, the attendees synthesized the information and recommend several detailed constructs for a Bay Optimization System. The workshop was attended by 45 participants representing experts in modeling and optimization as well as environmental managers representing all levels of government. The workshop agenda is included in Appendix A, the full list of attendees is provided in Appendix B, and the full set of workshop presentations are available at: http://www.chesapeake.org/stac/workshop.php?activity_id=251. The following list of management questions drove the planning and execution of the workshop.

- **What does optimization do?** How can it be useful in the context of Bay TMDL implementation planning, adaptive management and other Bay decision making? Who are the potential users of the system? What are the limitations of optimization systems?

- **What are the optimization objectives, decision variables and constraints that should be considered?** What are the key objectives to be modeled, and how can they be quantified? What technical, environmental, and regulatory constraints upon the decision variables are most crucial? Are there trade-offs or nonlinear interactions that should be considered?

- **What are the best mathematical optimization methods for use by the Bay Program given the identified objectives, decision variables, and constraints?** Consider the potential for incorporation into the Bay Program's existing decision-support tools.

- **What data inputs are needed to develop a Bay Optimization System?** Can information from monitoring trends be factored into the optimization system along with model data? How could results from a model uncertainty analysis be used to inform the optimization system?

The outcomes of this workshop provide the guidance that the Partnership needs to begin developing a Bay Optimization System on a timeline compatible with the 2017 midpoint assessment, Phase III WIP development and 2018-2019 milestone planning components. The workshop's recommendations facilitate the enhancement of the Partnership's existing suite of decision-support tools enabling the development of more equitable, efficient, and adaptive plans to achieve the Bay TMDL and other Bay Watershed Agreement goals.

Management Implications

Developing an implementation plan for achieving the goals of the Bay TMDL is relatively easy with CAST: simply increase the implementation levels of various BMPs until the desired load is achieved. However, developing an implementation plan that is equitable, minimizes costs, maximizes the achievement of the broader Bay Watershed Agreement goals and other potential co-benefits while accounting for nonlinear interactions of BMPs and the spatial variability of a complex watershed is currently impossible. Yet this detailed, cost effective and spatially variable plan is needed to meet the Partnership's mid-point assessment WIP and milestone planning goals. Optimization is a potentially useful approach to generating possible solutions for consideration that may better achieve the multiple goals while accounting for the complexities involved.

The Partnership's 2017 Chesapeake Bay TMDL midpoint assessment schedule calls for the development 2018-2019 Milestones and Phase III WIPs in late 2017 and by early 2019, respectively. Without the benefit of optimization based decision-support tools in place by that time, jurisdictions will be forced to continue using the existing approach of uniformly increasing implementation followed by trial and error adjustment as their mechanism for implementation planning.

Adaptive management is highlighted in the Bay TMDL and watershed jurisdictions' WIPs as a key component of the Bay TMDL accountability framework. Optimization tools will provide a tangible and useable way to adapt implementation approaches based on new information. Small adjustments in optimization constraints, variables and objective trade-offs, based on new information or understanding, will produce an adapted nominally optimal implementation scenario that can guide program and policy changes. Further, advanced optimization methods can be used to evaluate multistage strategies in which early actions lead to learning that can be used in later stages to fine tune implementation.

Introduction to Optimization

Workshop presentation by George Van Houtven, RTI International

Optimization systems can use any number of mathematical methods to consider a wide range of objectives, decision variables, constraints and the associated trade-offs to produce a recommended solution from the set of all feasible solutions. Objectives describe the outcomes to be pursued. Decision variables represent the variety of actions, how they can be distributed spatially and the interactions between them. Constraints are the limits placed on those actions. Collectively, these elements frame the optimization problem.

An example of a simple Bay TMDL optimization problem is:

Of all the possible types and combinations of feasible BMPs, which mix of BMPs will meet the TMDL load allocations at the lowest total cost?

In this example, the objective of the optimization problem is to minimize the total costs. The variables are all of the possible BMP types and extent of each that is used. The constraint is that the mix of BMPs in the solution must meet the TMDL load allocations. The optimization problem would be solved by evaluating multiple scenarios with different BMP combinations to determine their total cost and the resulting loads. Figure 1 represents the potential Pareto Front for cost minimizing scenarios and the solution that minimizes the total costs while also achieving the necessary load reduction.

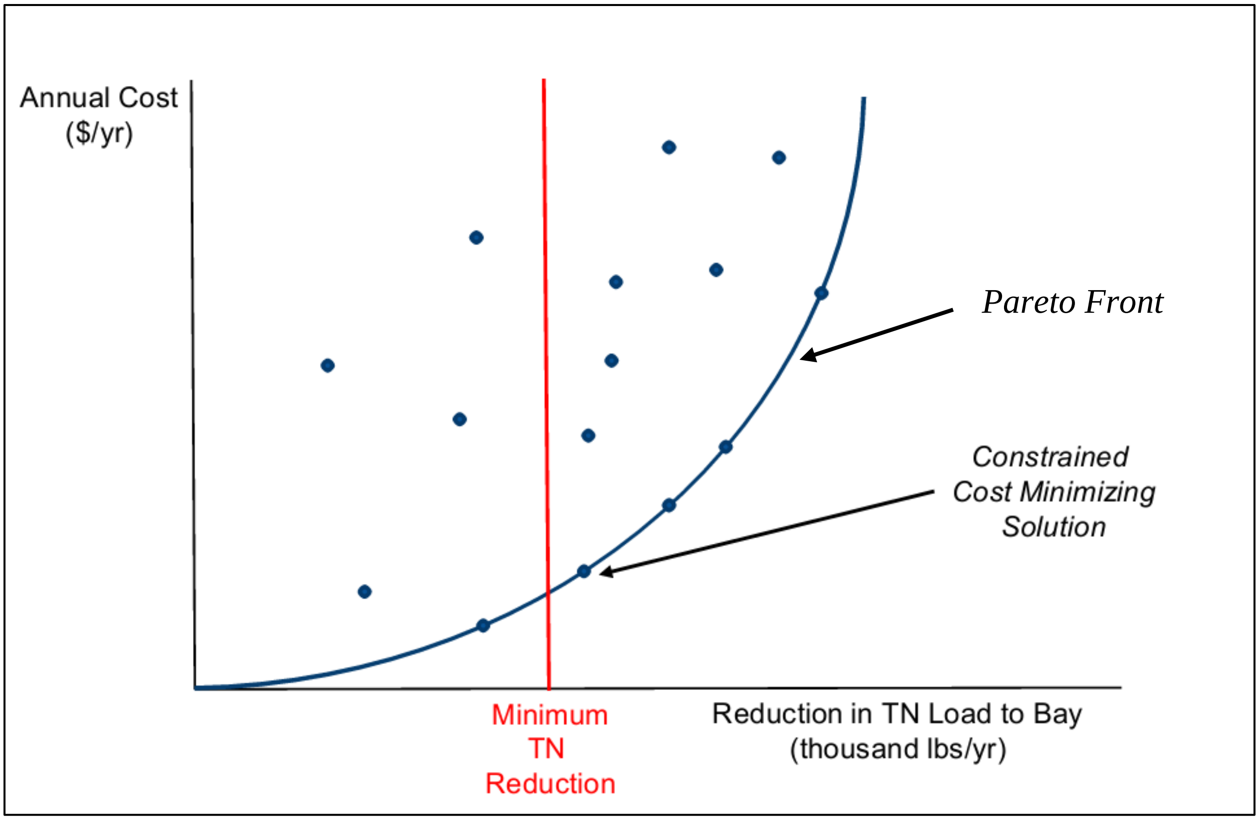


Figure 1. Pareto Front example.

While decision makers could use this simple optimization problem to produce a solution that minimizes costs, that solution may include a mix of BMPs that are scientifically, socially, and/or politically unacceptable. To address these concerns, additional constraints would need to be applied. For example, we may want to be more specific in the load constraint, specifying the loads for each sector and jurisdiction. We may also need to constrain the extent of one or many BMP types, such as limiting the extent of cover crops to ensure continued production of winter wheat. There may also be the need to constrain a combination of BMPs, such as limiting the extent of active agricultural land that can be taken out of production through a combination of land retirement, tree planting, wetland restoration, and grass or forest buffer establishment. There is also the option of constraining one or more variables by specifying an exact value to use for the variable rather than establishing a minimum or maximum. This could be used to specify an area of land to be treated with the stormwater performance standard practice, for example.

Another complicating factor is the desire to consider more than one objective in an optimization problem. In our example, if in addition to minimizing the total costs, we also had an objective of maximizing the accomplishment of the Bay Watershed Agreement goals and outcomes, we would be looking to solve a multi-objective optimization problem. This can be accomplished by directly solving for the multiple objectives, which is often complicated by having different units for the different objectives (dollars and percent accomplishment in our example). Alternatively, the multi-objective optimization can be accomplished by defining a weighted combination of the individual objectives as the single objective, or treating the additional objectives as constraints and solving the single objective problem repeatedly using different values for that constraint.

In addition to numerous variables and constraints and the desire to solve for multiple objectives, the complexity of an optimization problem is also related to the response characteristics of the system. If every unit of additional implementation produced the same incremental response, the response surface is considered linear, continuous and smooth (See Figure 2). This makes the optimization problem relatively easy to solve. At the other extreme, an optimization problem where the response surface is non-linear, non-smooth and discontinuous (See Figure 3) more complex optimization engines and specialized approaches are required to solve the optimization problem.

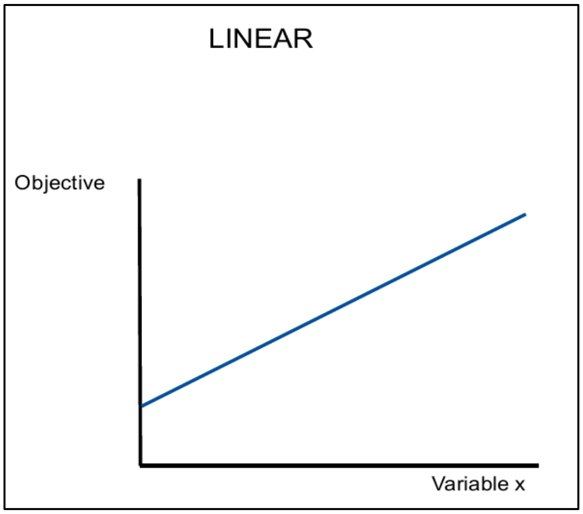


Figure 2. Linear response

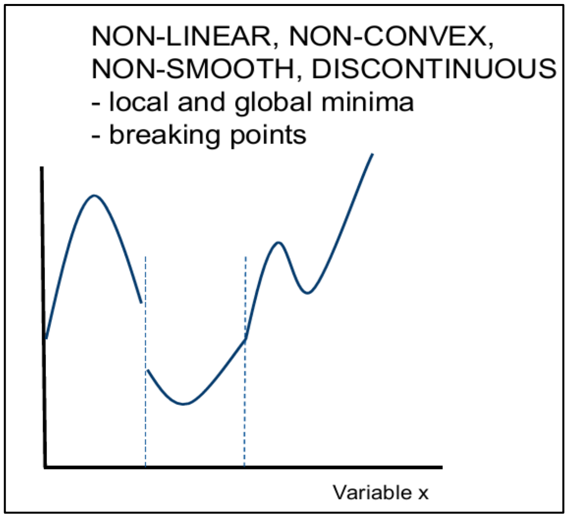


Figure 3. Non-linear, non-smooth and discontinuous responses.

Finally, optimization models can be static or dynamic and deterministic or stochastic. Thus far, the example we have described are static and deterministic, providing only the final BMP mix that achieves the TMDL at the least cost. A dynamic optimization would not only provide the final mix of BMPs but also the order and rate at which to install them over the remaining implementation period. A stochastic optimization would factor in uncertainty and solve for the probability of achieving the objective. A stochastic version of our example optimization problem might be: **Of all the possible types and combinations of feasible BMPs, which mix of BMPs will minimize costs such that there is only a 5% probability that the nutrient load limits will be exceeded.** As you have probably surmised, the use of dynamic or stochastic optimization also drive up the complexity of the optimization problem.

The more complicated an optimization problem is, the greater the computing resources and specialized optimization tools are needed to solve it. Optimization programs can be solvers or algorithms, computerized routines for solving specific types of optimization problems using systematic search methods to find the minimum or maximum point. Different solvers use different search methods to solve for the Pareto Front. Examples of solvers include:

- Simplex Methods for linear programming problems
- Newton Methods for smooth continuous non-linear optimization
- Genetic Algorithms for more complex non-linear non-smooth optimization

There are also optimization modeling software packages that allow users to formulate the optimization problem in mathematical terms and to draw from a menu of solvers depending on the type of problem. These can be commercial/proprietary software, which are usually more reliable and robust but also more expensive:

- General Algebraic Modeling System (GAMS)
- MATLAB
- Mathematica
- Excel Solver

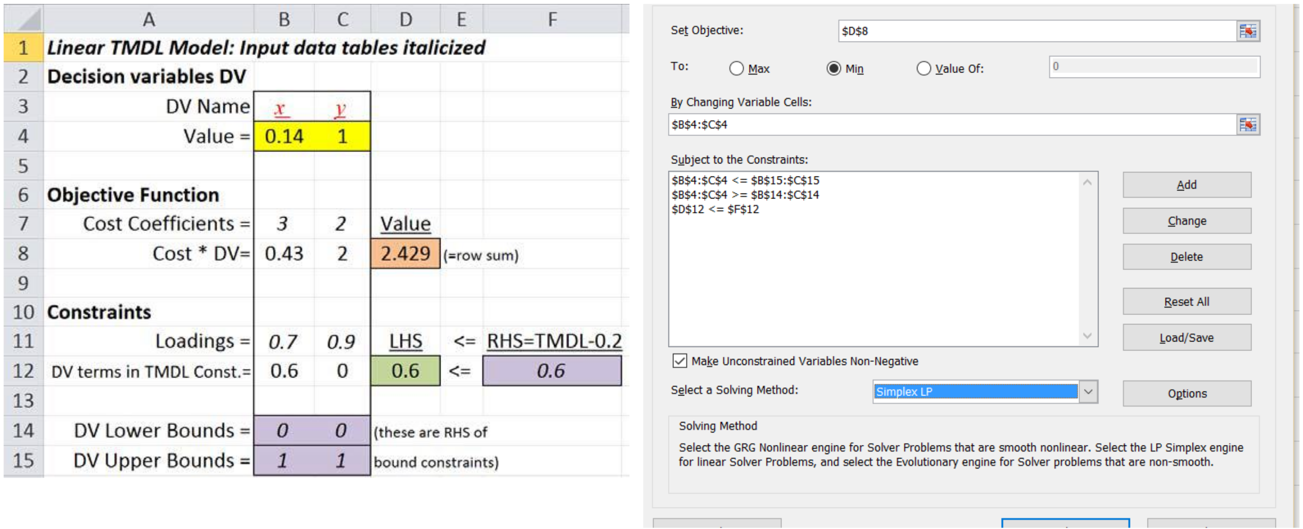
They can also be open source, such as

- Computational Infrastructure for Operations Research (COIN-OR)
- Dakota toolkit
- NEOS Server

Optimization Exercise

Workshop presentation by Ben Hobbs, The Johns Hopkins University

To help expand understanding of the basic concepts of optimization and the interactions between objectives, decision variables and constraints, the workshop attendees' participated in an exercise using Excel Solver. The exercise presented a simple linear optimization problem where BMPs x and y (decision variables) were to be implemented to achieve a specified reduction (constraint) at minimum cost (objective). Figure 4 shows the optimization problem set up in excel solver.



	A	B	C	D	E	F
1	***Linear TMDL Model: Input data tables italicized***					
2	**Decision variables DV**					
3	DV Name	*x*	*y*			
4	Value =	0.14	1			
5						
6	**Objective Function**					
7	Cost Coefficients =	*3*	*2*	Value		
8	Cost * DV=	0.43	2	2.429	(=row sum)	
9						
10	**Constraints**					
11	Loadings =	*0.7*	*0.9*	LHS	<=	RHS=TMDL-0.2
12	DV terms in TMDL Const.=	0.6	0	0.6	<=	*0.6*
13						
14	DV Lower Bounds =	*0*	*0*	(these are RHS of		
15	DV Upper Bounds =	*1*	*1*	bound constraints)		

Set Objective: $D$8

To: ○ Max ● Min ○ Value Of: 0

By Changing Variable Cells: $B$4:$C$4

Subject to the Constraints:

$B$4:$C$4 <= $B$15:$C$15
$B$4:$C$4 >= $B$14:$C$14
$D$12 <= $F$12

☑ Make Unconstrained Variables Non-Negative

Select a Solving Method: Simplex LP

Solving Method

Select the GRG Nonlinear engine for Solver Problems that are smooth nonlinear. Select the LP Simplex engine for linear Solver Problems, and select the Evolutionary engine for Solver problems that are non-smooth.

Figure 4. Excel solver optimization problem.

The workshop attendees then worked through a similar optimization problem but this time included a non-linear interaction between two of the decision variable BMPs, *y* and *z*. In each scenario, the participants then went through some "what if" analysis, modifying the constraints and decision variable cost coefficients to see how the optimized solution changed.

Working through these examples provided a better understanding and recognition of the utility of optimization to suggest good alternatives for further consideration while accounting for a large number of variables with complex interactions to achieve multiple objectives, examine tradeoffs and derive system performance risks. Specifically, participants recognized the potential applicability of optimization in the Bay TMDL implementation planning process to:

- Identify the least-cost portfolio of BMPs that achieves a TMDL;
- Efficiently address multiple objectives and understand the tradeoffs between them;
- Identify portfolios that are within X% of the least-cost portfolio, yet are distinctly different;
- Consider how uncertainty affects those solutions; and
- Consider where trades of pollutant credits could be environmentally and economically beneficial.

Examples of Optimization

BMP Choice for Nonpoint Source Control in the Minnesota Basin

Workshop presentation by Ben Hobbs

This case study of the Maple River watershed in southern Minnesota evaluated which BMPs to use in each of three sub-basins to reduce sediment loads. The optimization problem considered the uncertainty associated with the sources of the sediment and the tradeoffs of conducting additional research to help resolve the uncertainty. This is an implementation of adaptive management, in which early learning from initial actions helps to identify the optimal later (“recourse”) actions that modify and increase effectiveness of the plan. The optimization problem for this study was defined as:

Objective: minimize costs and sediment loads, probability weighted
Decision variables: seven BMPs treating four sediment sources
Decision variables: three research actions to improve understanding of sediment sources
Decision variables: three sub-watersheds
Constraint: sediment balance
Constraint: sensible combinations of BMPs

Publication: Jacobi, Hobbs & Wilcock, JWRP&M, 2013,
http://ascelibrary.org/doi/abs/10.1061/(ASCE)WR.1943-5452.0000282
Summary of follow-on study:
http://www.lcc.leg.mn/lwc/Meetings/2017/170327/Final%20Collaboration%20for%20Sediment%20Source%20Reduction%20Findings.pdf

StormWISE Optimization Screening Model for Stormwater Runoff Management

Workshop Presentation by Arthur E. McGarity, Department of Engineering, Swarthmore College

This case study of the Little Crum Creek Watershed in Suburban Philadelphia used the Storm **W**ater **I**nvestment **S**trategy **E**valuator (StormWISE) Optimization Screening Model to identify opportunities to reduce runoff volume and pollutant (nitrogen, phosphorus and sediment) loads while maximizing effectiveness of available funds. The tool prioritizes drainage zones, land uses, and urban green infrastructure BMPs for implementation while minimizing costs over entire watershed. This project used AMPL optimization software or Excel Solver to answer the following optimization problem:

Objective: minimize total costs over entire watershed
Decision variables: five urban green infrastructure BMPs
Decision variables: four developed land use categories
Decision variables: four sub-watersheds
Constraint: user specified pollutant reduction levels for sediment and nutrients

This presentation also described two tiers of watershed optimization models:

- **Low Resolution & Attribute Based** screening-level optimization identifies desirable attributes of potential BMP sites, but not the sites themselves.
    - Moderately detailed physical modeling can potentially be automated using GIS
    - Simplified & inexpensive to apply
    - Solution by classical methods or linear/nonlinear programming

- **High Resolution & Site Specific** watershed optimization attempts to identify specific sites throughout the entire watershed to prioritize for BMP installation
    - Very detailed physical modeling: distributed or small "lumps"
    - Expensive to apply
    - Solution by exhaustive search or heuristic (evolutionary) techniques

Finally, McGarity characterized a methodology for an ideal and complete watershed systems analysis as including:

- Geographic analysis
- Watershed simulation modeling and calibration with field data
- Low resolution optimization screening to prioritize attributes of potential sites
- Post-optimization simulation modeling for site selection and ranking

GreenPhilly Research Group: http://www.greenphilly.net
Philadelphia StormWISE demo: http://stormwise.greenphilly.net

Optimization Applied to Strategies for Achieving the Chesapeake Bay TMDL

Workshop presentation by George Van Houtven, RTI International

This presentation introduced an optimization modeling system developed for the Chesapeake Bay watershed to evaluate alternative strategies for achieving the Bay TMDL. The optimization model development was funded through projects for U.S. EPA (Office of Research and Development and the National Center for Environmental Economics) and for the Chesapeake Bay Commission.

The models analytical framework included a nine step process to identify the least-cost solution for achieving the Bay TMDL load limits and then estimate cost savings compared to non-optimized approaches. The inputs for developing the framework were based on the Bay Program's Chesapeake Bay Watershed Model (CBWM) Phase 5.3.2, including about 2,500 land-river segments; a simplification of the CBWM's 30 land uses into three crop, two pasture and two urban land uses; a subset of agricultural and urban BMPs and point source treatment tiers; their nutrient removal rates and annualized costs.

The optimization problem for this project was defined as:
Objective: minimize total costs of nutrient controls by selecting
Decision variables: number of acres of each BMP in each land-use category and land river segment (continuous) ~1.6 million variables
Decision variables: 16 possible treatment technology upgrades at 475 significant point source facilities (discrete)
Constraint: N and P delivered load reductions ≥ TMDL targets by basin OR by state OR by basin-state

Constraint: BMP treated acres ≤ available acres (by land-use and LR segment)
Constraint: agricultural land conversion BMPs ≤ ***X*** acres (by land-use and LR segment)

To avoid non-linearities, each feasible BMP combination was treated like a separate BMP with its own removal efficiency. To solve the resulting mixed discrete-continuous linear optimization problem, a Mixed Integer Linear Programming (MILP) approach was selected and solved using a branch-and-bound search method implemented in GAMS.

This base model was expanded to include a co-benefits objective of ecosystem services. The objective was refined to "minimize total NET costs of nutrient controls" with all of the variables and constraints remaining the same. The ecosystem services co-benefit included:

- Carbon sequestration and reduced greenhouse gas emissions
- Non-waterfowl hunting
- Duck hunting
- Air quality
- Brook trout habitat (non-monetized)
- Wetland water storage (non-monetized)

This more complex, but still simplified optimization framework was explored and recognized as potentially beneficial to Chesapeake Bay implementation planning in the 2011 EPA report entitled *An Optimization Approach to Evaluate the Role of Ecosystem Services in Chesapeake Bay Restoration Strategies* (https://www.epa.gov/sites/production/files/2014-03/documents/chesapeake-bay-pilot-report.pdf).

Meeting Water Quality Goals under Climate Change in Mahantango Watershed

Workshop presentation by Darrell Bosch and Zach Easton, Virginia Tech

This study assessed the effects of climate change on costs of meeting water quality goals from agriculture on a 423 hectare representative farm in the East Mahantango Creek watershed. Because climate change may affect variability of N loadings, N loading risk must be incorporated in the cost analysis. Safety first type models can be used to assess environmental risks by placing constraints on the probability of failing to meet the goal of reduced N loadings. The study used an upper partial moment approach to safety first (Qiu, Prato, and McCamley 2001), and used linear programming written in GAMS version 22.8 and MINOS solver.

This study's optimization problem was defined as:
Objective: maximize expected farm net revenue
Decision Variables: practices to reduce agricultural N loadings
Decision Variables: climate change projections
Constraint: land uses, animal numbers and manure disposal rules for representative farm
Constraint: crop rotations, livestock feeding requirements and crop nutrient requirements

Constraint: maintaining N loadings below a policy-determined level at a given probability, 14 loading constraints and 10 probabilities of exceeding the constraint

Overview of CBP Modeling System and Decision Support Tools

Workshop presentations by Gary Shenk and Olivia Devereux

These presentations described the construct of the Phase 6 Chesapeake Bay Watershed Model (CBWM) and the web-based decision support tools now in use by the Chesapeake Bay Program Partnership. Figure 5 depicts the various components of the Phase 6 CBWM.

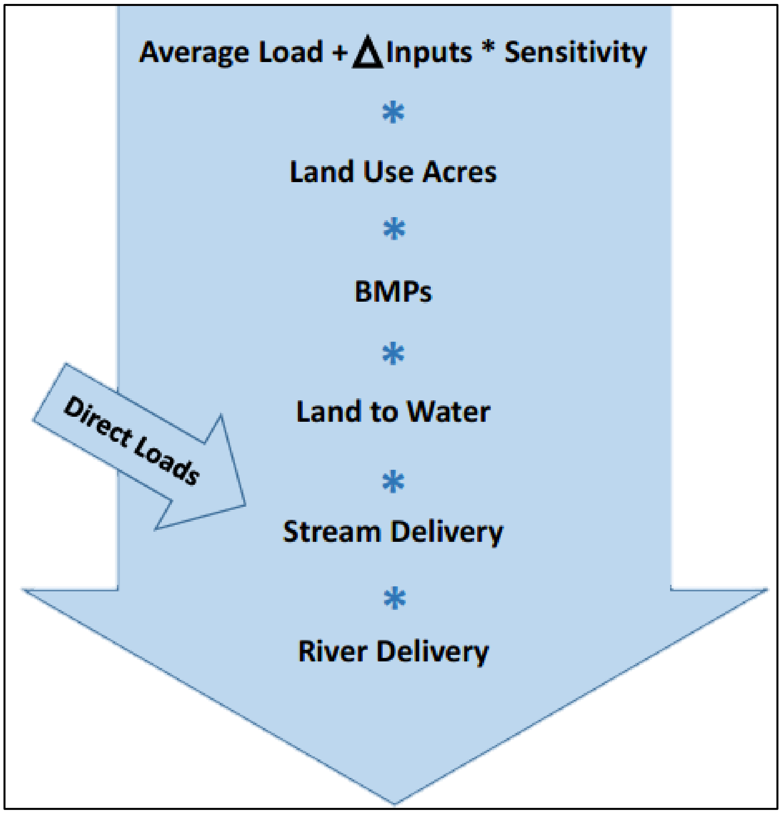


Figure 5: Phase 6 Chesapeake Bay Watershed Model structure.

This construct is built upon the 2049 land-river segments which collectively represent the Chesapeake Bay Watershed, each with its area split among up to 50 load sources and currently 12 agencies that split the land into the federal and non-federal load sources. The model essentially runs through the process depicted in Figure 5 for each combination of load sources and land-river segment to derive the loads for each pollutant. The Average Load and Sensitivity functions are fixed values for each land use, stored in look-up tables. The Land to Water, Stream Delivery and River Delivery factors are fixed values for each land-river segment, also stored in look-up tables.

The factors that represent policy levers include Δ Inputs, Land Use Acres and BMPs. While influenced by policy decisions, the Δ Inputs and Land Use Acres are largely the result of forecasted changes to land use, livestock population and the manure they generate. The main policy lever is Best Management Practices, BMPs. Currently the Bay Modeling tools include about 300 BMPs that can be applied to the various load sources. Some load sources have as few as three eligible BMPs, others have as many as 137 different BMPs that can be applied. The total of combined BMPs eligible on land uses is 2,175. Many of the interactions between BMPs are non-linear, non-smooth and potentially non-continuous in nature. The BMPs are also modeled differently, depending on their function. For example, some are efficiencies, but many are integrated into the nutrient generation and distribution portion of the models. The same BMP can also vary in terms of effectiveness by factors such as hydrogeomorphic region.

In addition to the Watershed Model, the Chesapeake Bay Program offers four web based decision support tools to facilitate development of plans that reduce nitrogen, phosphorus and sediment.

Facility Assessment Scenario Tool –BayFAST.org
Site specific planning tool where user defines the planning area and land uses.

Chesapeake Assessment Scenario Tool –CASTtool.org
Chesapeake Bay portion of NY, MD, WV, DE, DC, VA, PA included

Maryland Assessment Scenario Tool –MASTonline.org
Maryland-specific version of CAST. Maryland-specific geographies like State Highway Administration and Phase I and II areas are available through the interface. MAST also has loads available for historical years to assist with local TMDL watershed planning. [1]

Virginia Assessment Scenario Tool –VASTtool.org
Virginia-specific version of CAST. VAST is now identical to CAST.[1]

These tools provide an easily accessible system that can quickly and closely approximate the results of the Watershed Model. Users select the scale for their what-if scenario, then enter the extent of the BMPs and the land uses to which they should be applied. The tools output nitrogen, phosphorus and sediment load calculated for all source sectors for the specific what-if scenario. The tools also outputs to total annualized cost for the scenario based on established or user defined cost profiles for each BMP. The total costs included components for initial capital costs,

---

[1] Both the MAST and VAST tools will not exist in the Phase 6 version of the Chesapeake Bay watershed model as their full functionality will be built into the Phase 6 version of CAST.

opportunity costs and maintenance costs. The tools also allow for comparisons of acres, loads and costs among three user selected scenarios.

During the update of these tools scheduled for 2017, changes in the modeling system will allow the tools to produce results identical to those of the watershed model. With some changes to the user interface to allow for the selection of Objectives and the application of Constraints, these tools could serve as the foundation for a future optimization engine.

Defining Bay Optimization System Requirements

With the understanding of optimization and having seen several examples where optimization systems have been used, the workshop participants began to explore the user requirements of a future optimization system for the Chesapeake Bay. After brainstorming, discussion and dot voting by the workshop participants, the preliminary optimization problem was defined.

Primary objectives: minimize total costs (capital, installation, opportunity and maintenance)
Secondary objectives: maximize co-benefits
Tertiary objectives: maximize load reduction reliability
Decision variables: all BMPs within a land-river segment (about 2200)
Decision variables: implementation levels of waste water facilities within a land-river segment (0-several)
Decision variables: The sum of the above multiplied by the number of land-river segments for an optimization run. A county averages 10 land-river segments
Constraints: achieve user identified nitrogen, phosphorus and/or sediment load targets (by area, by sector, or both)
Constraints: user defined scale of scenario and optimization (county, multi-county, segmentshed, state-basin, basin, state, basinwide)
Constraints: user defined source(s) (agriculture, developed, septic, wastewater, natural, or any combination of these)
Constraints: user defined limits on BMP implementation levels (individually and by sector)
Constraints: land use limits on BMP implementation levels
Constraints: user defined limits on agricultural land retirement

For a large scale, basinwide, optimization across all source sectors, this represents a multi-objective optimization with about 41 million variables, many with non-liner response characteristics. At the smallest scale, a county, looking at only one source sector, the multi-objective optimization could be reduced to thousands of variables, likely still having some non-linear response.

The workshop participants identified a collection of potential co-benefits that could be important considerations for local partners. This following list is intended to supplement the various co-benefits associated with the outcomes in the 2014 *Chesapeake Bay Watershed Agreement*:

- Flood mitigation
- Air quality
- Drinking water protection/security (quality & quantity)
- Groundwater recharge/infiltration
- Bacteria loads
- Energy efficiency
- Combined sewer overflows (CSO) reduction
- Crime reduction
- Recreation
- Property values
- Economic development/jobs

Imagining the User Interface and User Experience

Workshop Breakout Session facilitated by Guy Stephens

In this facilitated breakout session, participants used a business case for an optimization system to explore the issues. They began by identifying potential users, or the audience for such a system, and the business needs those users might have for the system.

Primary users for the system as identified by the participants included:
- Local and county planning/public works agencies staff and managers
- State environmental, natural resources, and planning agencies staff and managers
- Regional planning/conservation districts
- Non-governmental organizations/environmental advocates
- Source sector interests
- Federal facility managers and staff

Other potential users included:
- NRCS state office staff and managers
- Technical service providers
- Watershed organizations
- Local elected officials
- County elected officials
- State elected officials
- Academic users

The group then identified the potential applications of the system from the perspective of the identified primary users.
- Help in development of state implementation plans (Bay Milestones and WIPs)

- Help in development of local implementation plans (local and Bay TMDLs)
- Develop sector implementation plans cost effectively
- Address the optimization of multiple co-benefits
- Minimize costs of BMP implementation
- Optimal use of BMPs on land use by county
- Make Bay TMDL load targets achievable
- Rethink the allocation of responsibilities by sector, by geography, by funding
- Recognize the value/influence of ecosystem services in local decision making
- Make Phase III WIP scenario that achieves nitrogen, phosphorus, and sediment targets for the lowest cost with the ability to tweak to see the different scenario costs
- Assist with the development of grant applications
- Help local governments document co-benefits of WIP implementation
- Identify cost savings within a source sector
- Provide a basic resource for planners to understand advantages and disadvantages of implementation options
- Assist progress towards other management strategy objectives

Participants then spent some time imagining, sketching and describing their vision of the optimization system's user interface. Some of the common elements included:

- Maps to select the geography of interest: state, local, county, watershed
- Pull down list to select the sector(s) of interest (selecting multiple sectors allows optimization across sectors when load targets are not sector constrained)
- Select the BMPs in toolbox by sector
- Constrain the levels of BMPs
- Identify the load targets to be achieved (by geography and/or sector(s) selected)
- Select objective: minimize annual costs, total costs, capital costs, etc.
- Select the co-benefits for consideration

Other components of the system might include:

- On the fly, updated optimization outputs using a series of graphics of costs and loads
- Help function, providing tutorials and training and contacts
- Selection of simple vs. advance version–the simple version would use default settings for many of the inputs and produce results quickly whereas the advanced version would allow user to customize selections possibly having to send results the next day
- Series of sliders for selecting the relative importance of various co-benefits to the user
- Selection of BMP implementation constraints using sliders
- Identify cost constraints
- Select output options

Participants recognized that the recommendations developed during this breakout should be validated prior to development of the optimizations tool. Potential mechanisms for a validation process include additional stakeholder interviews, potential user surveys, or additional workshops, among other techniques.

Findings and Recommendations

Participants agreed that the goal is to develop a Bay Optimization System that facilitates development of implementation scenarios that minimize costs and maximize the achievement of the broader Bay Watershed Agreement goals and other potential co-benefits while accounting for nonlinear interactions of BMPs and the spatial variability of a complex watershed. Local governments may be able to use the co-benefits information to identify other priorities that may be advanced by their actions, thereby expanding support for implementation. The development of a Bay Optimization System should be on a timeline compatible with the mid-point assessment, Phase 3 WIP and ongoing milestone planning. The Bay Optimization System should be integrated into our existing suite of decision-support tools, likely through CAST.

Participants agreed that the ultimate optimization problem for this project could be defined as:

> **Primary objective:** minimize total costs (capital, opportunity, operations and maintenance)
> **Secondary objective:** maximize Co-Benefits
> **Tertiary objective:** maximize load reduction reliability (address uncertainty)
> **Decision variables:** all BMPs including trading and nitrogen/phosphorus exchange (up to ~300)
> **Decision variables:** all land uses (50)
> **Decision variables:** all land-river segments (2,049)
> **Constraints:** achieve user identified nitrogen, phosphorus and/or sediment load targets (by geographic scale, by sector, or both).
> **Constraints:** users want the ability to relax or tighten up constraints within sectors, between sectors, and across geographies.
> **Constraints:** user defined geographic scale (county, multi-county, segmentshed, state-basin, basin, state, basinwide)
> **Constraints:** user defined source(s) (agriculture, developed, septic, wastewater, natural, or any combination of these)
> **Constraints:** user defined limits on BMP implementation levels (individually and by sector)
> **Constraints:** land use limits on BMP implementation levels
> **Constraints:** user defined limits on Agricultural land retirement. Retention of farm land is a goal of several jurisdictions (One of the constraints should allow users to specify a maximum amount of farm land taken out of production)

The desire for a complex, fully functional Bay Optimization Systems is not without risks. Participants recognize the possibility that as the system gets more complex, with more objectives and constraints, unanticipated results may cause users to question the accuracy of the models themselves. Extensive training, user help functionality and system documentation may help minimize this risk.

Our first optimization priority should be the minimization of costs to achieve nitrogen, phosphorus, and sediment target loads using a select and constrained set of BMPs, with reporting on a short list of quantified co-benefits after the fact.

Second priority would be factoring in co-benefit scoring early on in the optimization process as opposed to after the fact reporting.

The third priority in the longer term would drive towards true multiple objective optimization to maximize co-benefits as well as minimize costs. Participants suggested that an exploratory first step could include setting up a limited suite of scenarios which cover a majority of situations users are going to face in the Bay watershed.

Conclusion

The development of the Bay optimization system as an integral and evolving component of the Chesapeake Bay Program partnership's suite of decision support tools will facilitate development of implementation plans and milestones that are equitable, minimize costs, and maximize the achievement of broader Bay Watershed Agreement goals along with other identified co-benefits. The Bay Optimization System will also empower informed adaptive management as the Bay Program Partnership strives to meet their collective Bay restoration goals for 2025.

The Partnership should work toward the goal of developing a true multi-objective optimization tool. As the system development progresses from screening to simulation then to optimization, data, information, and components should be integrated into the decision support tools as soon as they are available. A likely progression for the development of such components may include:

- BMP co-benefit scores to inform user choices
- Expanded understanding of BMP response and non-linearities
- BMP cost effectiveness data to inform user choices
- Identification of dominant BMPs
- Generic screening level optimization solutions
- Geographic targeting strategies
- Single objective optimization system to minimize costs of achieving nitrogen, phosphorus, and sediment target loads using a select set of cost effective BMPs where response is understood
- Application of some co-benefits scoring based on results of single objective optimization
- Iteration of cost optimization with co-benefit based constraints
- Expanded understanding of BMP reduction reliability
- Expanded understanding of co-benefit quantification, monetization or benefit relevant indicators
- Drive towards true multiple objective optimization to maximize co-benefits and reduction reliability as well as minimize costs.

References

Jacobi, S.K. 2009. Environmental Systems and Decision Analysis Models for Aiding Environmental Policy Decisions under Deterministic and Stochastic Settings, Ph.D. Dissertation, Dept. Geography & Environmental Engineering, The Johns Hopkins University.

Jacobi, S.K., B.F. Hobbs, and P.R. Wilcock. 2013. A Bayesian Framework for Cost-Effective Sediment Reduction in Agricultural Watersheds: Framework and Application to the Minnesota River Basin. J. Water Resources Planning & Management (ASCE), 139(5): 534-543.

Qiu, Z., T. Prato, and F. McCamley. 2001. Evaluating Environmental Risks Using Safety-First Constraints. American Journal of Agricultural Economics 83: 402-413.

United States Environmental Protection Agency (U.S. EPA). 2012. An Optimization Approach to Evaluate the Role of Ecosystem Services in Chesapeake Bay Restoration Strategies. U.S. EPA/600/R-11/001

United States Environmental Protection Agency (U.S. EPA). 2010a. Chesapeake Bay Phase 5.3 Community Watershed Model. EPA903S10002. CBP-TRS-303-10. Chesapeake Bay Program Office. Annapolis, MD.

United States Environmental Protection Agency (U.S. EPA). 2010b. Chesapeake Bay Total Maximum Daily Load for Nitrogen, Phosphorus and Sediment, Appendix L. Setting the Chesapeake Bay atmospheric deposition allocations. U.S. Environmental Protection Agency. Washington, D.C.

Van Houtven, G., R. Loomis, J. Baker, R. Beach, and S. Casey. 2012. Nutrient credit trading for the Chesapeake Bay: An economic study. Research Triangle Park, NC: RTI International.

Appendix A: Workshop Agenda

"Cracking the WIP"
Designing an Optimization Engine to Guide Efficient Bay Implementation

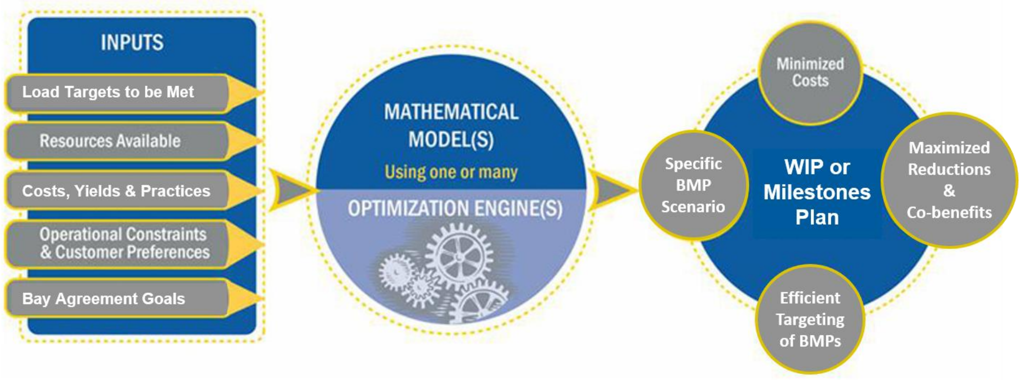
Scientific and Technical Advisory Committee Workshop

February 17-18, 2016

O' Callaghan Annapolis Hotel
Galway Suite, 4th Floor
174 West St. Annapolis, MD 21401
http://www.chesapeake.org/stac/workshop.php?activity_id=251

Workshop Objective: The workshop will explore alternative optimization techniques for use in potential decision-support tools to develop implementation plans and support adaptive management. Participants will assess common optimization objectives, decision variables and constraints for applicability to the Chesapeake Bay TMDL and the broader Watershed Agreements goals. Finally, the attendees will synthesize the information and recommend one or more potential detailed constructs for a Bay Optimization System. The following is list of management questions that should drive the planning and execution of the workshop.

- What does optimization do? How can it be useful in the context of Bay TMDL implementation planning, adaptive management and other Bay decision making? Who are the potential users of the system? What are the limitations of optimization systems?
- What are the optimization objectives, decision variables and constraints that should be considered? What are the key objectives to be modeled, and how can they be quantified? What technical, environmental, and regulatory constraints upon the decision variables are most crucial? Are there trade-offs or nonlinear interactions that should be considered?
- What are the best mathematical optimization methods for use by the Bay Program given the identified objectives, decision variables, and constraints? Consider the potential for incorporation into the Bay Program's existing decision-support tools.
- What data inputs are needed to develop a Bay Optimization System? Can information from monitoring trends be factored into the optimization system along with model data? How could results from a model uncertainty analysis be used to inform the optimization system?



Day 1: Wednesday, February 17, 2016

**Please note that agenda is subject to change as a result of workshop discussion*

Time	**Topic**	**Speaker**
9:30 – 10:00 am	**Registration and Coffee (provided)**	
10:00 am	**Introductions/Logistics/Agenda**	James Davis-Martin (VDEQ)
10:10 am	**Workshop Scope and Desired Outcomes** – The workshop is designed to generate consensus around clear requirements for building optimization features into the modeling tools.	Rich Batiuk (EPA/CBPO)
10:30 am	**Introduction to Optimization**—What is it, how it works, methods, common applications, strengths, weaknesses, data requirements, processing requirements.	George Van Houtven (RTI)
11:00 am break-outs ***Kilkenny Suite***	***For Policy/Planning Representatives –*** Optimization exercise using Excel to demonstrate how the method works numerically.	Ben Hobbs (JHU)
Galway Suite	***For Optimization/Modeling Experts –*** 5-minute Introductions to relevant work and expertise related to workshop	*Optimization/Modeling Experts*
12:00 pm	**Lunch (provided)**	
12:45 pm	**Examples of Optimization (20 mins each) –** Brief presentations will provide an overview of previous work and address the following topics: Methods, objectives, constraints and decision variables used, scale, processing/computation time for the system, who were the system users and their level of training, what components are most applicable for use in the Bay, any elements that were problematic.	1) Ben Hobbs/Arthur McGarity (Swarthmore) 2) George Van Houtven *Bay-wide* 3) Zach Easton/Darrell Bosch (Virginia Tech) *Regional*
2:25 pm	**Break**	
2:40 pm break-outs ***Kilkenny Suite***	***For Policy/Planning Representatives*:** **User "Requirements"** – what Bay implementation planners want from an optimization tool ("dream system"). Users include local government planners, state WIP leads, federal facility managers, advocacy groups etc. Topics include: scale, trading, N/P exchange, risk/reliability	Facilitated discussion – Tim Paris, Attain Users of the tools, not the optimization experts
Galway Suite	***For Optimization/Modeling Experts*:** **Overview of CBP Modeling System** and available data sets that could inform Optimization (include description of scale/data density, technical restraints)	1) Gary Shenk (USGS/CBPO) /Lew Linker (EPA/CBPO) *Models* 2) Olivia Devereux (Devereux Environmental Consulting)

	Learn more about models and data to help inform (e.g. CAST/Scenario Builder)	*Data & Tools* 3) Mark Bennett (USGS) *Monitoring*
3:55 pm	**Reconvene**	
4:00 pm	**Report back from Break-outs** – Report from user requirements, discussion, and assessment of difficulty to implement given available systems, data and tools	Facilitated discussion – Tim Paris, Attain
5:00 pm	**Prioritizing Requirements for Optimization – Informal Voting**	James Davis-Martin
5:30 – 7:00 pm ***John Barry Restaurant***	**Reception**	

Day 2: Thursday, February 18, 2016

**Please note that agenda is subject to change as a result of workshop discussion*

8:00-8:30 am	**Light Breakfast (provided)**	
8:30 am	**Agenda/Review of Desired Outcomes and Results of Requirements Voting**	Rich Batiuk (EPA/CBPO)
8:50 am	**Develop Outline of Objectives, Decision Variables and Constraints for Priority Requirements –** Decision variables include BMPs, nutrients, others.	Facilitated discussion – James Davis-Martin (VDEQ)
10:20 am	**Break**	
10:35 am break-outs ***Kilkenny Suite***	***For Policy/Planning Representatives*:** **User Interface + User Experience –** Define how policymakers and planners want to interact with an optimization tool.	Facilitated discussion – Guy Stephens (UMCES)
Galway Suite Policy representatives define the front-end user interface, while modelers frame out the back-end of an optimization system.	***For Optimization/Modeling Experts*:** Identify the best construct (method, models, data, and scale) for an Optimization System that meets the Priority Requirements. Determine "nuts and bolts" including data needs, processing needs (e.g. time to wait for scenario results, online or delivered later)	Olivia Devereux (Devereux Environmental Consulting)
11:50 am	**Lunch (provided)**	
12:35 pm Consensus building with small groups at each table	Decide on an approach to achieving priorities (e.g. computational platform, objectives that are optimized, etc.) The questions discussed here will be refined based on prior session results. Small groups of mixed expertise/background.	Rotate around tables (~20 mins each), with table ambassadors to record ideas from discussions.
1:50 pm	**Group Reconvene and Report Out**	*Table Ambassadors*
2:20 pm	**Break**	
2:35 pm	**Identification of Outstanding Questions** – Getting on the 'same page'	James Davis-Martin
3:20 pm	**Thank You/Wrap up/Next Steps**	Rich Batiuk
3:30 pm	**Adjourn**	

Appendix B: Workshop Participants

Name	**Affiliation**	**Email**
Allen, Greg	EPA/CBPO	allen.greg@epa.gov
Batiuk, Rich	EPA-CBPO	Batiuk.Richard@epa.gov
Bennett, Mark	USGS/CBPO	mrbennet@usgs.gov
Berg, Neil	RAND Corp	nberg@rand.org
Bisland, Carin	EPA/CBPO	bisland.carin@epa.gov
Bosch, Darrell	Virginia Tech	bosch@exchange.vt.edu
Busch, Greg	MDE	gregory.busch@maryland.gov
Cho, Se Jong	JHU	sejong@jhu.edu
Currey, Lee	MDE/CBP Modeling WG	lee.currey@maryland.gov
Davis-Martin, James	VADEQ	James.Davis-Martin@deq.virginia.gov
Devereux, Olivia	Devereux Env. Consulting	olivia@devereuxconsulting.com
Dixon, Rachel	STAC Staff	dixonr@chesapeake.org
Easton, Zach	Virginia Tech/STAC	zeaston@vt.edu
Fisher, Erik	CBF	EFisher@cbf.org
Gattis, Mary	Alliance for the Chesapeake Bay/LGAC	mgattis@allianceforthebay.org
George, Jim	MDE	jim.george@maryland.gov
Goulet, Norm	NVRPDC	ngoulet@novaregion.org
Hartman, Alana	WV DEP	alana.c.hartman@wv.gov
Hobbs, Ben	JHU	bhobbs@jhu.edu
Hung, Fengwei	JHU	fwhung0807@gmail.com
Hurd, Martin	DC DOEE	martin.hurd@dc.gov
Kelly, Renee	SESYNC (Formerly STAC Staff)	rkelly@sesync.org
Linker, Lewis	EPA-CBPO	LLinker@chesapeakebay.net
McGarity , Arthur	Swarthmore College	amcgari1@swarthmore.edu
McGee, Beth	CBF	bmcgee@cbf.org
Myers, Doug	CBF	DMyers@cbf.org
Paris, Tim	Attain	tparis@chesapeakebay.net
Phillips, Scott	USGS/CBPO	swphilli@usgs.gov
Power, Lucinda	EPA/CBPO	power.lucinda@epa.gov
Ribaudo, Marc	USDA/STAC	mribaudo@ers.usda.gov
Rigelman, Jessica	J7LLC	jrigelman@j7llc.com
Schwartz, Stu	UMBC/Coalition for Smarter Growth	stu_schwartz@umbc.edu
Shenk, Gary	USGS/CBPO	GShenk@chesapeakebay.net
Shortle, James	Penn State	jshortle@psu.edu
Sincock, Jennifer	EPA Region 3	Sincock.Jennifer@epa.gov
Stephens, Guy	UMCES/CBPO	gstephen@chesapeakebay.net
Swanson, Ann	CBC	aswanson@chesbay.us
Sweeney, Jeff	EPA/CBPO	jsweeney@chesapeakebay.net

Tesler, Ted	PA DEP	thtesler@pa.gov
Van Houtven, George	RTI	gvh@rti.org
Volk, Jennifer	U of Delaware	jenn.volk@udel.edu
Wainger, Lisa	UMCES/STAC	wainger@umces.edu
Wieland, Robert	Main Street Economics	robert.wieland@gmail.com
Wolf, Kristen	PA DEP	kwolf@pa.gov
Wood, David	EPA/CBPO	Wood.DavidM@epa.gov

Appendix C: Presentation Summaries

Introduction to Optimization
George Van Houtven, RTI International

Link to presentation: Introduction to Optimization

This presentation provided workshop participants with a broad overview of optimization methods and their potential uses in developing watershed implementation plans and other local strategies for meeting the requirements of the Chesapeake Bay TMDL. One objective was to provide participants who had limited previous exposure to optimization methods with an understanding of the basic concepts and approaches. Another objective was to introduce key tools and issues as a starting point for subsequent discussions in the workshop about how optimization methods could most usefully applied in the Chesapeake Bay context. The main questions addressed in the presentation were: (1) what is optimization and what are its main elements, (2) what are some of the main types optimization problems, (3) what are the main approaches for solving optimization problems, and (4) what types of modeling software are available for optimization? It defined optimization as a mathematical approach for analyzing and solving a particular type of decision problem – i.e., finding the "best" solution from the set of all feasible solutions, when the criteria for "best" depend on the decision context. It emphasized that optimization should be thought of as support tool for decision making rather than as a substitute for professional judgment. The main concepts and elements were illustrated using an example where the main objective was to minimize the total annual costs of meeting the TMDL load reduction requirements, by selecting the mix (types and acreage) of agricultural best management practices (BMPs) to be applied in a county. Several main types of optimization problems were described and compared, including most importantly distinctions between linear and nonlinear programming problems and single versus multi-objective optimization. The presentation concluded by discussing the main types solving algorithms that are used. In particular, it distinguished between and discussed the relative advantages of (1) more traditional gradient-based methods and (2) non-gradient-based methods (e.g. genetic algorithms).

Meeting Water Quality Goals under Climate Change in Mahantango Watershed
Darrell Bosch[1], Zach Easton[2], and Moges Wagena[2]
[1]Agricultural and Applied Economics
[2]Biological Systems Engineering
Virginia Tech

Link to presentation: Meeting Water Quality Goals

Elevated nutrient levels are acknowledged as the primary factor contributing to fish dieoffs, aquatic "dead zones" and increased primary productivity in many estuaries including the Chesapeake Bay. While numerous policies have been developed, perhaps the most comprehensive effort to address nutrient pollution in the Chesapeake Bay is the U.S. Environmental Protection Agency's Total Maximum Daily Load (TMDL) program. The program aims to insure that Best Management Practices (BMPs) to control nitrogen (N) and phosphorus (P) loadings are in place that will enable the Chesapeake Bay to achieve its designated uses and associated water quality goals by 2025. Agriculture is a major source of nutrient and sediment loadings to the Bay; consequently, the reduction of agricultural non-point source pollution is an important component of the Chesapeake Bay TMDL.

In this study we assess the effects of climate change on costs of meeting water quality goals from agriculture. Because climate change may affect variability of N loadings, N loading risk must be incorporated in the cost analysis. Safety first type models can be used to assess environmental risks by placing constraints on the probability of failing to meet the goal of reduced N loadings. We use an upper partial moment approach to safety first (Qiu, Prato, and McCamley 2001). The environmental target and desired probability of meeting the target are defined. The model maximizes expected returns subject to the constraint that the upper partial moment of loadings be less than a preset limit.

The manager's objective is to maximize expected farm net revenue subject to a constraint on maintaining N loadings below a policy-determined level at a given probability. For climate scenario j, the cost (C_j) (excluding transactions costs) of meeting an environmental goal for reduced N loading can be represented as expected revenues from farming without the N loading constraint minus expected revenues with the constraint. If j_0 is the baseline climate scenario and j_1 is the projected scenario for climate change, then the effects of climate change on the cost of meeting the water quality goal can be represented by $\Delta C = C_{j1} - C_{j0}$. Costs are estimated for a 423 hectare representative farm using linear programming.

Results

The model has been run for current climate conditions based on 1987-2010 weather.

Farm net returns are estimated with allowable N loadings varied from 500 kg to 7,000 kg. Allowable probabilities of exceeding the limit are varied parametrically from 0.5 to 0.05. The unconstrained farm return above variable cost is $300,679. With N loadings restricted to 500 kg, baseline returns are reduced by 64, 76, and 85% when the allowable probability of exceeding the constraint is set at 0.5, 0.25, and 0.05, respectively. Costs decline with increased allowable loadings reaching 0 at a 7,000 kg loading limit with 0.05 probability of exceeding the limit.

We are currently running the SWAT VSA model with climate scenario A2, a medium-high greenhouse gas emissions and climate change scenario, for the years 2040-2070. Climate scenarios are downscaled to the regional level based on recent simulations from NARCCAP (North American Climate Change Assessment Program). Distributions of N loadings and costs of complying with N loading reductions are being estimated for each scenario as was done under the baseline. Our preliminary analysis suggests that costs of achieving water quality goals increase significantly with increasing variability of N loads. If, as expected, climate change scenarios result in more variable N loadings, water quality goals will be more expensive to achieve with climate change. This information should be helpful to water quality planners who desire to project water quality protection costs over the long term.

References

Qiu, Zeyuan, Tony Prato, and Francis McCamley. "Evaluating Environmental Risks Using Safety-First Constraints." *American Journal of Agricultural Economics* 83(2)(May 2001): 402-413.

Summary of CBP Online Decision Support Tools
Olivia Devereux, Devereux Environmental Consulting

Link to presentation: Overview of Decision Support Tools

There are four existing Chesapeake Bay Program decision support tools to facilitate development of plans that reduce nitrogen, phosphorus and sediment:

- Facility Assessment Scenario Tool – BayFAST.org
  Site specific planning tool where user defines the planning area and land uses.
- Chesapeake Assessment Scenario Tool – CASTtool.org
  Chesapeake Bay portion of NY, MD, WV, DE, DC, VA, PA included
- Maryland Assessment Scenario Tool – MASTonline.org
  Maryland-specific version of CAST. Maryland-specific geographies like State Highway Administration and Phase I and II areas are available through the interface. MAST also has loads available for historical years to assist with local TMDL watershed planning.
- Virginia Assessment Scenario Tool – VASTtool.org
  Virginia-specific version of CAST. VAST is now identical to CAST.

These tools output nitrogen, phosphorus and sediment load for What-If scenarios of different BMPs. All use the same assumptions and calculation methods as the Chesapeake Bay Program's Watershed Model. The loads are calculated for all sources in the watershed.

- Developed, including MS4, Phase I & II municipalities
- Agriculture, including CAFOs
- WWTP and Industrial facilities
- Forest and other natural areas

Users identify the BMPs that give the greatest load reductions and specify the extent these BMPs are to be implemented. Output includes the acres of each BMP and the loads of nitrogen, phosphorus and sediment. The cost per acre for each BMP is also provided.

The BMPs are calculated using different methods. Some are calculated as land use load changes, others are efficiencies, and still others have unique methodologies. BMPs are calculated in a stepwise process. There is not a set amount of reduction per BMP that is constant. Interaction effects are considered by calculating BMPs in various groups and in specified sequences. As such, there is no set reduction per BMP and each scenario will result in a different load reduction per BMP depending on the mix of BMPs, land use available, and implementation levels. This BMP calculation method adds complexity to developing an optimization algorithm.

In Phase 6 of the Chesapeake Bay Models, calculations in the CAST suite of tools are identical to all other Chesapeake Bay Models. The models are transitioning to integrated logic engines. In Phase 6, there will be expanded capacity to calculate credits for nutrient and sediment trading. Trading will be an additional tab on the website. The calculation functionality is already built-in. We need only add the page, and any downloadable summary information.

To add optimization to the CAST suite of tools, a batch process needs to be developed along with the optimization functionality in the interface. Ways to simplify calculations and increase speed are:

- Grouping the approximately 200 BMPs and only calculating optimization with the representative member of the group

- Using isolated effects to make calculations linear

Immediate data needs are:

- Calculating uncertainty associated with BMPs/load reduction reliability
- Determining unit cost changes with the amount of BMP implemented

Discussion: Supporting Optimization - User Experience and User Interface

E. Guy Stephens University of Maryland Center for Environmental Science

The presentation *Supporting Optimization - User Experience and User Interface* was designed to discuss the concepts of User Interface (UI) and User Experience (UX). The goals of the presentation were intended to allow the audience to 1) Better understand who the audience is and their needs related to optimization; 2) Explore how users might interact with a web based optimization tool and; 3) Understand participants' values and how you would prioritize needs related to optimization.

We began by discussing User Experience. User experience (UX) focuses on having a deep understanding of users, what they **need**, what they **value**, their **abilities**, and also their **limitations**. UX considers not just how the product or service looks, how it functions, or the features it holds, but also **how it feels** to the user and how the user feels toward it. We next discuss the Discovery process and the steps needed to understand user needs, this included:

- **Defining your business case:** What as an organization do you hope to accomplish?
- **Determining your audience:** Who will use the product or service?
- **Exploring user needs:** What tasks would a user need to accomplish?
- **Validating your assumptions:** User research to verify your audience and user needs.

We discussed research methods of the Discovery process including:

- **Stakeholder interviews:** Interview project stakeholders and determine what they hope to see out of the project.
- **User workshop:** Meet with actual end users for the project and determine needs and desires for the project.
- **Comparative analysis:** Look at other similar products and determine strengths and weaknesses.

Next we defined User Interface (UI) as the interface used in software that allows a user to interact with the product. This includes the elements of a page, such as: buttons, text fields, checkboxes, radio buttons, dropdown lists, list boxes, toggles, date field, breadcrumb, slider, search field, pagination, slider, tags, icons, tooltips, icons, progress bar, notifications, message boxes, modal windows and more.

During exercises we conducted Discovery research to determine our audience and business case for an optimization tool. The draft business case that emerged from the session was: **"Develop a tool to support the development of state and local implementation plans that focuses on**

cost and co-benefits.” The envisioned primary audience for the optimization tool was local and state governments. Secondary audience were envisioned to include: Federal agencies, NGO’s, Regional Planning & Development Council Staff, County Elected Officials and Academic Users.