# *Modeling Workgroup Meeting Quarterly Review*

# Optimization update: Opt1-Opt6.

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# *Agenda*

- Objective 1: Understanding the CAST system and Development of an Efficient Single-objective Hybrid Optimization Procedure
  - April 1, 2020 to September 30, 2021 (18 months)
- Current Accomplishments:

  1) A sample-based selection approach (**Opt1**)

  2) A simplistic model-based optimization algorithm using point-based method (**Opt2**)

  3) Interface our optimization method with CAST system (**Opt3**)

  4) Population-based genetic algorithm (**Opt4**).

  5) Hybrid population-point based optimization method (**Opt5**).

  6) Development of a user interface to interact with our developed algorithms (**Opt6**)
- Next Steps:

  1) Opt6 testing

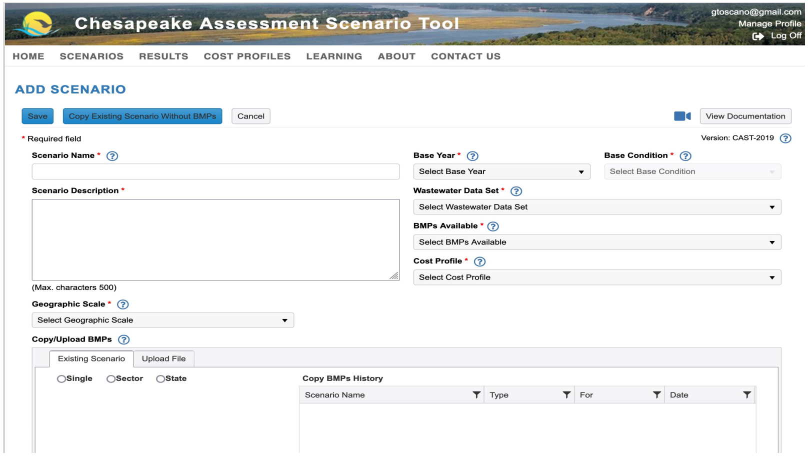
# Adopted models

## Analytical Model

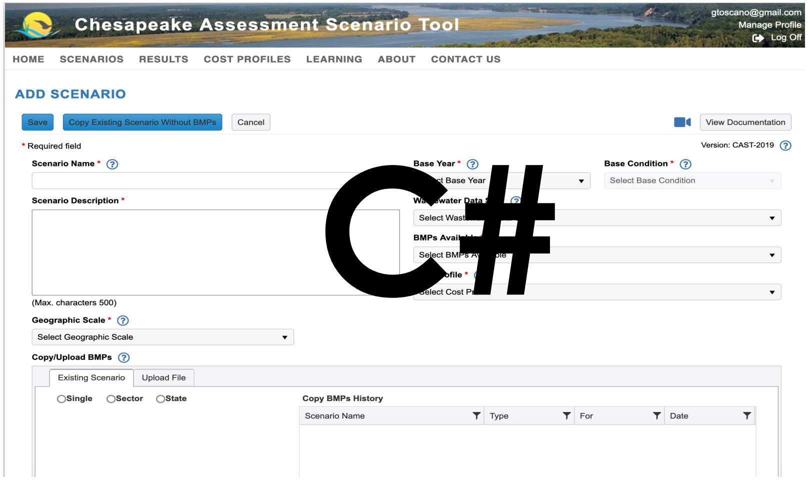
$$
\begin{aligned}
\text{Minimize} \quad & f(\mathbf{x}) = \sum_{s \in S} \sum_{h \in H_s} \sum_{u \in U} \sum_{b \in B_u} \tau_b x_{s,h,u,b}, \\
\text{Subject to} \quad & \sum_{s \in S} \sum_{h \in H_s} \sum_{u \in U} \left[ \alpha_{s,h,u} \phi_{s,h,u} \Pi_{G^B \in \mathcal{G}^B} \left( 1 - \sum_{b \in G^B} \eta_{s,h,b} \frac{x_{s,h,u,b}}{\alpha_{s,h,u}} \right) \right] \leq \Theta, \\
& \sum_{b \in G^B} x_{s,h,u,b} \leq \alpha_{s,h,u}, \quad \forall s \in S, \; h \in H_s, \; u \in U_s, \; G^B \in \mathcal{G}^B, \\
& x_{s,h,u,b} \geq 0, \quad \forall s \in S, \; h \in H_s, \; u \in U_s, \; b \in B_u.
\end{aligned} \tag{1}
$$

The variable $x_{s,h,u,b}$ indicates the acres used for implementing a BMP $b$ to reduce a load resource $u$.

## WebCAST




## CoreCAST




**Highlights**

- Gradients
- Jacobians
- Hessian matrix
- Fast calculation
- Fast convergence
- Abstraction
- Accuracy

**Highlights**

- Well-stablished
- Validated
- Web interface
- Manual execution

**Highlights**

- C# (fast implementation)
- Callable
- Slower than analytical model

# Previous presentation

- Understanding of the CBWS problem
  - Spatial Hierarchy
  - Group of BMPs
  - Decision Variables
  - Justification
- Reducing Complexity
  - Dimensionality reduction
  - Screening solutions based on non-dominance
- Encouraging results

# *A sample-based selection approach (Opt1)*

- No optimization is used
- Sample the BMPs at random
- Help us to understand the problem better

- Optimization algorithm is needed to get better solutions.

# A simplistic model-based optimization algorithm using point-based method (Opt2)

- Analytical model (efficiency BMPs)
- Users can provide reduction limits for Nitrogen, Phosphorus and/or Sediment from the base scenario
- Interior point-based method
  - Exact derivatives
  - Exact Jacobian
  - Hessian Matrix
  - Smart initial point
  - Variable reduction
  - BMP screening based on Non-dominance

# Interface our optimization method with CoreCAST system (Opt3)

- We interfaced our Opt2 approach with CoreCAST
  - Base conditions are accessible through CoreCast
  - Final solution provided by Opt2 is reevaluated on CoreCast

# *Population-based Genetic Algorithm developed to solve the Analytical Model (Opt4).*

- Optimization methods:
  - Point-based: Fast, sensitive to initial point
  - Population-based: Global approach to near-optimality
- Genenetic Algorithm is flexible to handle practicalities
- Base Genetic Algorithm (without any customization) implemented from scratch in C++

# *Hybrid point-population based optimization method (Opt5)*

- Hybridized GA with an interior-point-based approach:
  - Opt4 with real representation hybridized with Opt2.
- Final solution evaluated in CoreCast

# *Development of a user interface with optimization (Opt6)*

- The approach comprises Opt2-Opt5
- User interface allows
  - Selection of BMPs
  - Selection of implementation locations (land-river-segments) and area
  - Allocation of resources (e.g. incentives) for each BMP
  - Final solutions are executed in CoreCast
- Capability of sharing optimization results

# *Example*

- Two counties (Bradford, PA; Howard, MD)
- # Variables: 45,077. # Constraints: 3,256.
    - N: 7,052,101 (lbs), P: 643,091 (lbs), Sediments: 93,5849,260 (lbs)
- Optimized by Opt6
- Watershed Cost vs State Cost (independently)
- Preference incorporation:
    - Limit BMP application
    - Limit BMP of a specific land-river-segment
    - Exclude BMP
    - Modify Cost of BMP

# Summary

- A sample-based selection approach showed the needs for an optimization approach
- The analytical model is quite accurate
- Interior-point-based method can optimize the analytical model.
- The  interface to automatically executes CoreCast
- Users can call our optimization approach through a web interface.

# Technical Reports

- 1. Hernandez-Suarez, J. S., Toscano-Pulido, G., Nejadhashemi, A. P., and Deb, K. (2021). Development of an Efficient Optimization Framework for Improving Water Quality in the Chesapeake Bay Watershed. COIN Report Number 2021012. Computational Optimization and Innovation Laboratory, Michigan State University, East Lansing.
- (https://www.egr.msu.edu/~kdeb/reports.shtml)
- 2. Toscano-Pulido, G., Hernandez-Suarez, J. S., Blank, J., Nejadhashemi, A. P. and Deb, K. (2021). Systematic Development of Single-objective Optimi-zation Approaches for Chesapeake Bay Watershed Management. COIN Re-port Number 2021013. Computational Optimization and Innovation Labora-tory, Michigan State University, East Lansing.
- (https://www.egr.msu.edu/~kdeb/reports.shtml)

# Thank you