Scenario Optimization Tool for CAST
(the time-averaged Phase 6 watershed model)

10 December 2018
Water Quality Goal Implementation Team (WQGIT) Meeting

Daniel Kaufman and the CBPO Modeling Team

Goals: Investigate, develop, test, and implement an optimization system for the Chesapeake Assessment Scenario Tool (CAST) that will facilitate identification of more cost-effective and otherwise optimal approaches to pollutant load reduction for CBP partners.

Status: Beta version development

1 **Overview**

- Achievements / progress
- Plan

2 **Details**

- CAST and optimization problem description
- Methods
- Preliminary results
- Near-term goals and longer-term vision

Since December, 2017

Highlights

Programmatic

Presented and gathered feedback from:

- Water Quality Goal Implementation Team (WQGIT)
- Workgroups
  - Watershed Technical
  - Modeling
  - Urban Stormwater
  - Wastewater Treatment
- Scientific, Technical Assessment, and Reporting (STAR) team
- Scientific and Technical Advisory Committee (STAC)
- Chesapeake Research & Modeling Symposium
- Optimization Tool Development Advisory and Support Committee

- Drafted response to STAC workshop for CBP Management Board

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Spring 2018

Vision:

- features
- system structure
- interconnections with CAST
- technical challenges
- scenario generation

High-level approach towards confronting challenges and opportunities

Since December, 2017

Highlights

Technical

Development:

- **Designed and implemented prototype optimization model** using efficiency BMPs (a sub-population of all BMPs) for cost and load reduction objectives
- **Operationalizing** of prototype for running optimization "studies" on the cloud
- **Flexible** software base that will be useful when extending to include other BMPs

Analyses of the efficiency BMP optimization results have provided insight into problem characteristics

ASC reviewed working prototype, using subset of BMPs, and concluded it is well formulated without fatal flaws

Plans

Near-term:

Beta version in first quarter 2019 using only efficiency BMPs (those whose effects can be most readily formulated into a mathematical programming model) to provide utility, gather feedback, and identify issues.

Longer-term:

Test heuristic optimization algorithm(s) to **iteratively sample the scenario-space**. And/or incorporate additional BMPs into existing framework.

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Current system

Best Management Practices (BMPs)

- Forest Buffers
- Rain Gardens
- Cover Crops

Chesapeake Assessment Scenario Tool (CAST)

Loads

Cost

Current system

Not feasible to exhaustively try potential strategies

Best Management Practices (BMPs)

Chesapeake Assessment Scenario Tool (CAST)

Loads

Cost

STAC Workshop

"…[m]odels that can identify potential strategies for efficiently advancing multiple goals and objectives of the broader Chesapeake Bay Watershed Agreement are needed."

Workshop goal(s)

- review and examine optimization modeling approaches / applications in a water quality context
- examine capacity to integrate an optimization engine with existing tools developed by the CBP to guide WIP development

Goals of a Bay optimization system:

- Objectives:
  - Minimizing total costs
  - Maximizing co-benefits
  - Maximizing load reduction reliability
- Equitable distribution of effort among jurisdictions / source sectors
- Limits on retirement of agricultural land
- Ability to use the tool at various scales (county -> baywide)

Stepwise approach, and incorporate into CAST (the Bay Watershed Model)

Current system

Not feasible to exhaustively try potential strategies

Best Management Practices (BMPs)

Chesapeake Assessment Scenario Tool (CAST)

Loads

Cost

Optimization tool

Not feasible to exhaustively try potential strategies

Best Management Practices (BMPs)

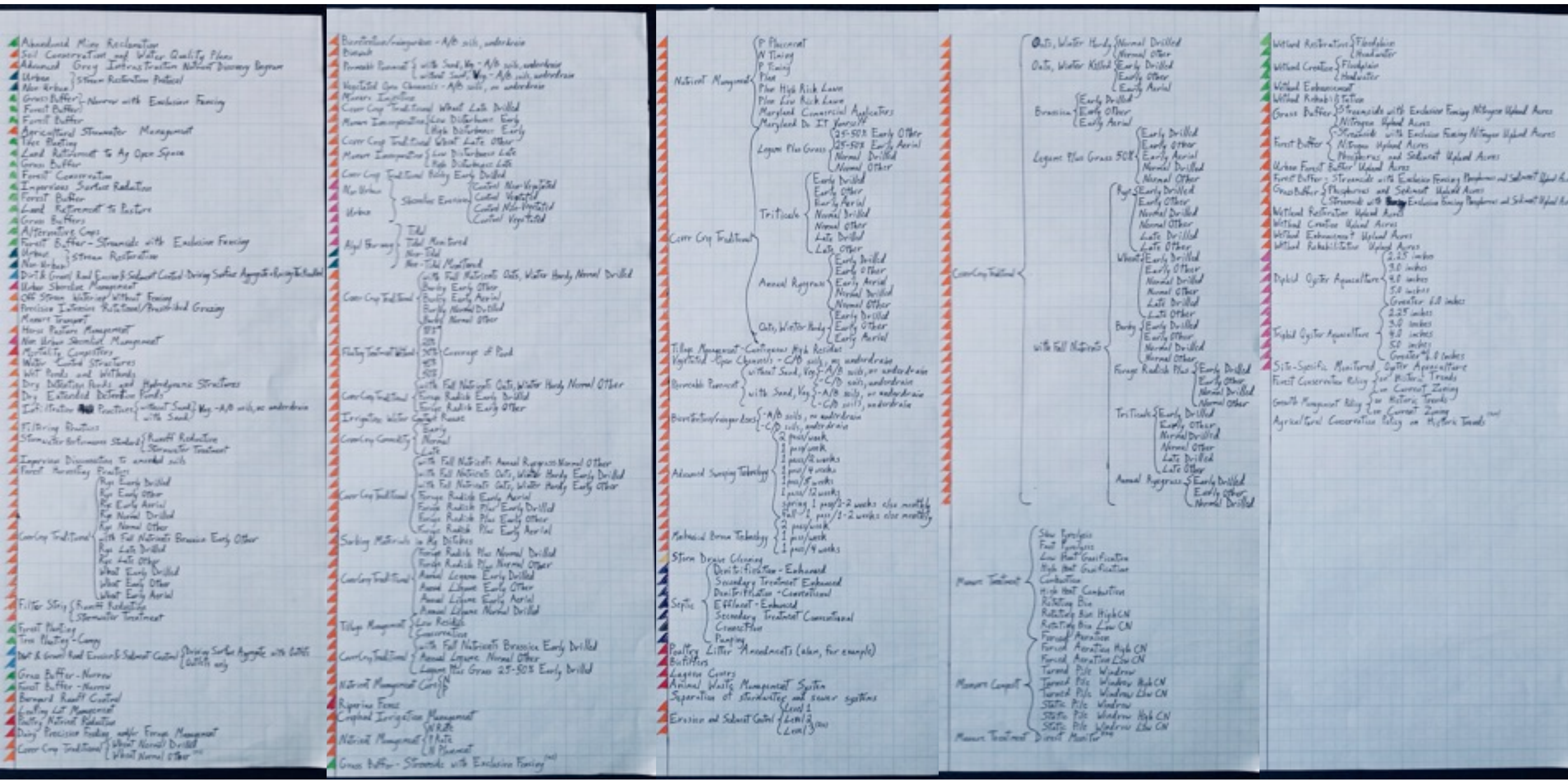
Chesapeake Assessment Scenario Tool (CAST)

Loads

Cost

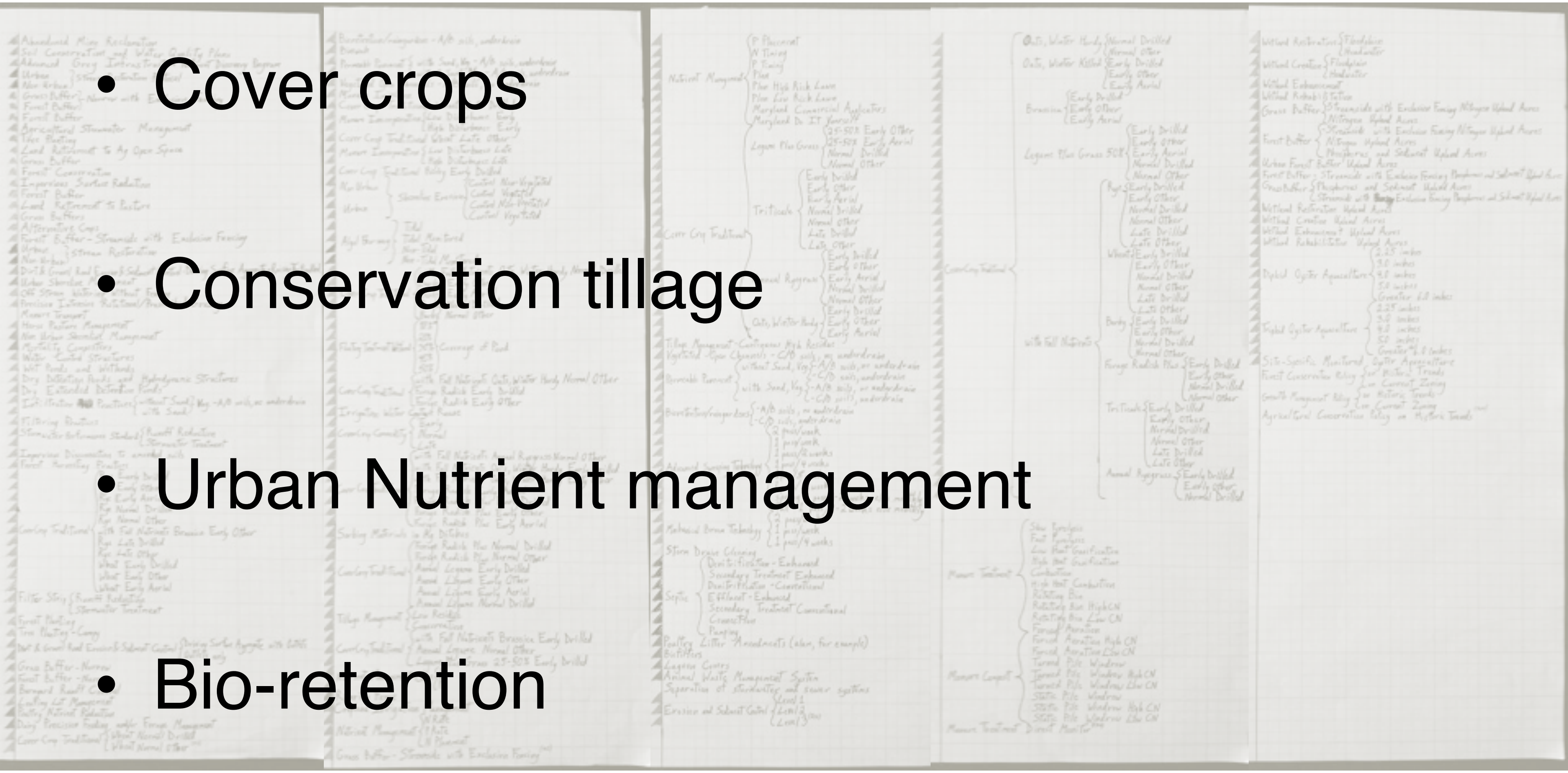
Identify low-cost strategies

Best Management Practices (BMPs) in CAST



Orange = Efficiency BMPs

Efficiency BMPs include:



- Cover crops
- Conservation tillage
- Urban Nutrient management
- Bio-retention

Prototype methods

- Cover crops
- Conservation tillage
- Urban Nutrient management
- Bio-retention

Minimize
(total cost)

$$\sum_{\substack{Segments \\ BMPs \\ LoadSources}} (cost * BMPacres)$$

Constrained by:
(Target load)

The same calculations as in CAST

Using CAST data for acres available, BMP efficiencies & costs, base loading, load sources, etc.

Optimization as search

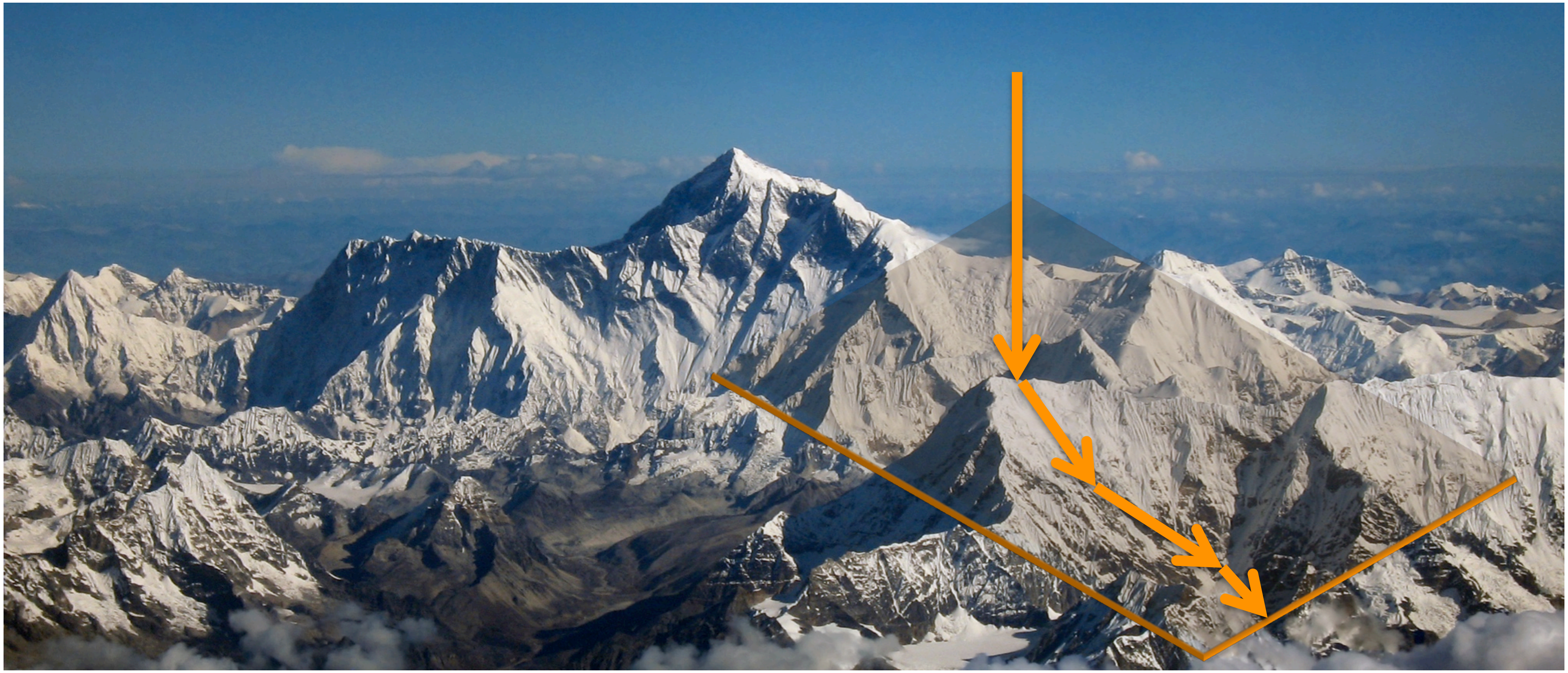
How would you go about finding the lowest point? Without GPS :(

Optimization as search

Constraints limit the search region

Optimization as search

Move in the direction of the steepest slope, towards a minimum



Prototype methods

Code formulated with **Pyomo**

(algebraic modeling language library for python) developed by Sandia National Laboratories

PYOMO

Instances solved using **IPOPT**

(interior point / barrier method solver) developed at Carnegie Mellon Univ. and available as part of the Computational Infrastructure for Operations Research (COIN-OR)

COIN|OR

Minimize (total cost)

$$\sum_{\substack{Segments \\ BMPs \\ LoadSources}} (cost * BMPacres)$$

Constrained by: (Target load)

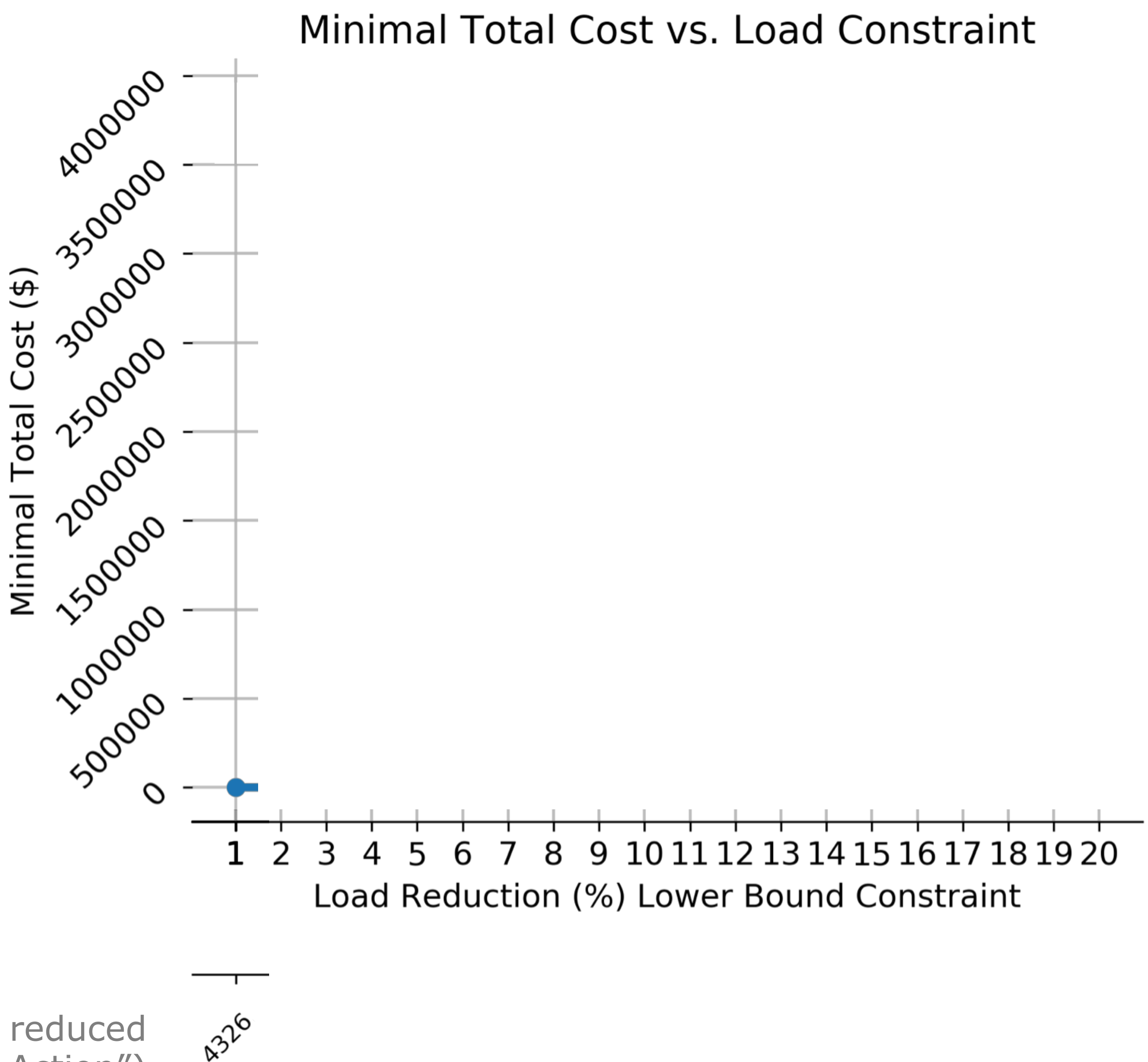
The same calculations as in CAST

Using data on acres available, BMP efficiencies & costs, base loading, load sources, etc.

Objective:
Minimize Total Cost ($)

Costs are estimated in 2010 dollars. Costs represent a single year of cost rather than the cost over the entire lifespan of the practice. Costs are annualized average costs per unit of BMP (e.g.: $/acre treated/year). Capital and opportunity costs are amortized over the BMP lifespan and added to annual operations and maintenance (O&M) costs for a total annualized cost. Costs are those incurred by both public and provide entities. Default costs were prepared for EPA using existing data. Bay jurisdictions were provided with the opportunity to review and amend the unit costs for BMPs in the Phase 2 WIP. However, alternative costs for practices can be specified by a user.

All results are draft/preliminary, and subject to revision.



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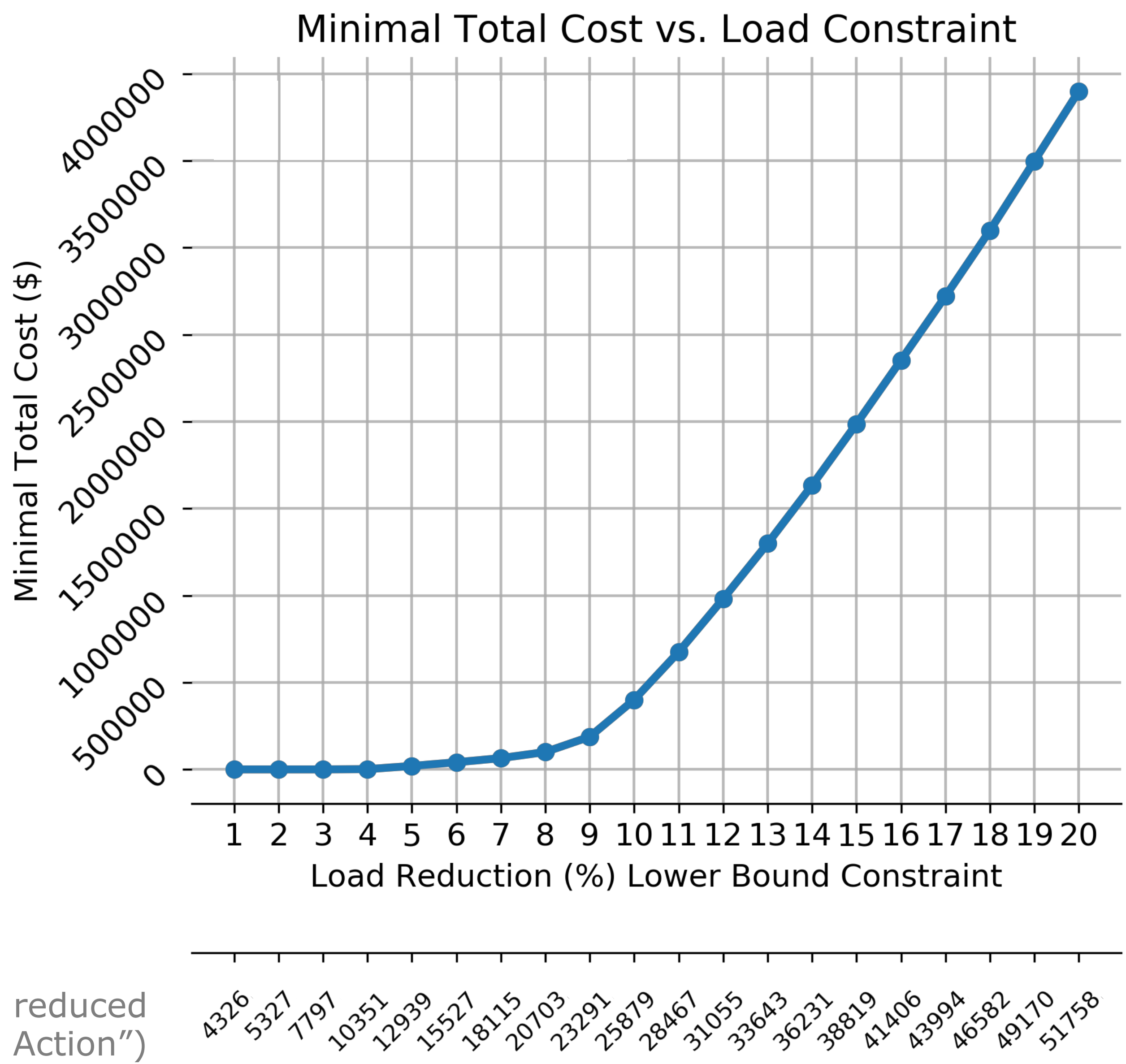

Prototype methods

Minimize
(total cost)

$$\sum_{\substack{Segments\\BMPs\\LoadSources}} (cost * BMPacres)$$

Constrained by:
(Target load)

Prototype methods

Two Model Versions

Maximize (load reduction)

$$\%\,LoadReduction_{\{segment,\ pollutant\}}$$

Constrained by: (Cost bound)

Minimize (total cost)

$$\sum_{\substack{Segments\\ BMPs\\ LoadSources}} (cost * BMPacres)$$

Constrained by: (Target load)

Multiple options to specify when running an optimization study

Primary Optimization Specifications

Select geography ➡ County X or multiple counties

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Select objective ➡ minimize cost or maximize load reduction

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Select objective ➡ maximize load reduction

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Select objective ➡ maximize load reduction

Select main constraint ➡ achieve target load reduction or limit to specified total cost

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Select objective ➡ maximize load reduction

Select main constraint ➡ limit to specified total cost

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Select objective ➡ maximize load reduction

Select main constraint ➡ limit to specified total cost

Select main constraint ➡ ____________________

Primary Optimization Specifications

Select geography ➡ Charles county, MD

Select objective ➡ maximize load reduction

Select main constraint ➡ limit to specified total cost

Select main constraint ➡ $100,000 … $1.9 mil

Objective:
Maximize
Load Reduction ($)

Costs are estimated in 2010 dollars. Costs represent a single year of cost rather than the cost over the entire lifespan of the practice. Costs are annualized average costs per unit of BMP (e.g.: $/acre treated/year). Capital and opportunity costs are amortized over the BMP lifespan and added to annual operations and maintenance (O&M) costs for a total annualized cost. Costs are those incurred by both public and provide entities. Default costs were prepared for EPA using existing data. Bay jurisdictions were provided with the opportunity to review and amend the unit costs for BMPs in the Phase 2 WIP. However, alternative costs for practices can be specified by a user.

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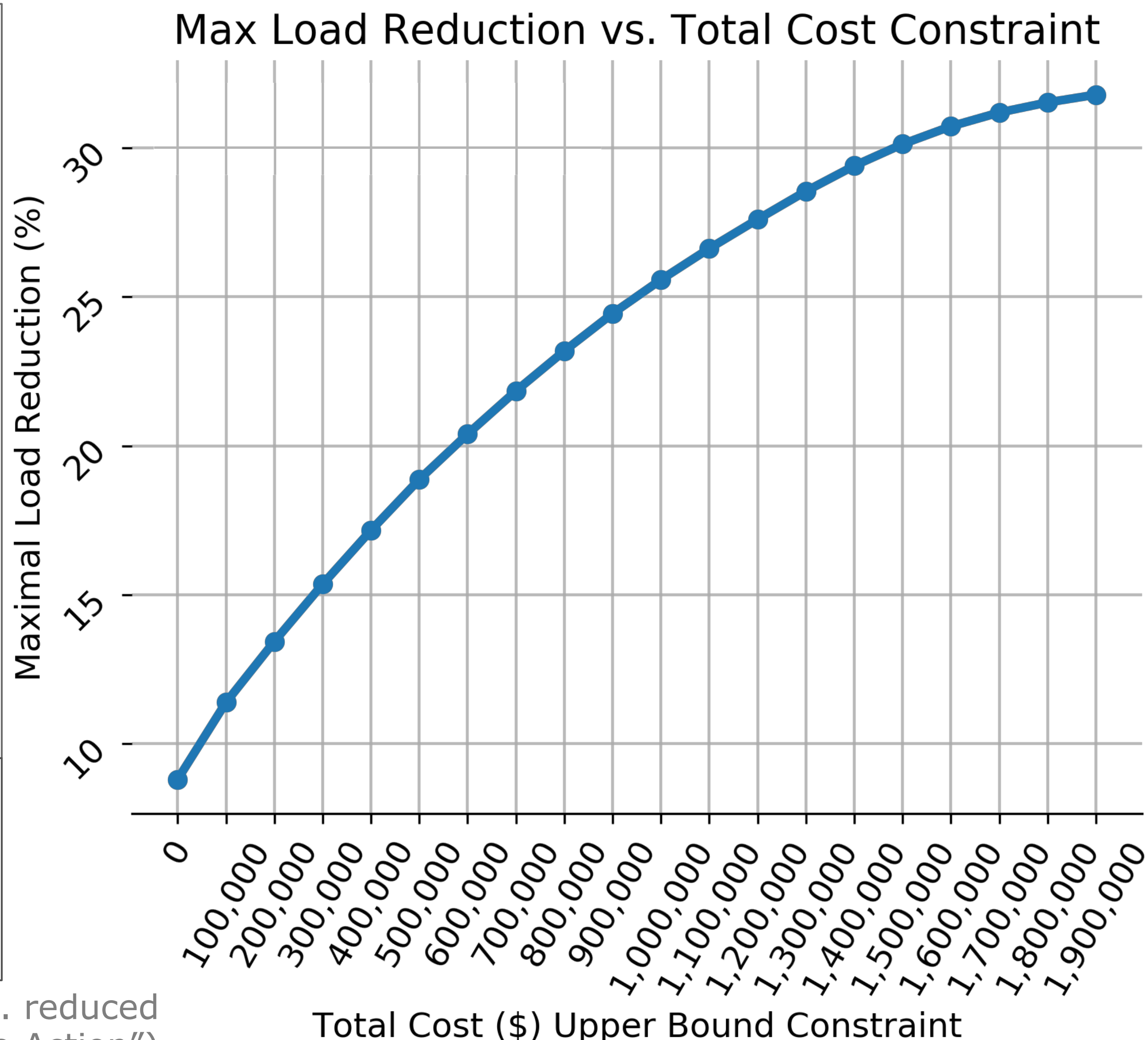


N lbs. reduced (from "2010 No Action")

Next steps

Prepare optimization prototype for Beta release:

- Ensure robust solutions for more geographic regions, for different base loading years
- Account for existing constraints, structural/cumulative BMPs
- Perform "John Henry" tests – compare manually obtained solutions

Concurrent discovery for incorporating other BMPs

Summary

- Developed and implemented prototype optimization model using efficiency BMPs for cost and load reduction objectives

- Preparing for Beta release of optimization tool results involves further *operationalizing results generation*, *ensuring robustness*, and *updating model* to include different base years and structural BMPs

- Current results are draft/preliminary, and subject to revision.
  - Tool will not be ready for use in Phase III WIP development.
  - Beta version prototype will likely not include BMPs other than efficiencies. There are other BMPs, e.g. Buffers, that are important for reducing load.

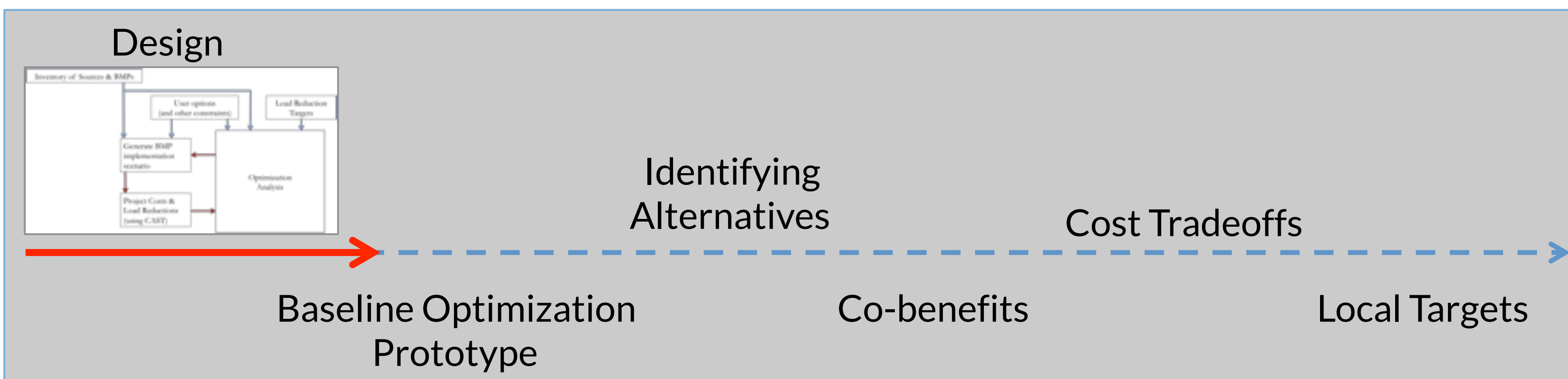
Will be shaped by feedback

Near-term:

Beta version in first quarter 2019 using only efficiency BMPs (those whose effects can be most readily formulated into a mathematical programming model) to provide utility, identify issues, & gather feedback. Not only is feedback desired, but it will be crucial for ensuring the success and usefulness of future Beta versions.

Longer-term:

Test heuristic optimization algorithm(s) to **iteratively sample the scenario-space**. And/or incorporate additional BMPs into existing framework.



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Hart, William E., Carl D. Laird, Jean-Paul Watson, David L. Woodruff, Gabriel A. Hackebeil, Bethany L. Nicholson, and John D. Siirola. Pyomo – Optimization Modeling in Python. Second Edition. Vol. 67. Springer, 2017.

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A. Wächter and L. T. Biegler, **On the Implementation of a Primal-Dual Interior Point Filter Line Search Algorithm for Large-Scale Nonlinear Programming, *Mathematical Programming* 106(1), pp. 25-57, 2006**