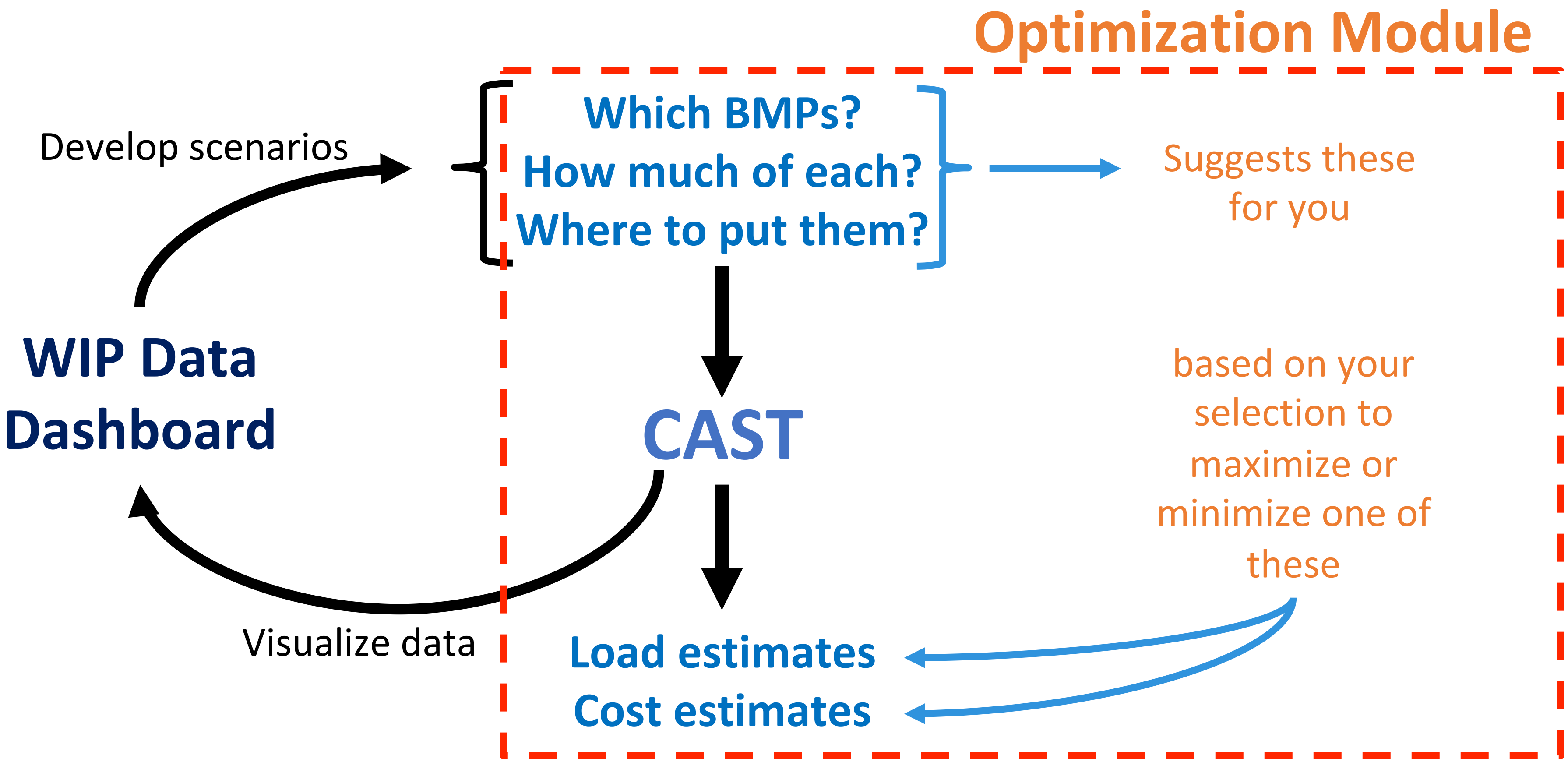
Scenario Optimization Tool for CAST
(the time-averaged Phase 6 watershed model)

21 February 2019
Agriculture Workgroup Conference Call

Daniel Kaufman and the CBPO Modeling Team

Project Goal: 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


Optimization Module
Develop scenarios
Which BMPs?
How much of each?
Where to put them?
Suggests these
for you
WIP Data
Dashboard
CAST
based on your
selection to
maximize or
minimize one of
these
Visualize data
Load estimates
Cost estimates

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*.

Longer-term:

Incorporate additional BMPs into optimization framework, and/or test heuristic optimization algorithm(s) to iteratively sample the scenario-space.

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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

Best Management Practices (BMPs)

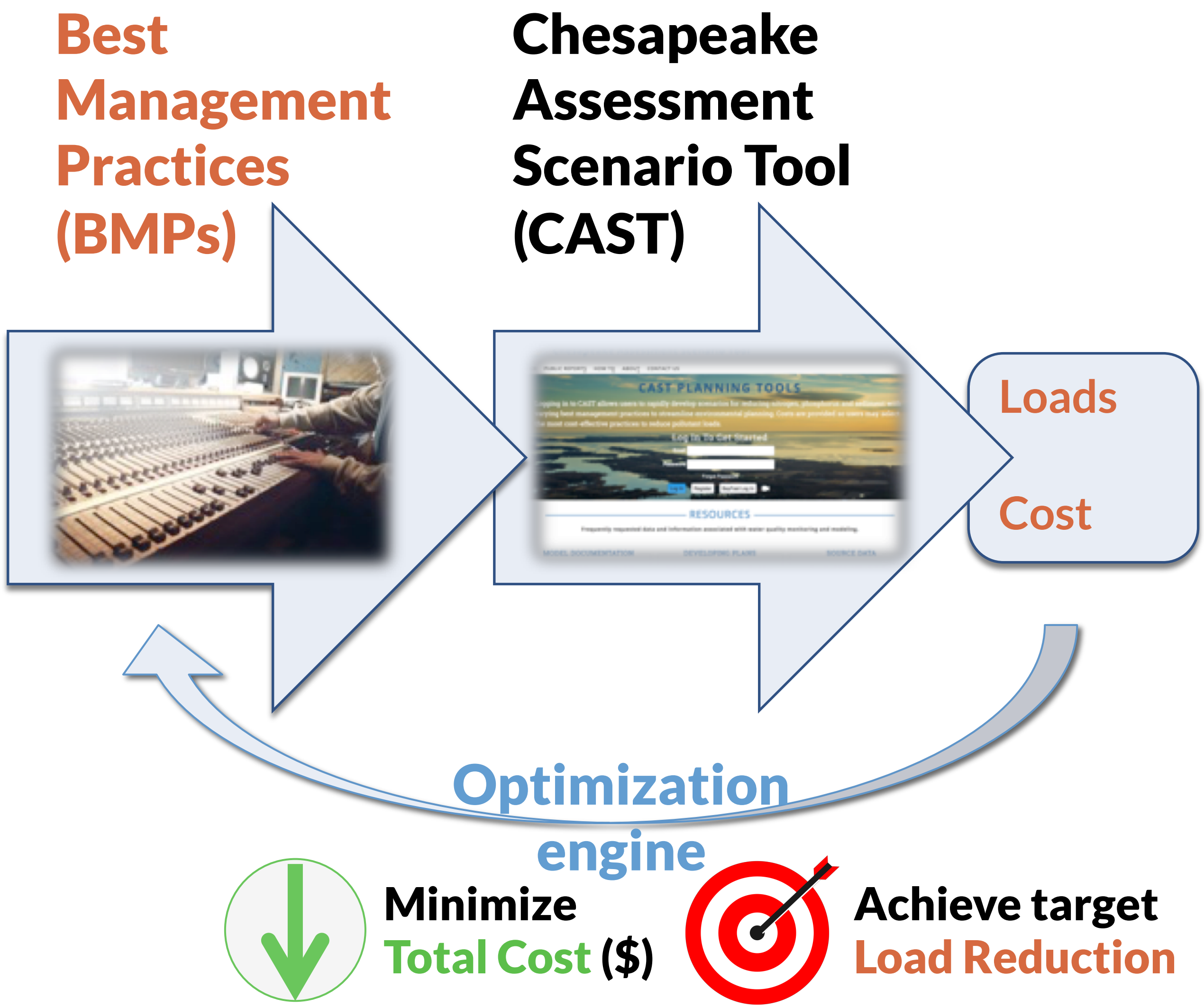
Chesapeake Assessment Scenario Tool (CAST)

Not feasible to exhaustively try potential strategies

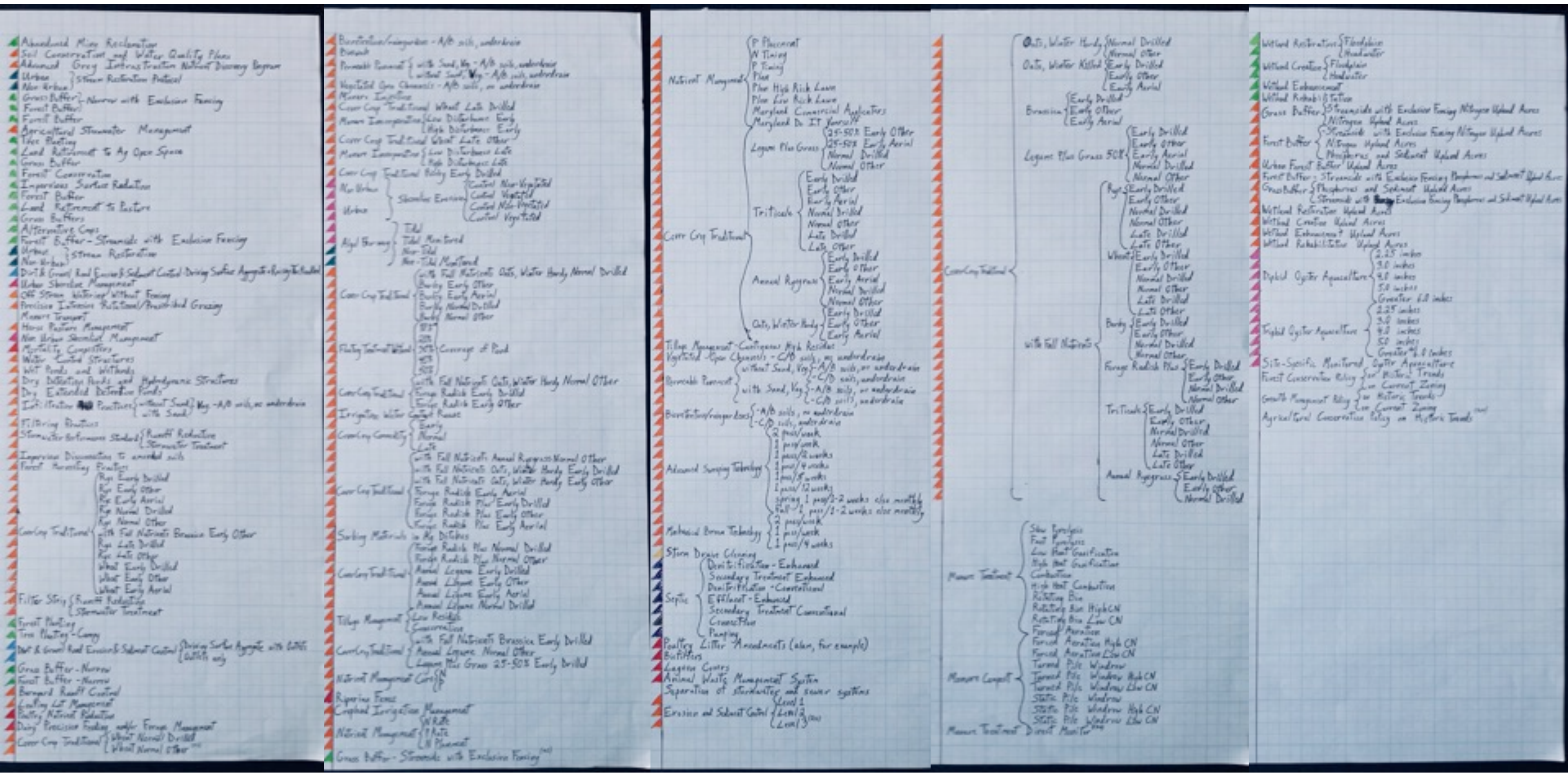
Loads

Cost

Developing Optimization Engine

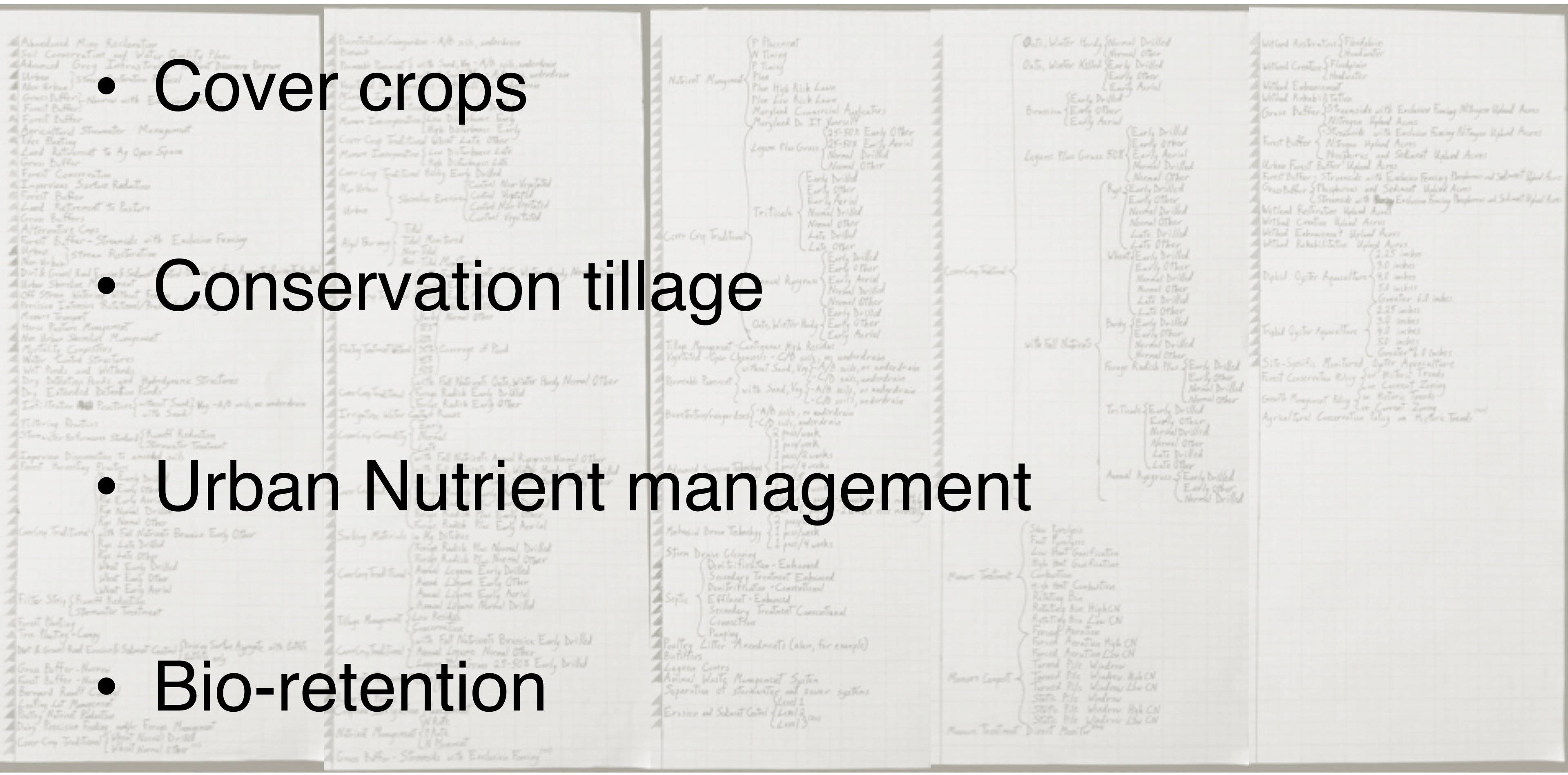


Best Management Practices (BMPs) in CAST



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

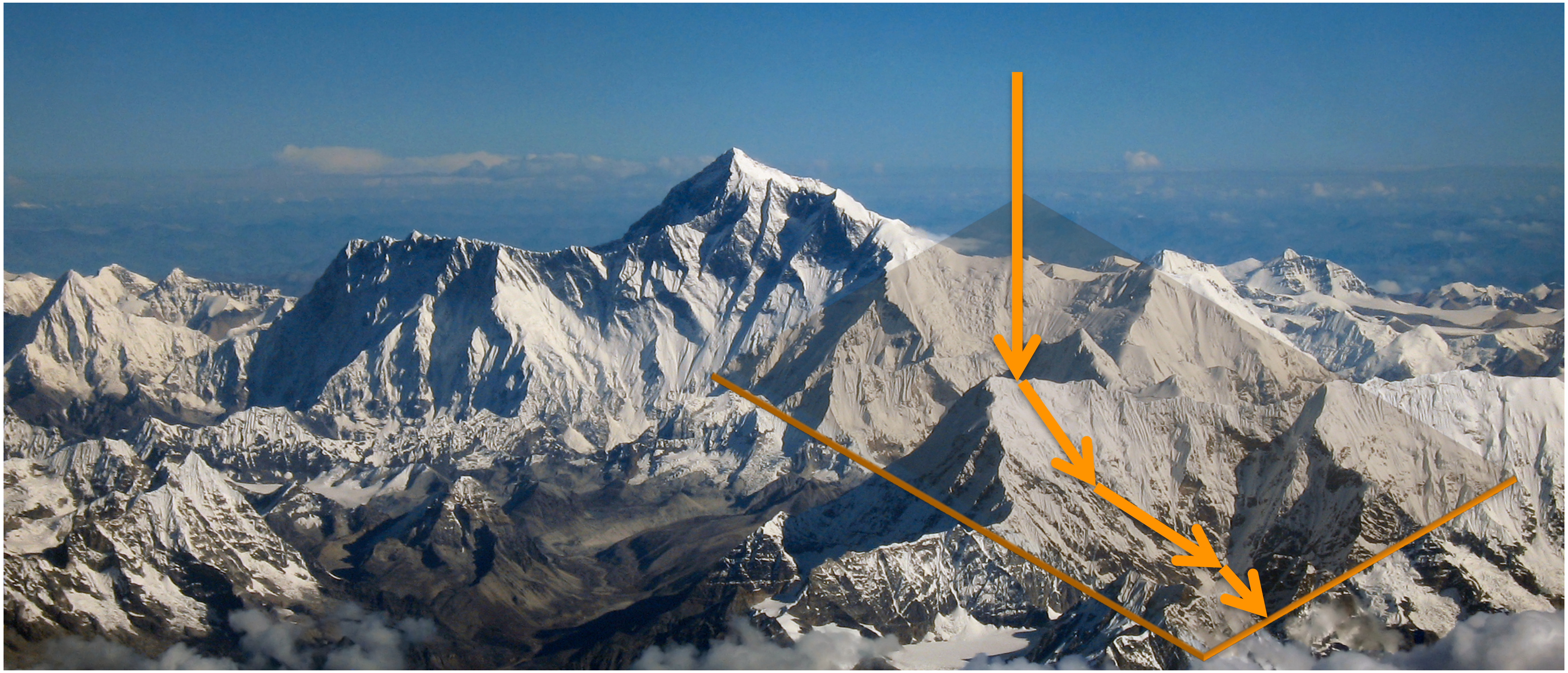
How would you go about finding the lowest point? Without GPS :(

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

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)

Minimize (total cost)

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

Constrained by: (Target load)

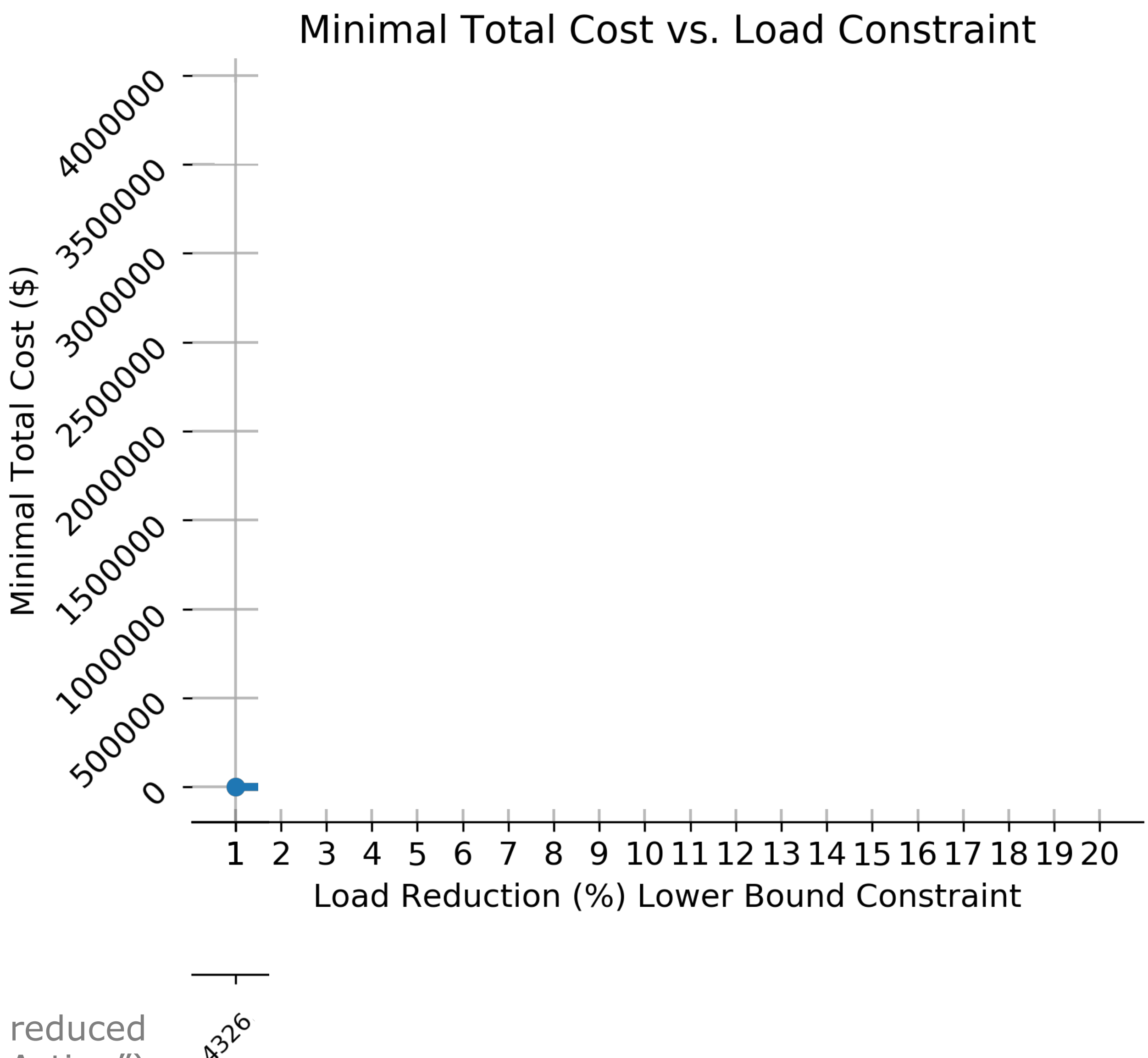
The same calculations as in CAST

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.



N lbs. reduced (from “2010 No Action”)

Objective:
Minimize Total Cost ($)

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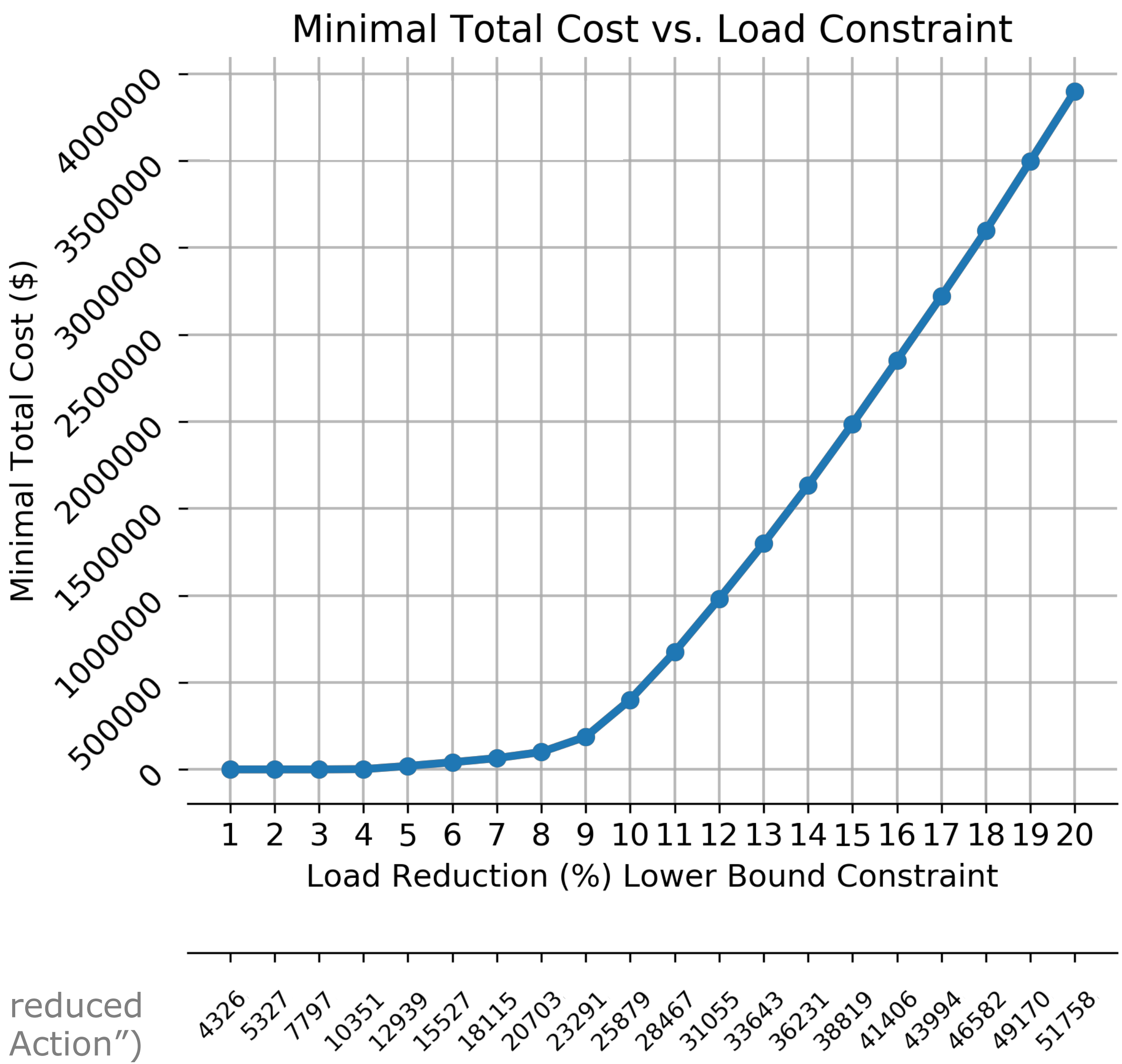

Estimated BMP Costs and Options

- Cost for Rye Early Drilled Cover Crop Traditional on 50 acres = $3,447 when using default in CAST

(this was calculated with watershed average of *$68.94 per acre*)

- But you or any person using CAST could change the cost per acre to, e.g. $125, and then Rye Early Drilled Cover Crop Traditional on 50 acres would be = $6,250*

Primary Optimization Specifications

Select geography ➡ County X or multiple counties

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Select objective ➡ minimize cost or maximize load reduction

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Select objective ➡ minimize cost

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Select objective ➡ minimize cost

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

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Select objective ➡ minimize cost

Select main constraint ➡ achieve target load reduction

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Select objective ➡ minimize cost

Select main constraint ➡ achieve target load reduction

Select main constraint ➡ ______________________

Primary Optimization Specifications

Select geography ➡ Lancaster county, PA

Select objective ➡ minimize cost

Select main constraint ➡ achieve target load reduction

Select main constraint ➡ 1% … 40%

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.

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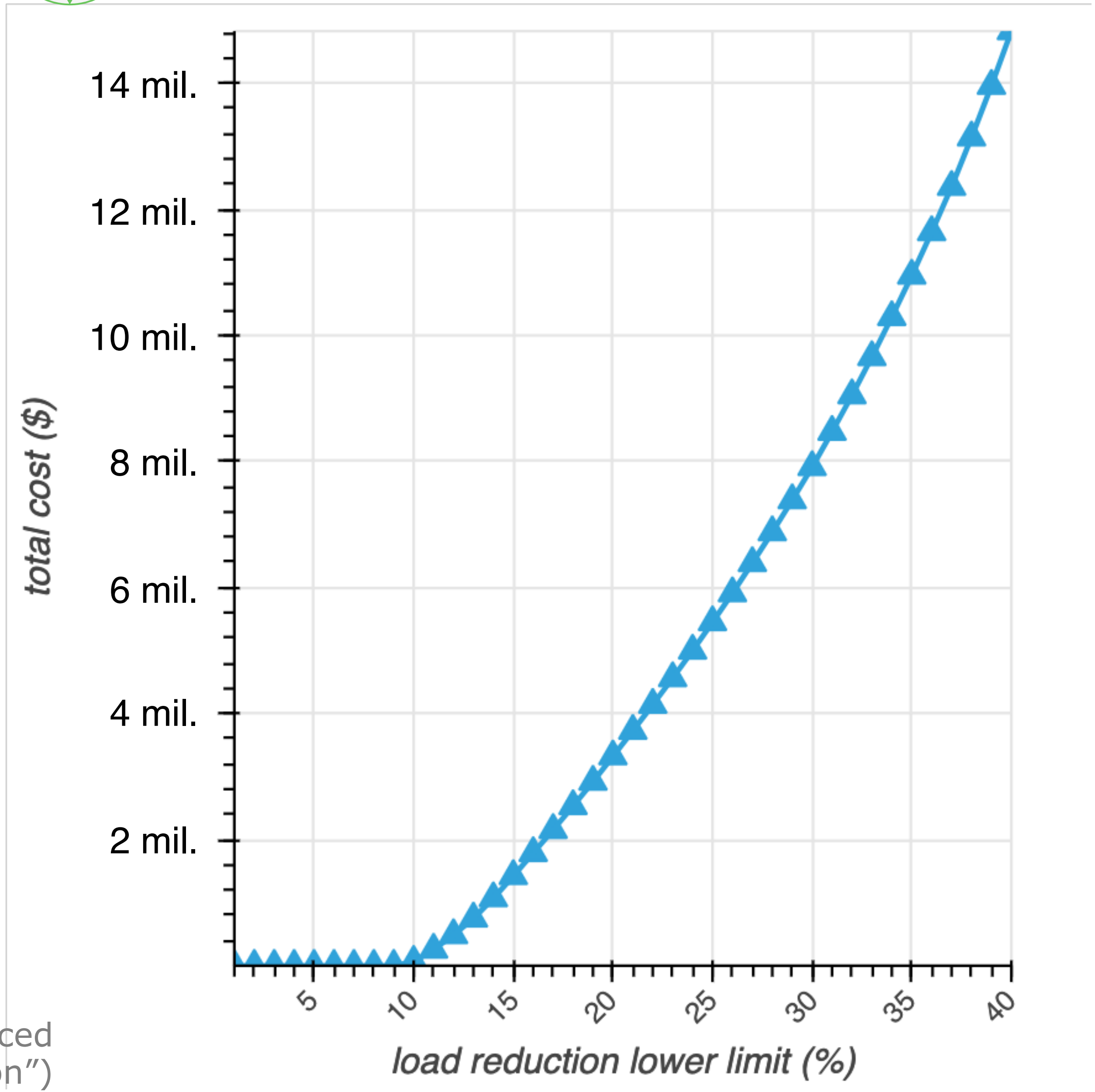
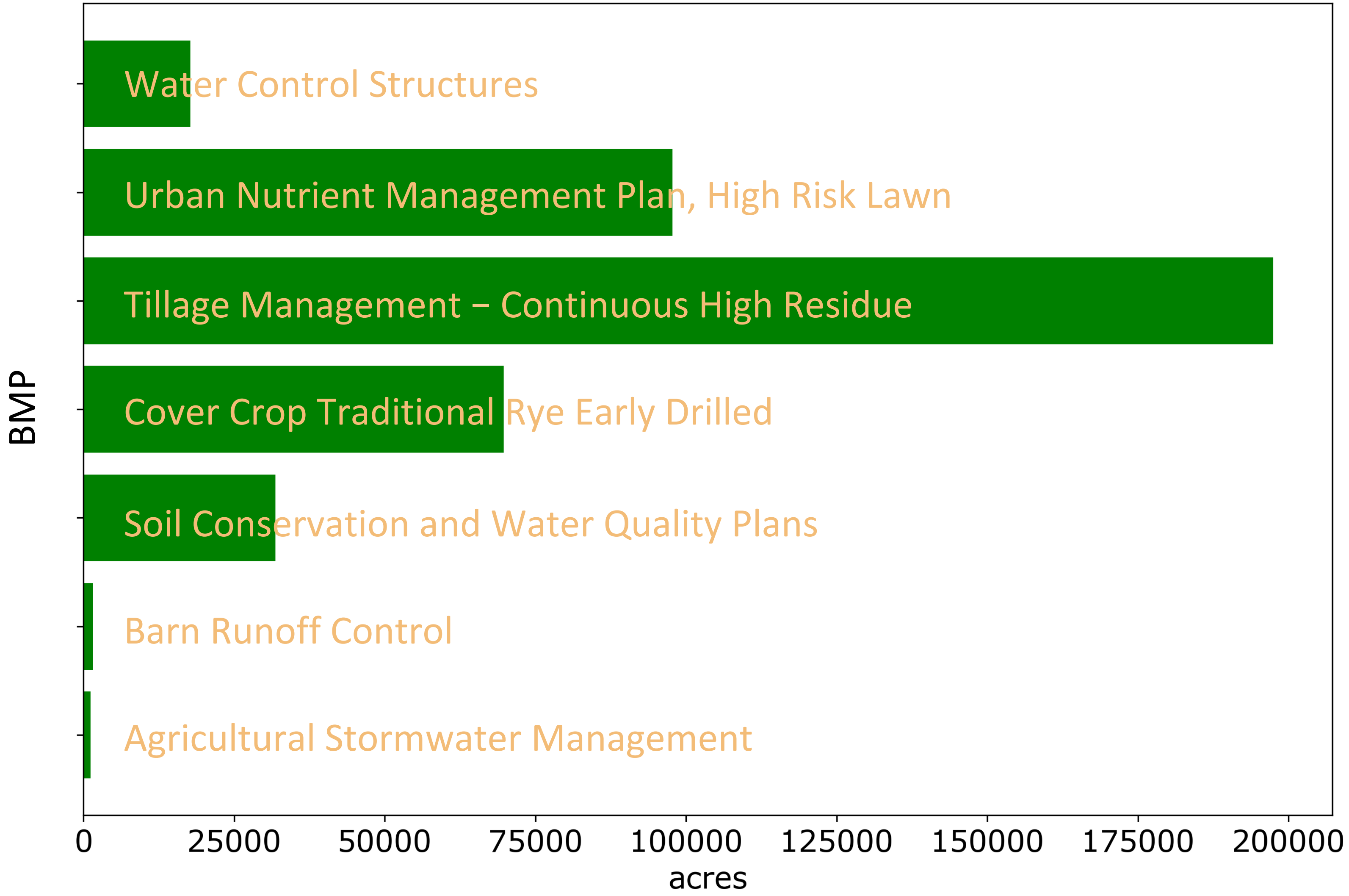


N lbs. reduced
(from "2010 No Action")

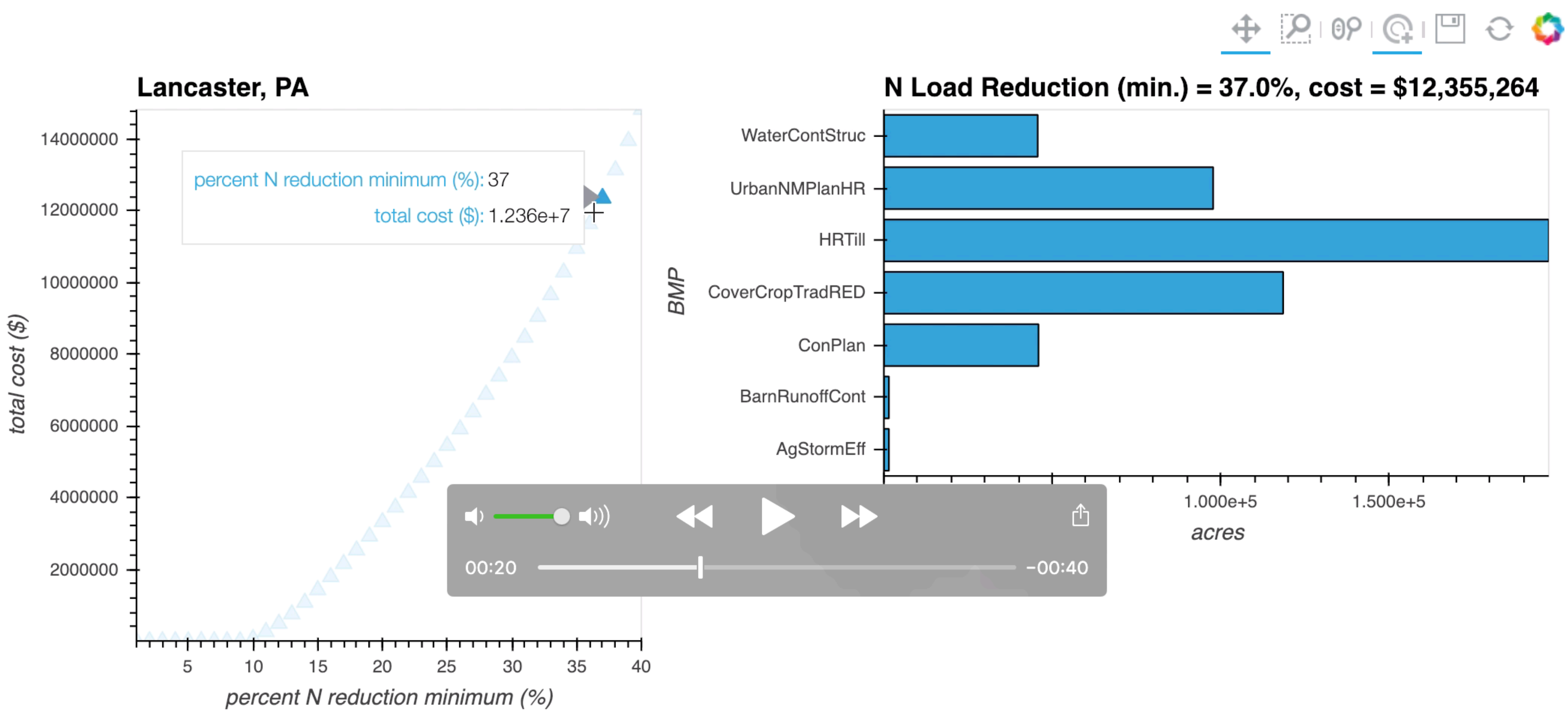
Lancaster, PA



Objective:
Minimize
Total Cost ($)


```
tap_dmap = hv.DynamicMap(tap_barchart, streams=[stream])

layout = (scatter + tap_dmap.options(invert_axes=True, width=550))
layout
```



Continuing

- Working on including additional, complex, BMPs. Multiple approaches.

- Collaboration with Advisory and Support Committee and Dr. Skipper

Advisory & Support Committee

External Collaboration

Summary

“Straw-arm” prototype
(Part of straw-man)

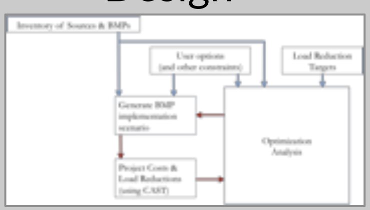
- Developed and implemented prototype optimization model using efficiency BMPs for cost and load reduction objectives
- Preparing for Beta release of optimization tool results involves further testing, design, and, with time permitting, updating model to include different base years
- Current results are draft/preliminary, and subject to revision.
  - **Prototype is not intended for use in Phase III WIP development. Intention is for it to be useful down the road in milestone planning and beyond.**
  - Beta version prototype will not include BMPs other than efficiencies. There are other BMPs, e.g. Buffers, that are important for reducing load.

Will be shaped by feedback: Beta-1 is a first step

Actively searching for ways to engage decision makers at all scales (local, county, municipal, state, etc.) for their guidance and feedback on prototype design.

Email me (Danny) at: dkaufman@chesapeakebay.net

Design



Identifying Alternatives

Cost Tradeoffs

Baseline Optimization Prototype

Co-benefits

Local Targets

References

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.

Hart, William E., Jean-Paul Watson, and David L. Woodruff. "Pyomo: modeling and solving mathematical programs in Python." Mathematical Programming Computation 3(3) (2011): 219-260.

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**