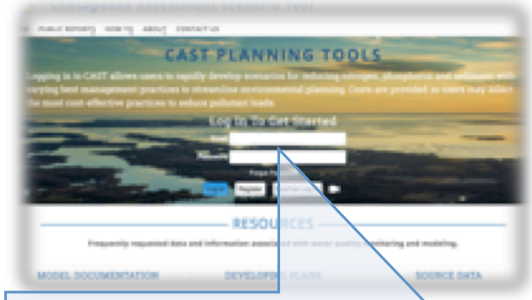
Scenario Optimization Tool for CAST
(the time-averaged Phase 6 watershed model)

20 February 2019
Modeling Workgroup Quarterly Review

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.

BMP effects simulated in CAST



Best Management Practices (BMPs)

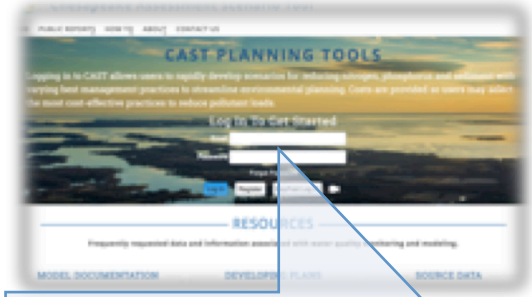
Chesapeake Assessment Scenario Tool (CAST)

Less nutrients

Less sediment

Would like to find low-cost BMP strategies, but not feasible to exhaustively try potential scenarios

Developing optimization engine



Best Management Practices (BMPs)

Chesapeake Assessment Scenario Tool (CAST)

Less nutrients

Less sediment

Optimization engine

Minimize Total Cost ($)

Achieve target Load Reduction

PLANS

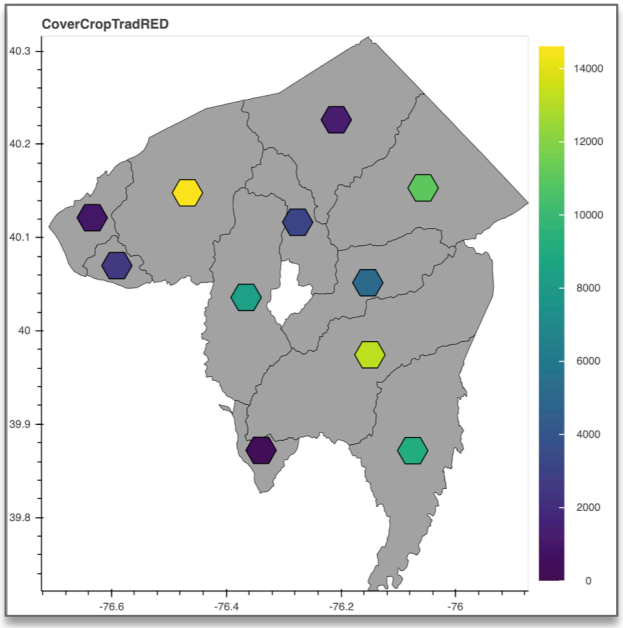
Near-term:

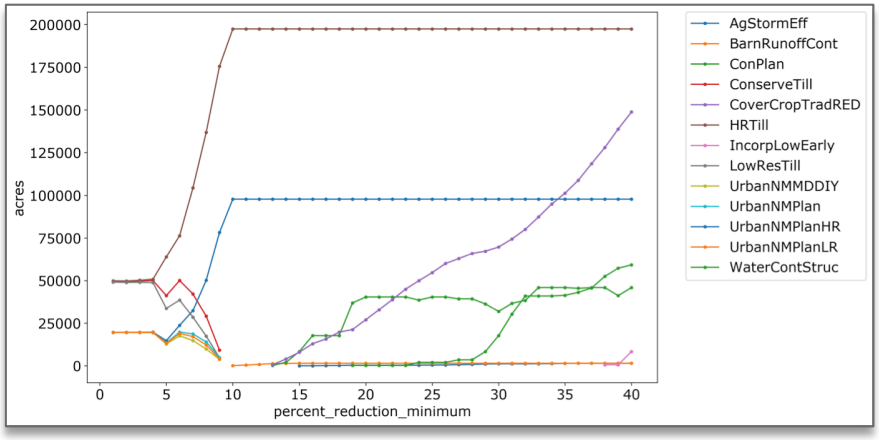
Beta version in first quarter 2019 using only efficiency BMPs (those whose effects can be most readily formulated into a mathematical programming model) to *provide utility & gather feedback*.

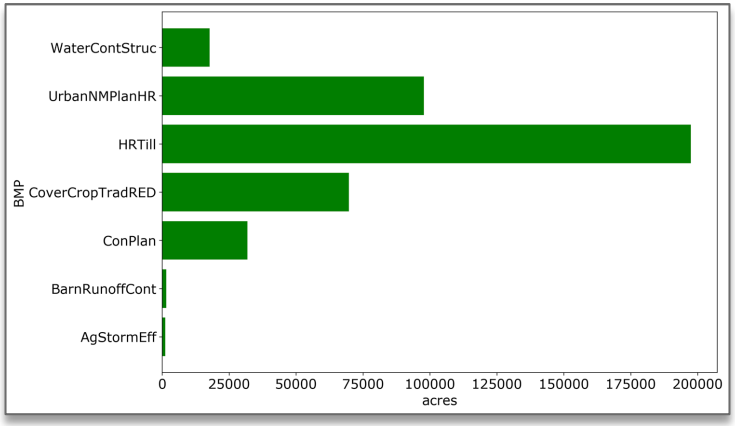
Longer-term:

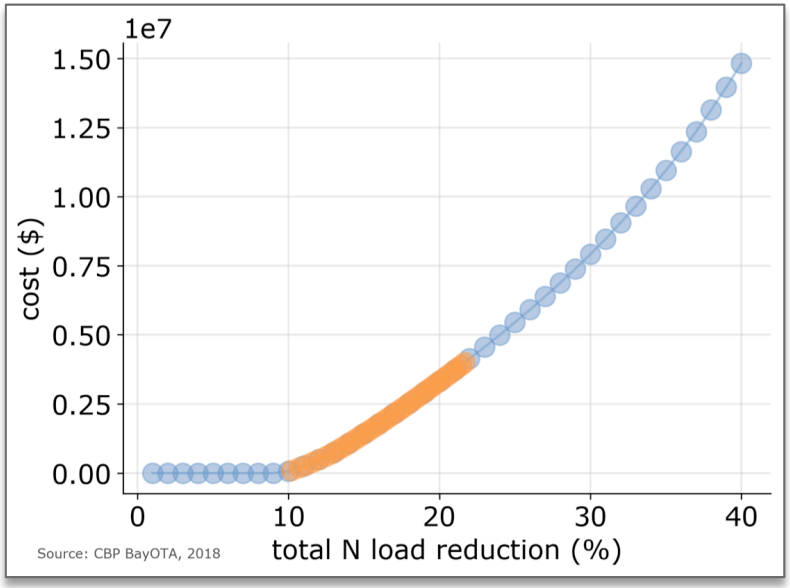
Incorporate additional BMPs into optimization framework, and/or test heuristic optimization algorithm(s) to iteratively sample the scenario-space.

Version Beta-1 Prototyping



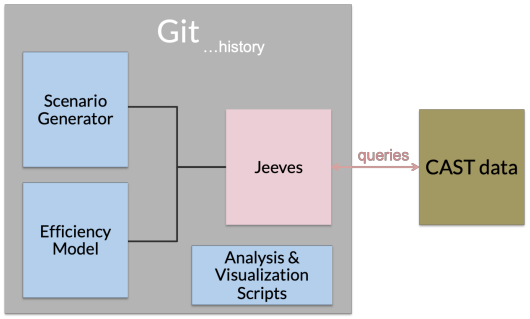




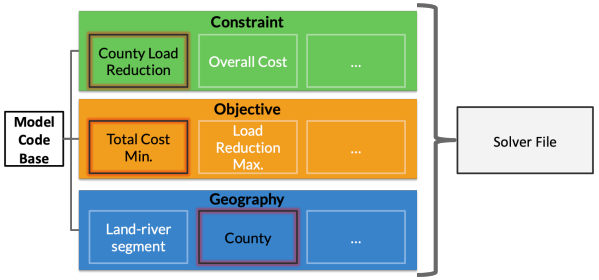


Last ModWG Meeting: **Software updates**

1. Code base restructuring



2. Model generation for different studies



3. Code interface for specifying runs

```
# Example instantiation
s = Study(objectivetype='costmin',
          geoscale='county',
          geoentities=['Montgomery, MD'],
          baseconstraint=5)  # ≥ 5% N load reduction

# Example solving
solver_diagnostics, solution_csv, data, objective = s.go()
```

Path to Version **Beta-1**

- Test outputs
  - adapt code for outputting to CAST CSV format
- Design / interface
- Different base load years (*time permitting*)

How can we present preliminary results while having the page serve as a great feedback-gathering apparatus?

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

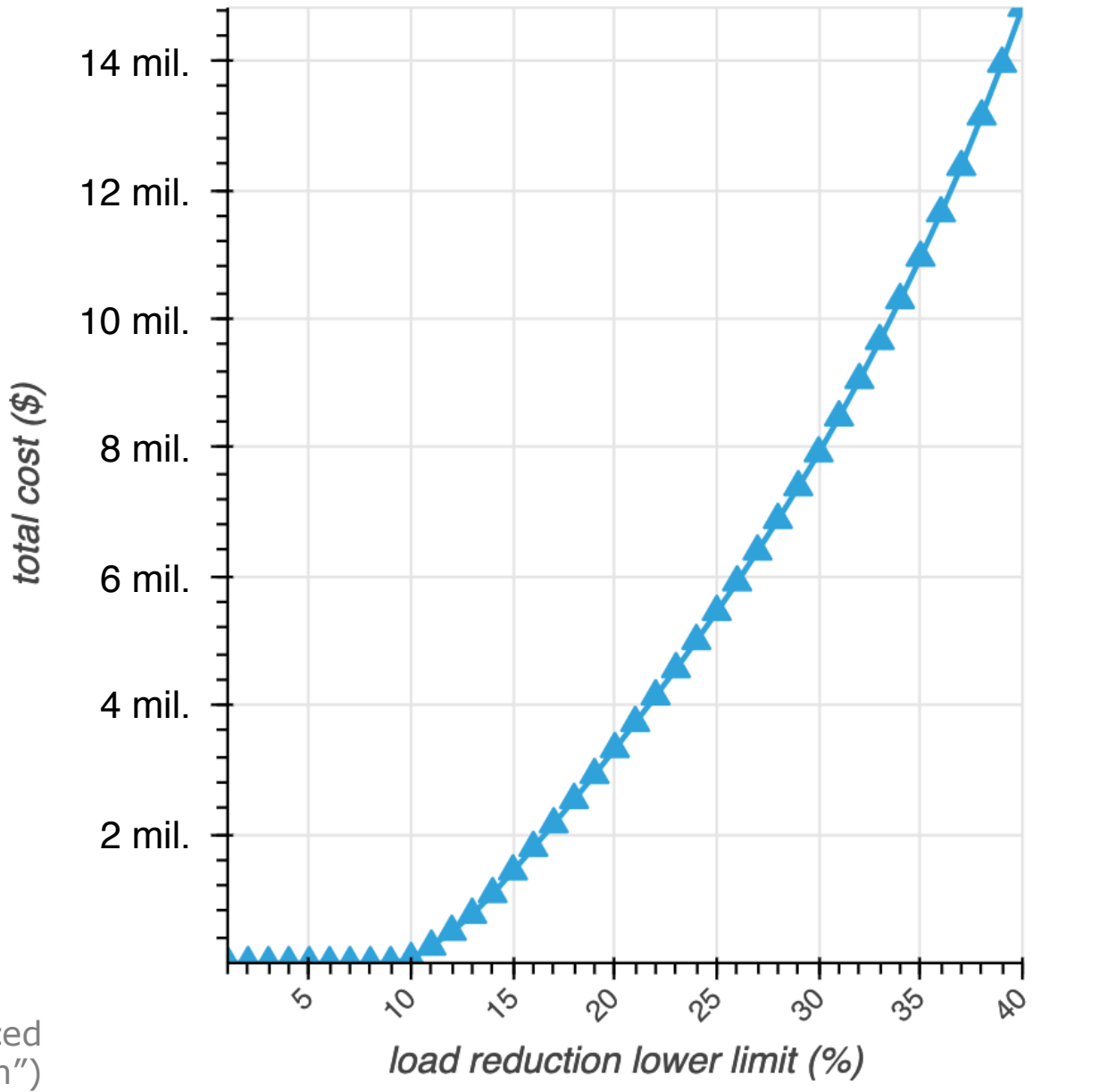
Select main constraint ➡ achieve target load reduction

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.

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

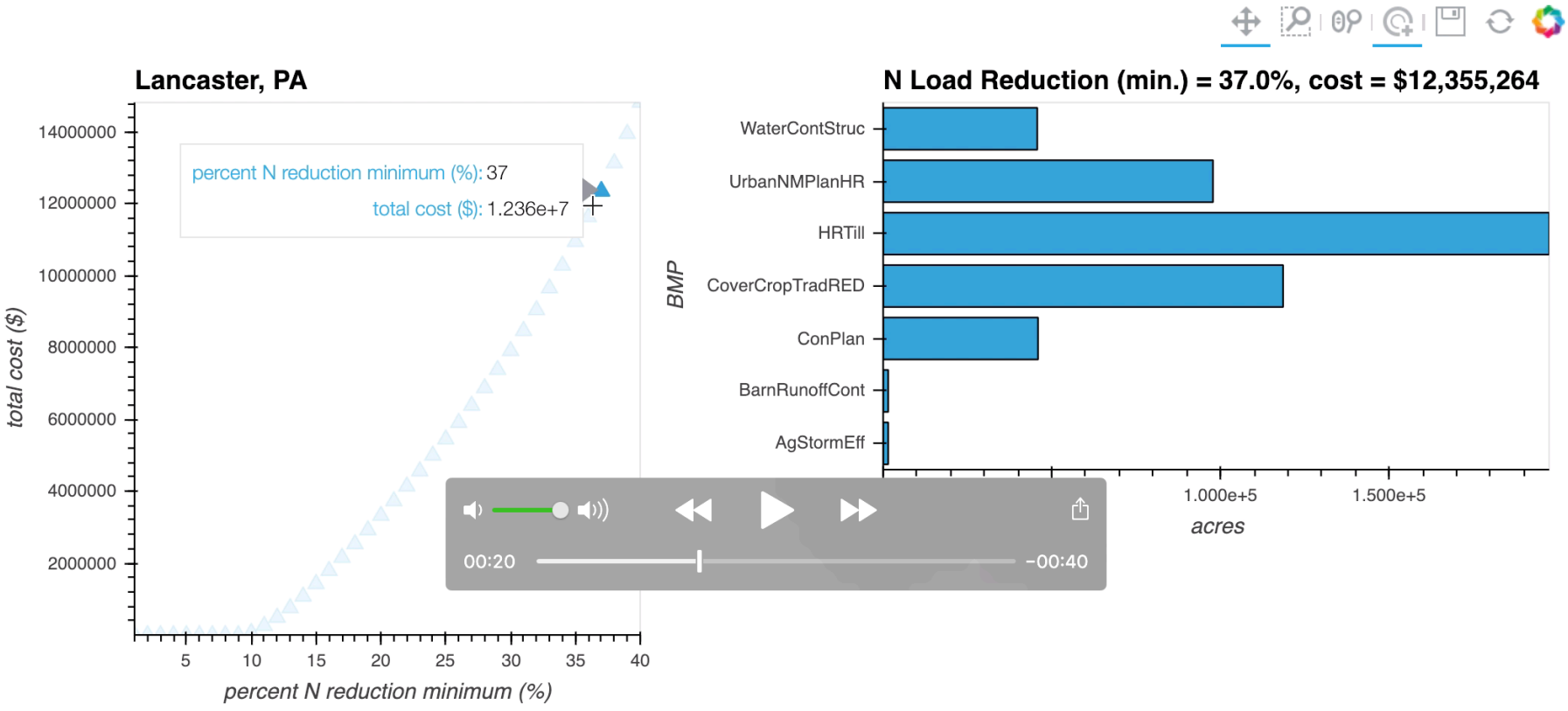


N lbs. reduced
(from "2010 No Action")

Objective:
Minimize
Total Cost ($)

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

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



Objective:
Maximize
Load Reduction ($)

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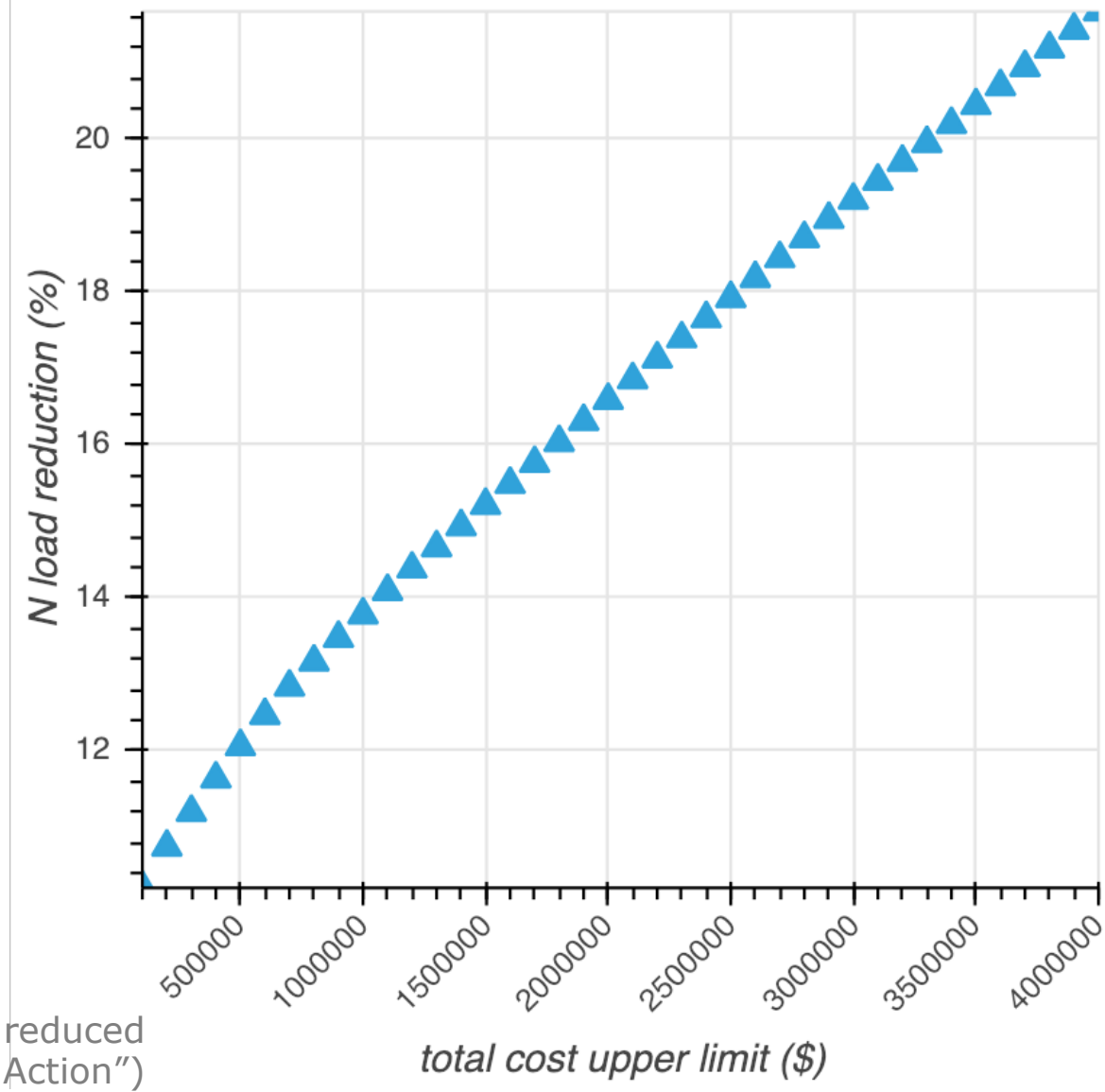

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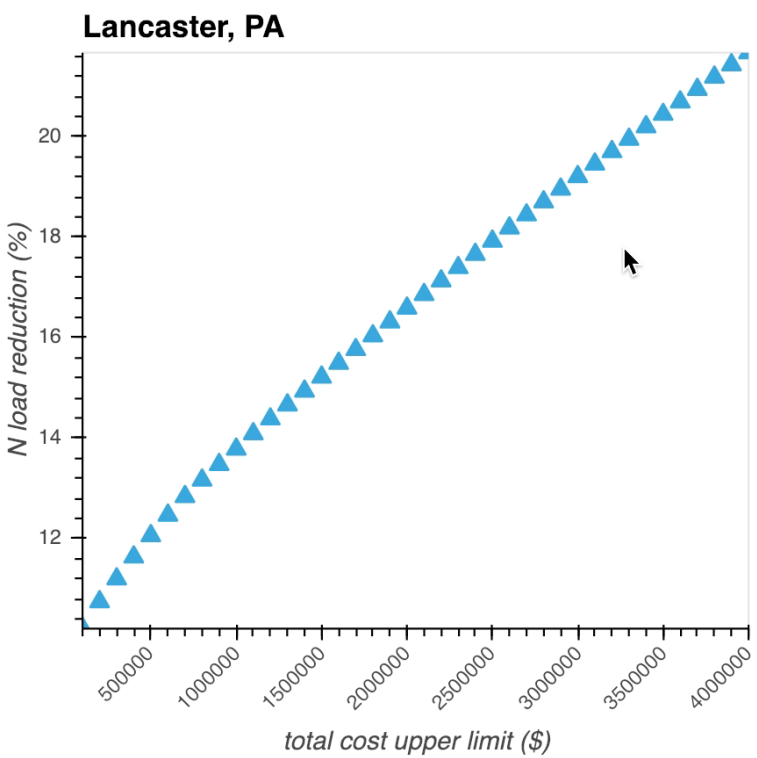
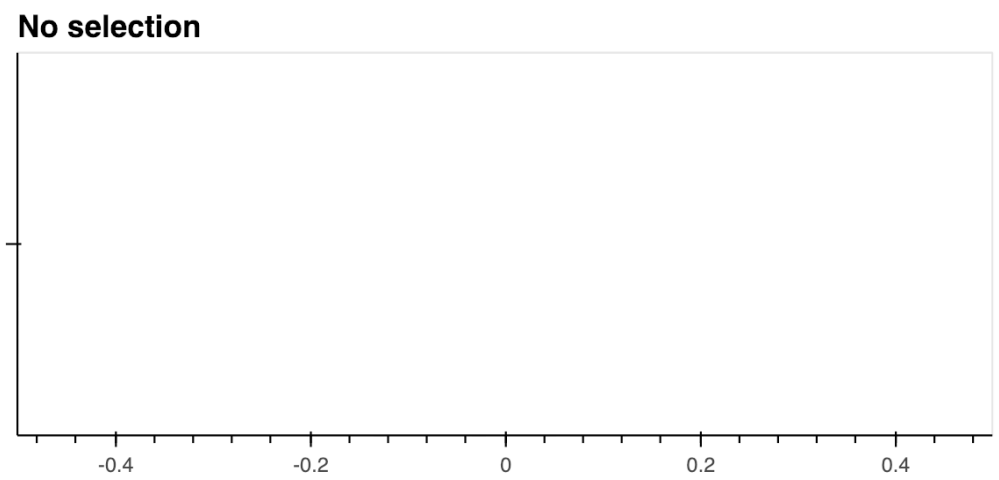
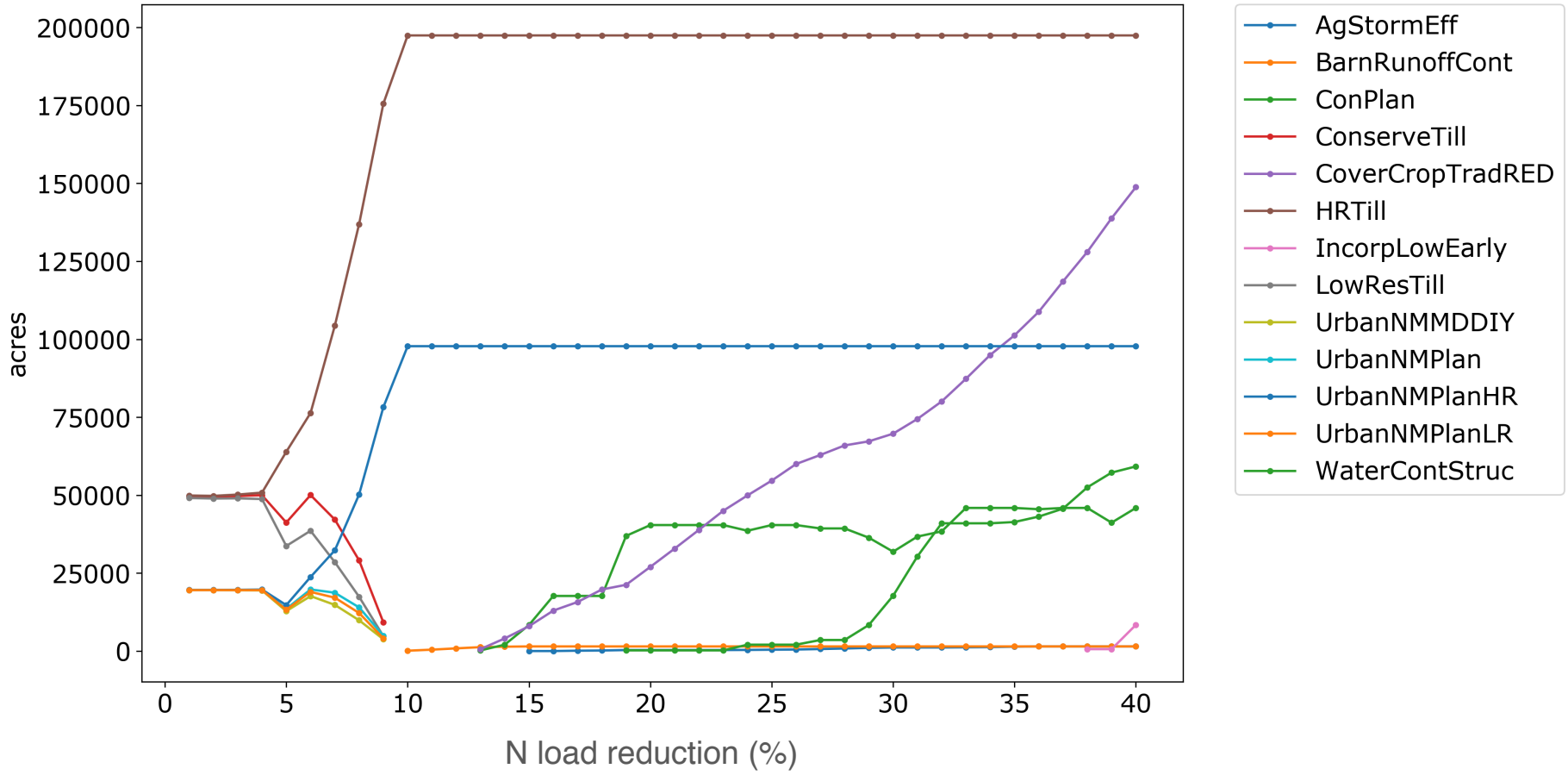




Lancaster, PA

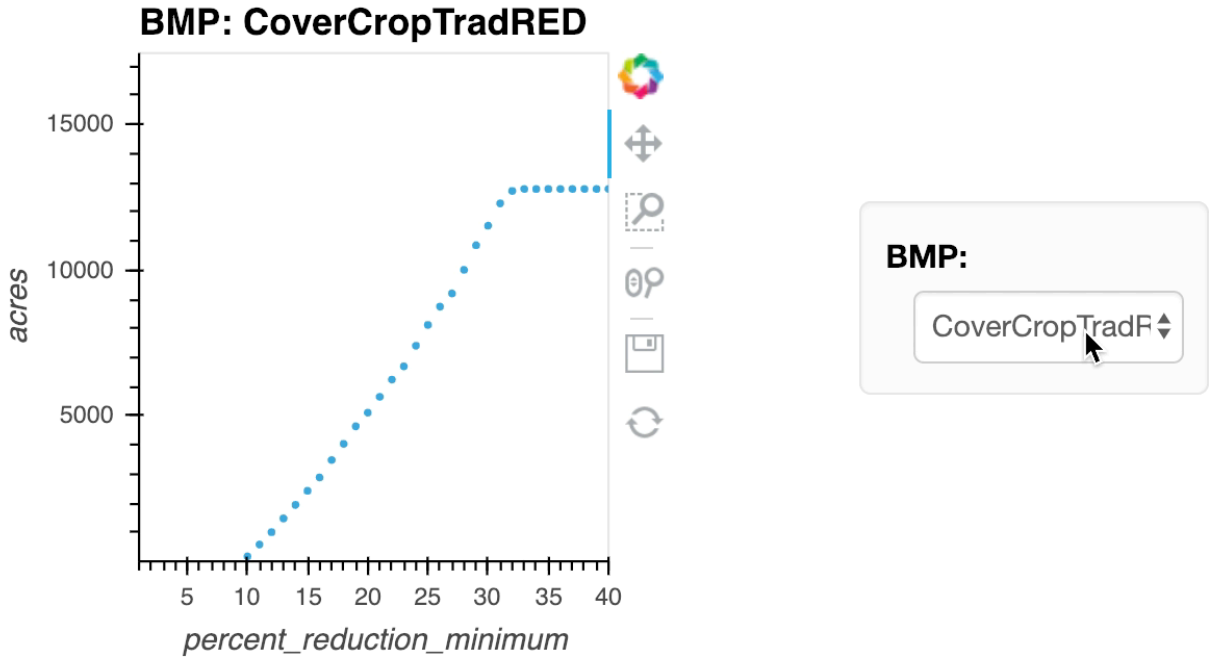


Selecting BMPs

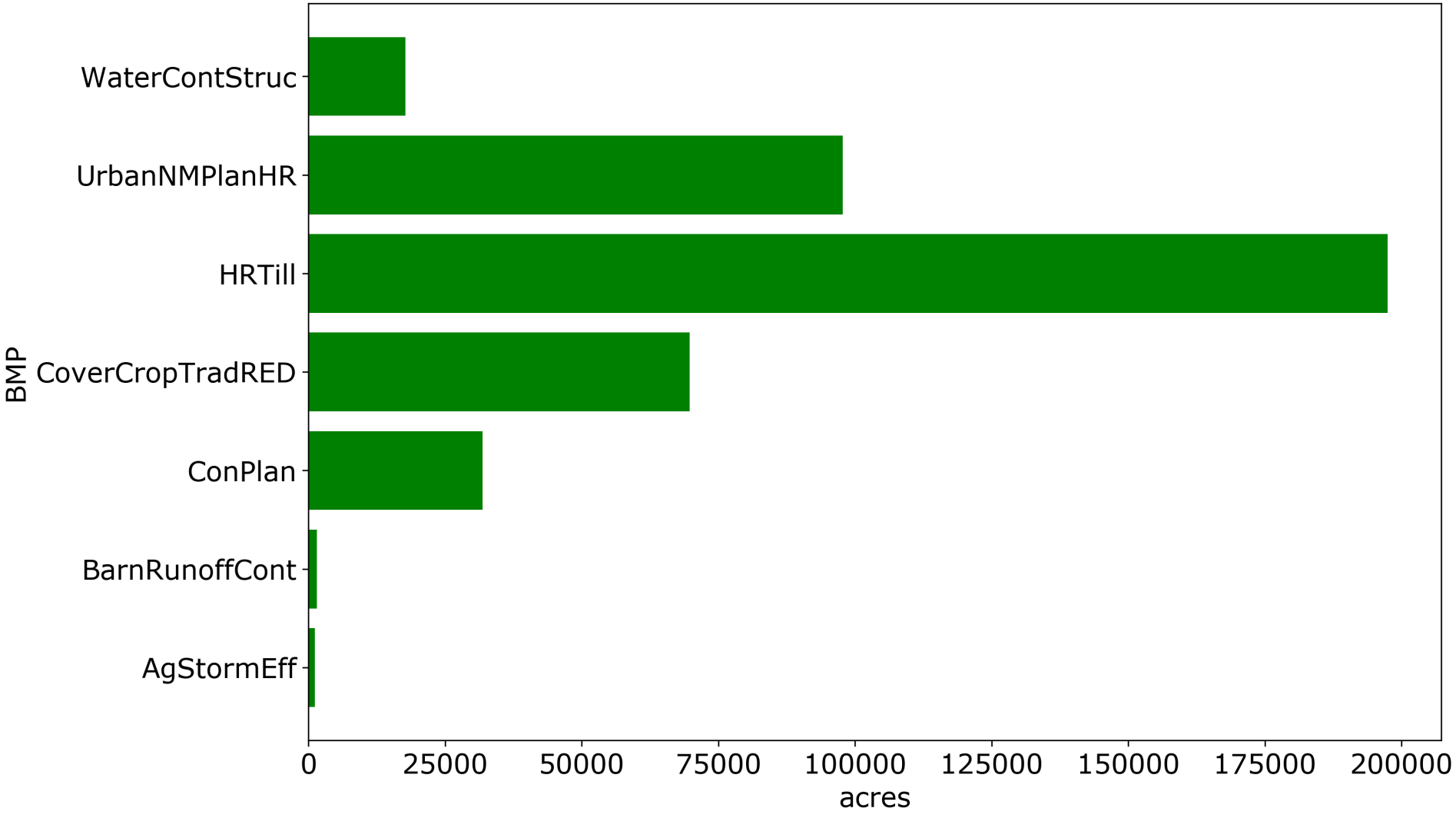
In [65]:
```
coords = {b: hv.Scatter(merged_costmin_bmptotals.loc[merged_costmin_bmptota
                        'percent_reduction_minimum', 'acres')
          for b in list(merged_costmin_bmptotals['bmpshortname'])}

hv.HoloMap(coords, kdims='BMP')
```

Out[65]:



Lancaster, PA



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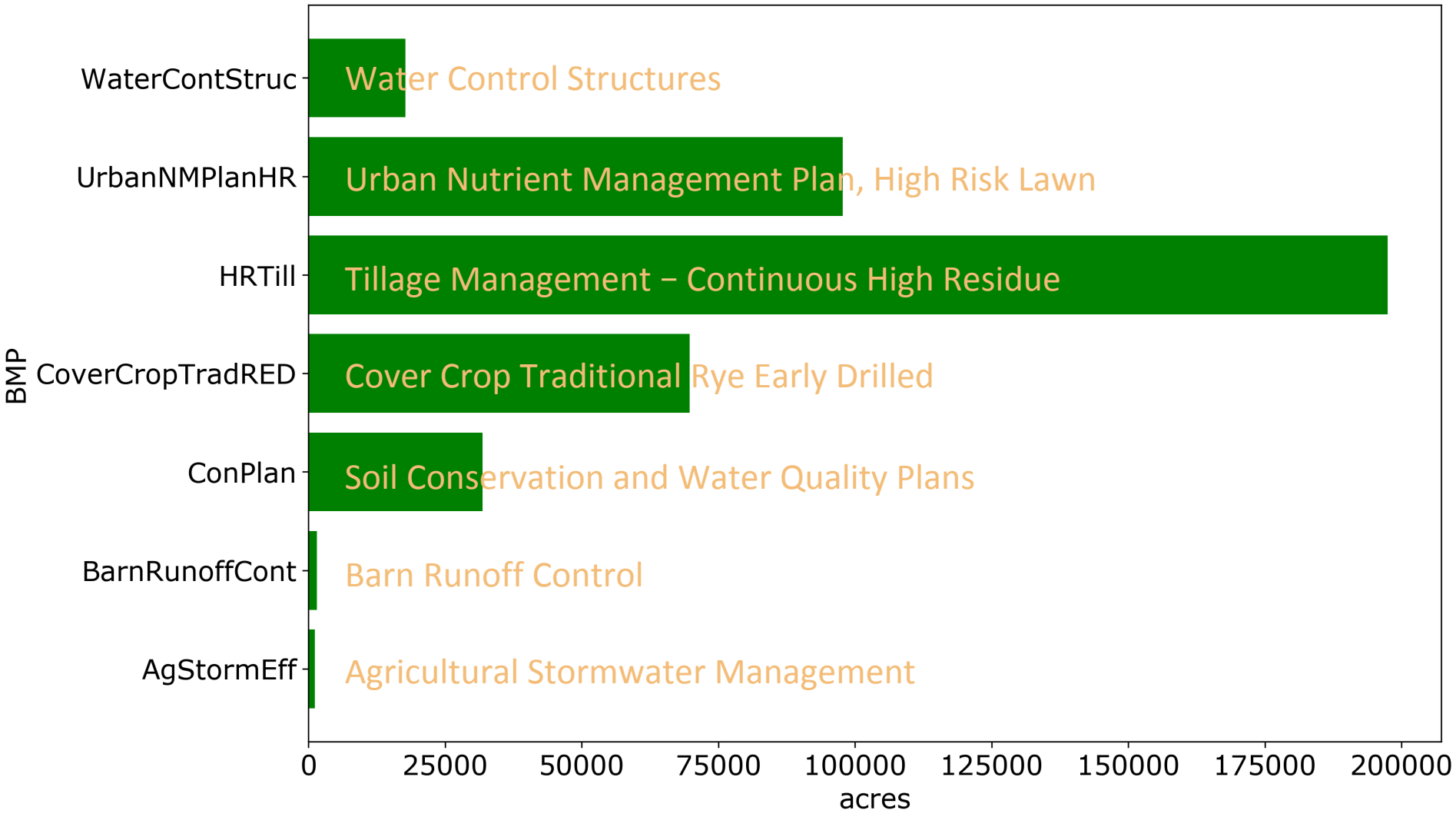

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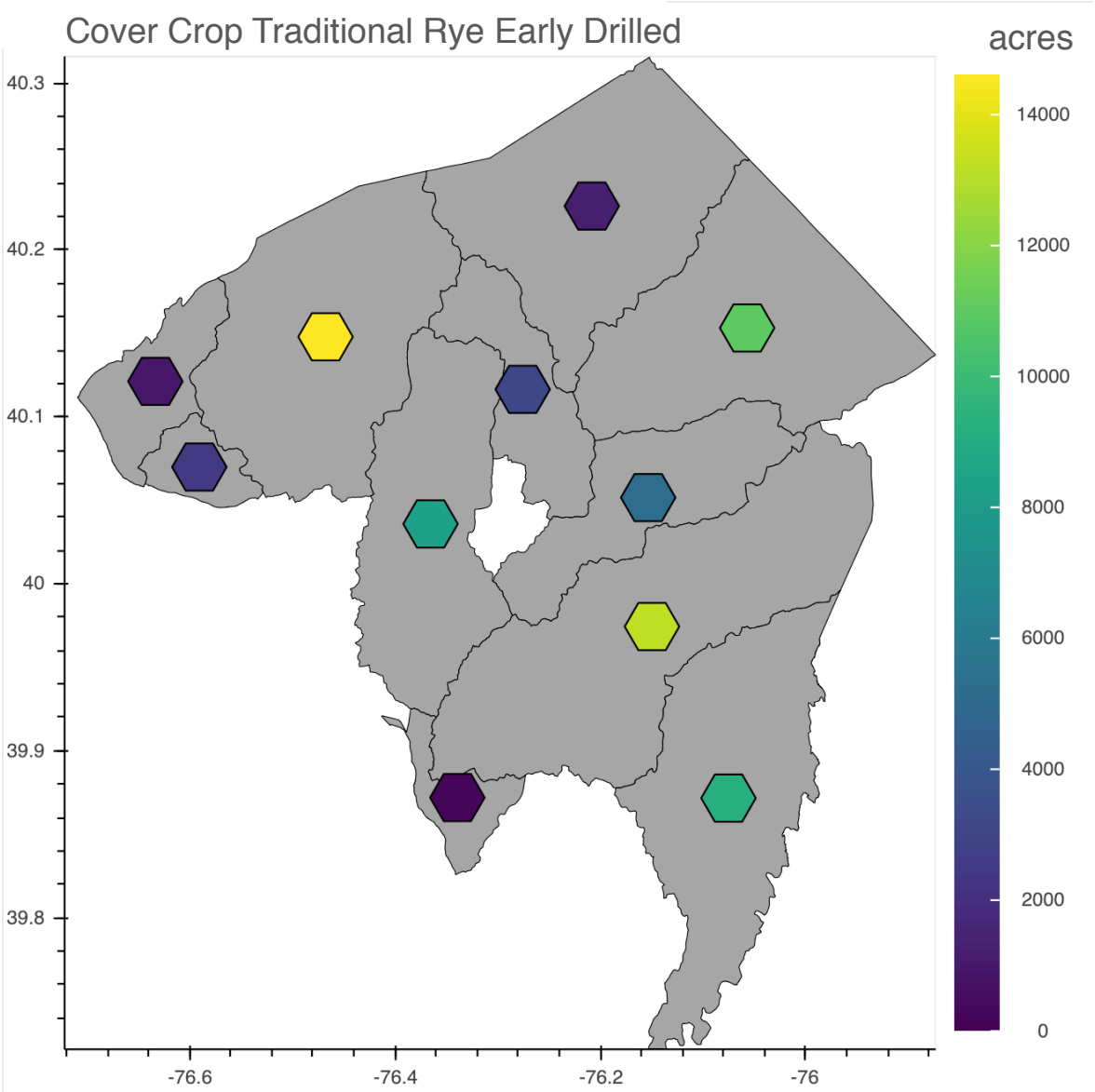

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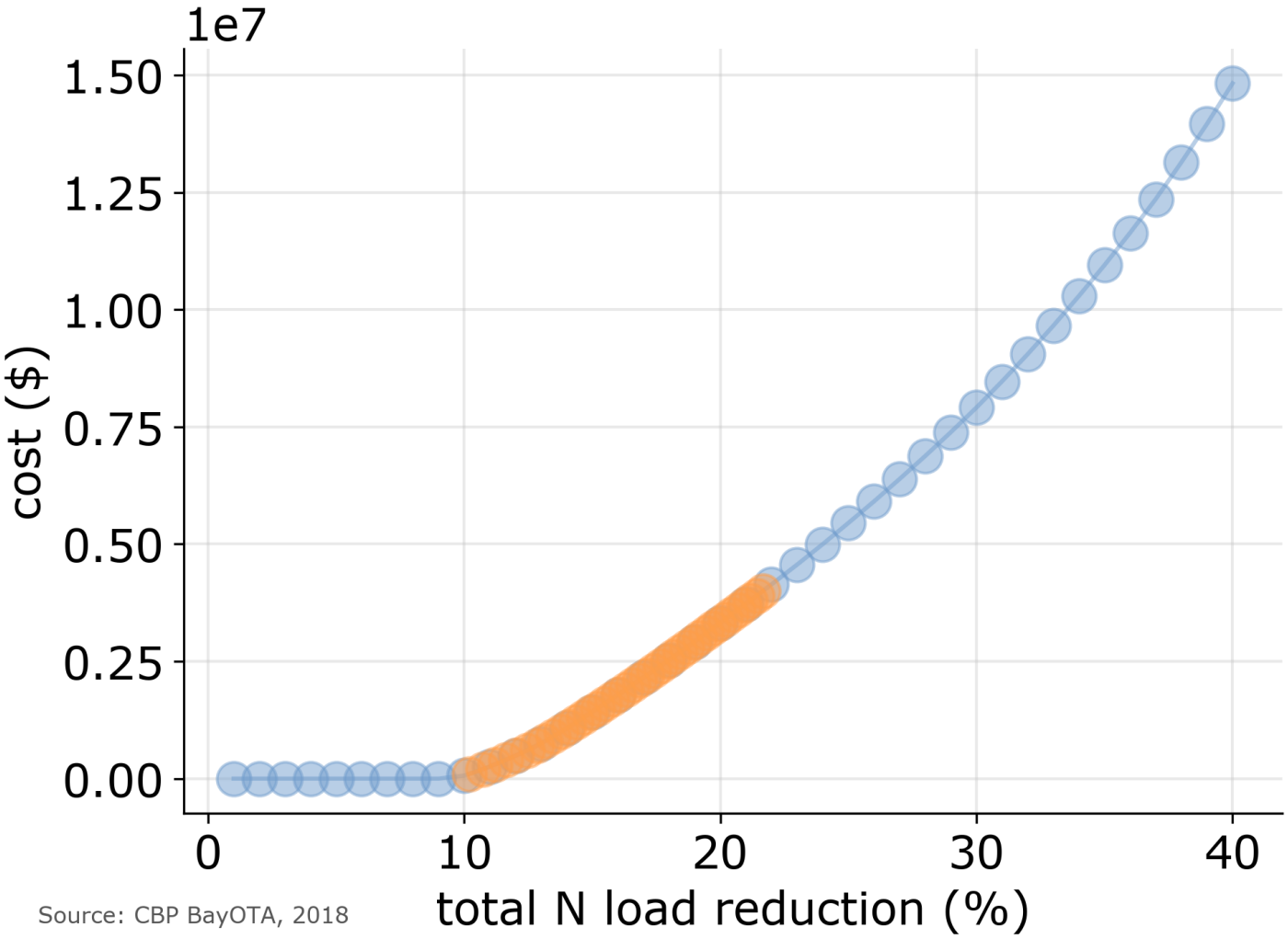


Source: CBP BayOTA, 2018

Continuing

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

- Collaboration with Advisory and Support Committee and Dr. Skipper






Advisory & Support Committee

External Collaboration

Current status

"Straw-arm" prototype
(Part of straw-man)

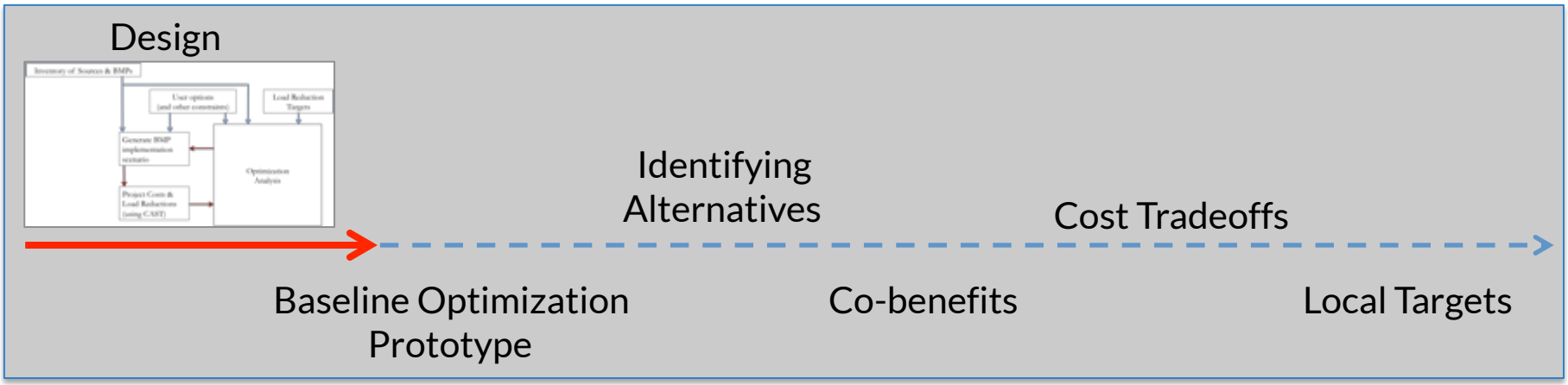
- Results are draft/preliminary, and subject to revision.
- Prototype is not intended for use in Phase III WIP development.
- Beta version prototype will not include BMPs other than efficiencies. There are other BMPs, e.g. Buffers, that are important for reducing load.

Cost information (from the CAST documentation): The Chesapeake Bay Watershed [cost profile] is an average of all states… Costs are estimated in 2010 dollars. 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. The interest rate for capital and opportunity costs is 5%. Costs are those incurred by both public and provide entities. Costs represent a single year of cost rather than the cost over the entire lifespan of the practice. 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.

Will be shaped by feedback

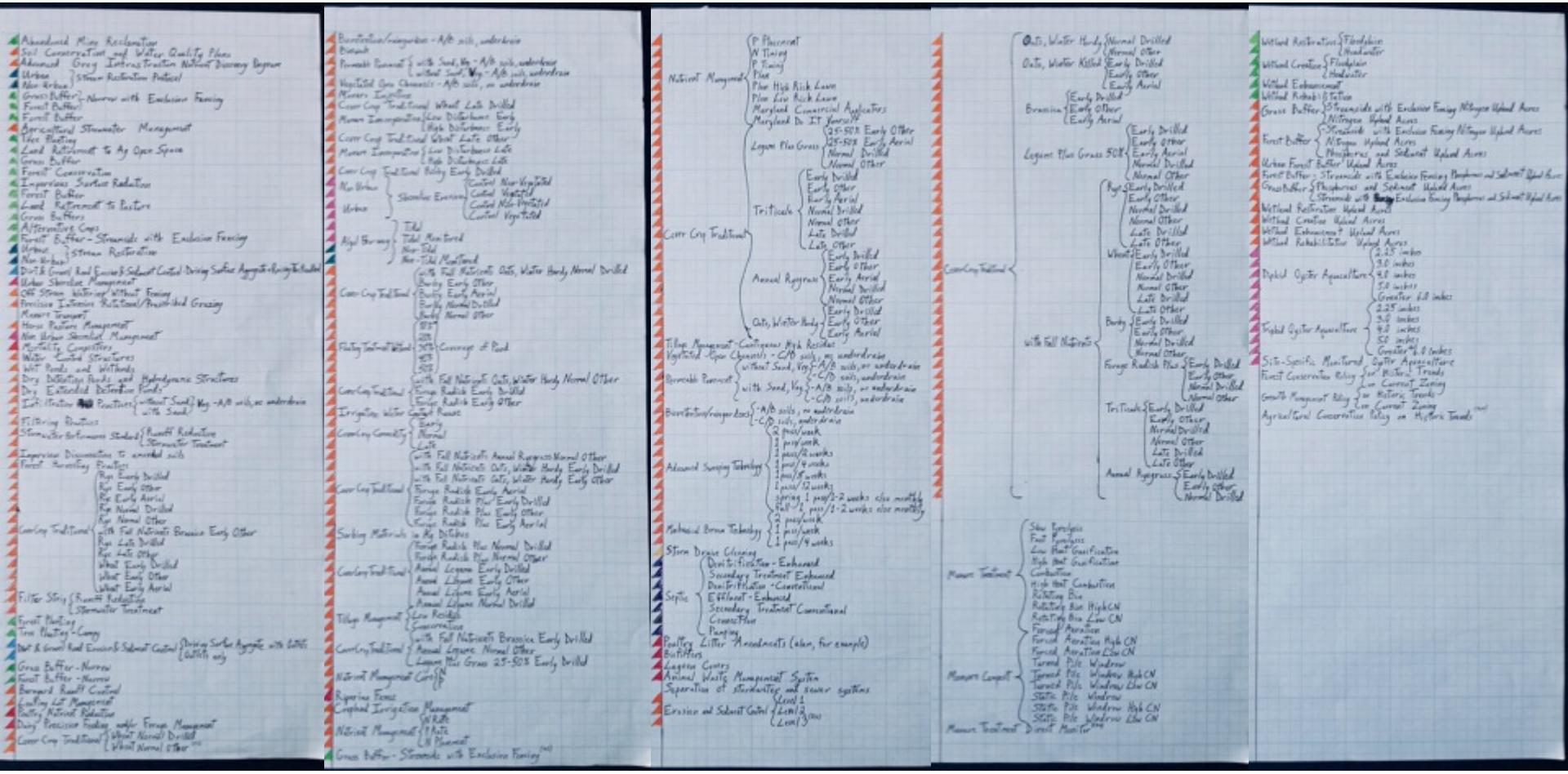
Actively searching for ways to engage local decision makers at all scales (county, municipal, state, etc.) for their guidance and feedback on prototype design.

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



Extra slides follow

Best Management Practices (BMPs) in CAST



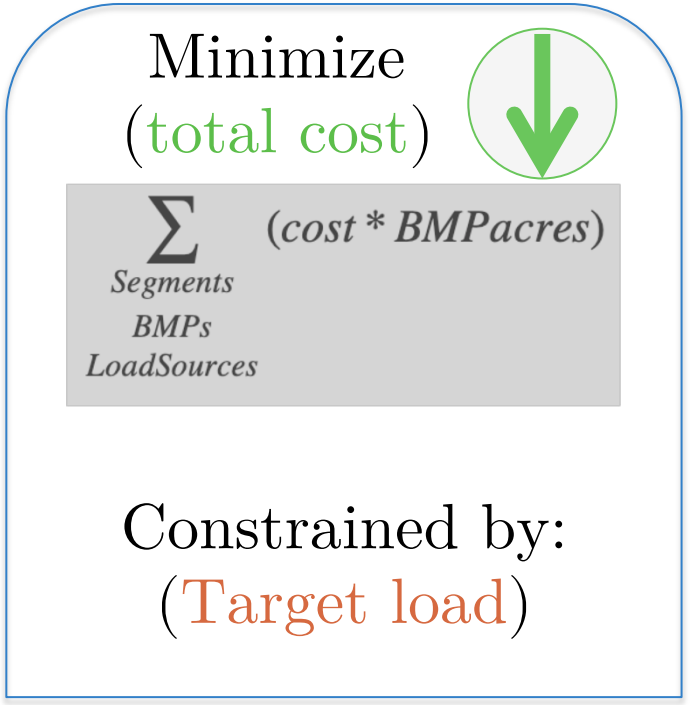
Orange = Efficiency BMPs

Efficiency BMPs include:

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

Prototype methods

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



The same calculations as in CAST

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

Main Software Tools/Requirements

- Model code formulated with Pyomo[1]
  (algebraic modeling language library for python) developed by Sandia National Laboratories.

- Model instances solved using IPOPT[2]
  (interior point / barrier method solver) developed at Carnegie Mellon Univ. and available as part of the Computational Infrastructure for Operations Research (COIN-OR)

[1]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.

[2]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