

Beta-2

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

8 October 2019 – Modeling Workgroup Quarterly Meeting
Danny Kaufman, Kevin Asplen, 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 non-federal CBP partners.

Optimization Development Timeline (2018-2021)

Straw version

Evaluation of a “straw” version prototype (formulated for a single land-river segment)

Tool Updates and Prototyping

- Efficiency BMP online tool is updated with new features for **Beta-2**
- Non-efficiency BMPs are researched and strategy for including them in optimization is developed.

Optimization application for Climate Change targets

Optimization tool with non-efficiency BMPs begins to be used for climate change target planning

Initial Prototyping

Programming objectives and designs for the prototype were considered and revised

Beta-1 released

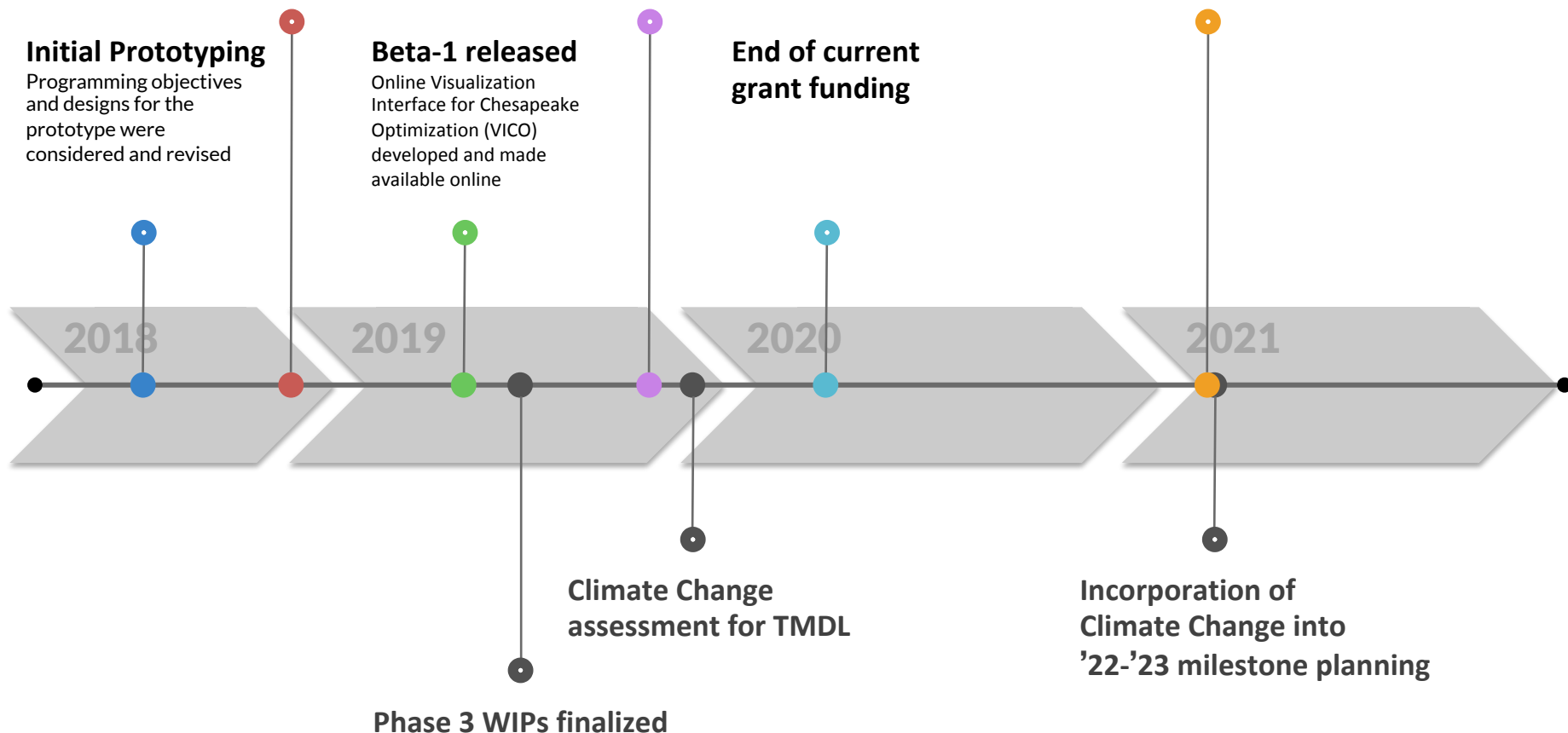
Online Visualization Interface for Chesapeake Optimization (VICO) developed and made available online

End of current grant funding

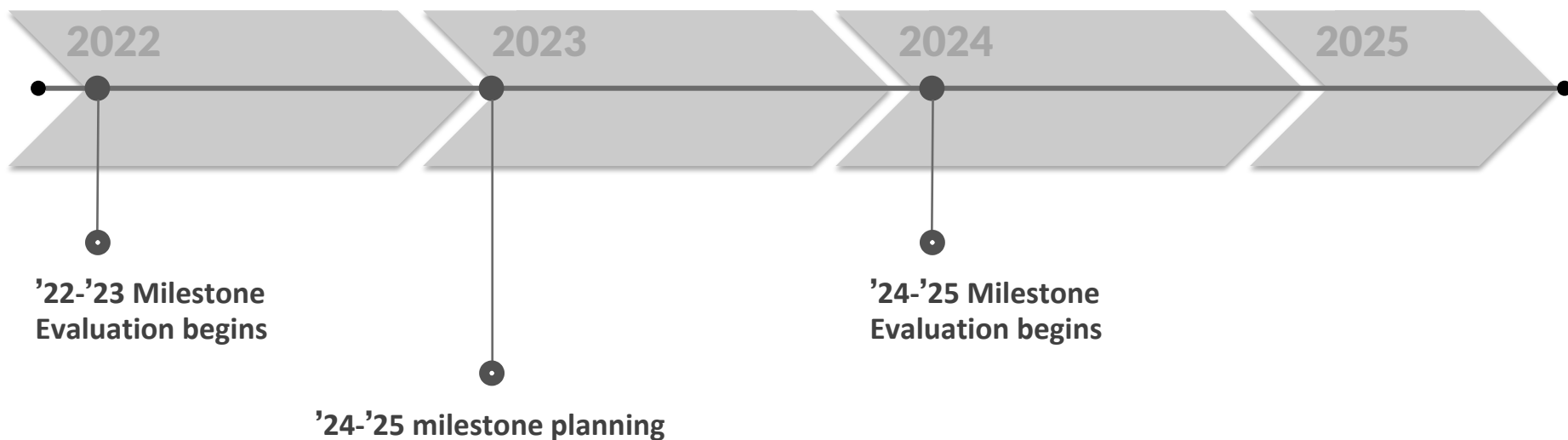
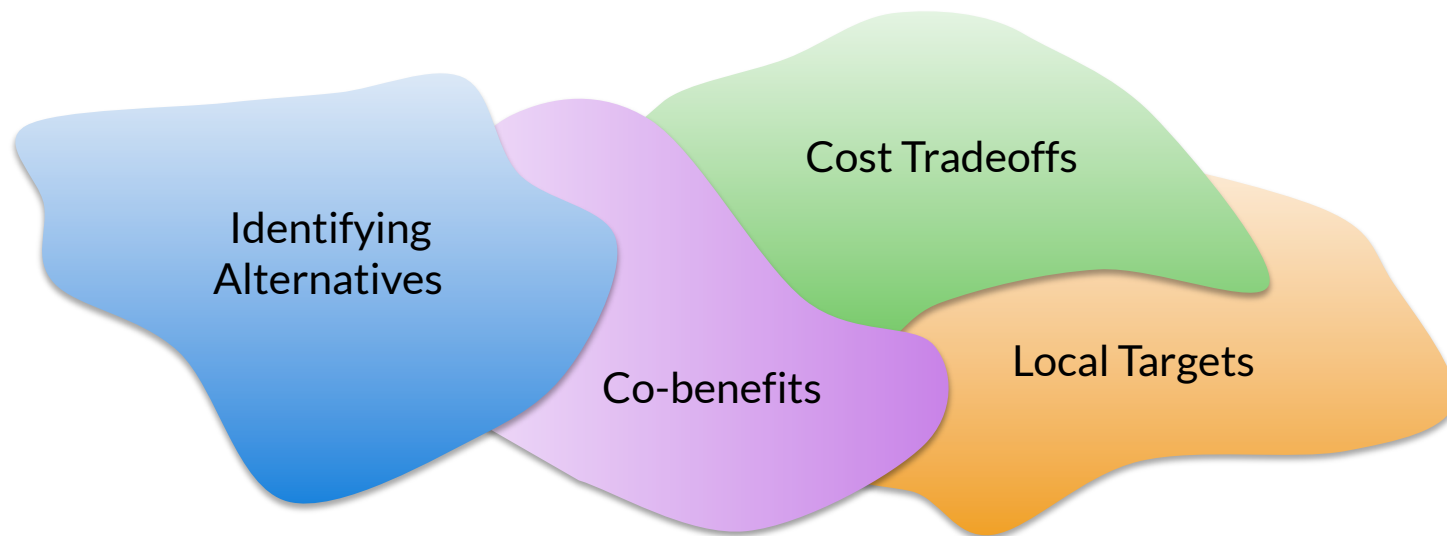
Climate Change assessment for TMDL

Incorporation of Climate Change into '22-'23 milestone planning

Phase 3 WIPs finalized



Optimization Development Timeline (2022-2025)



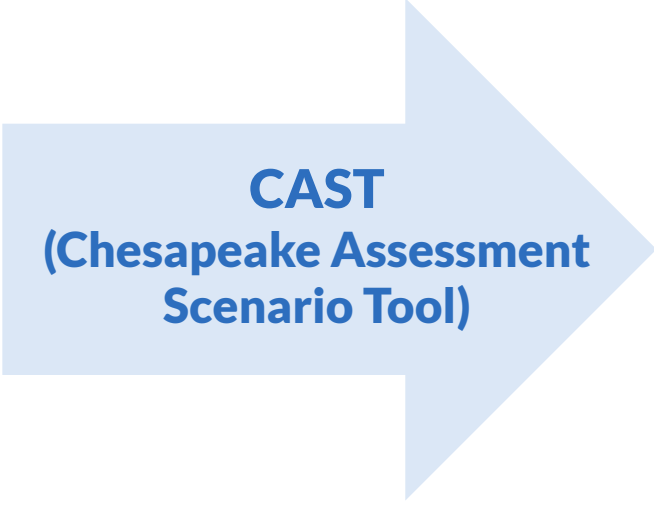
Outline

Optimization challenge (“The Wall”) update

Online tool updates

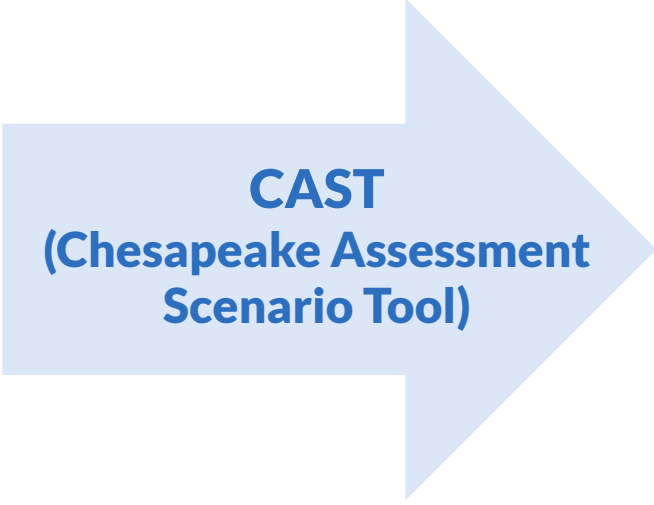
Ongoing development & planned updates

Optimization challenge



CAST
**(Chesapeake Assessment
Scenario Tool)**

Optimization challenge



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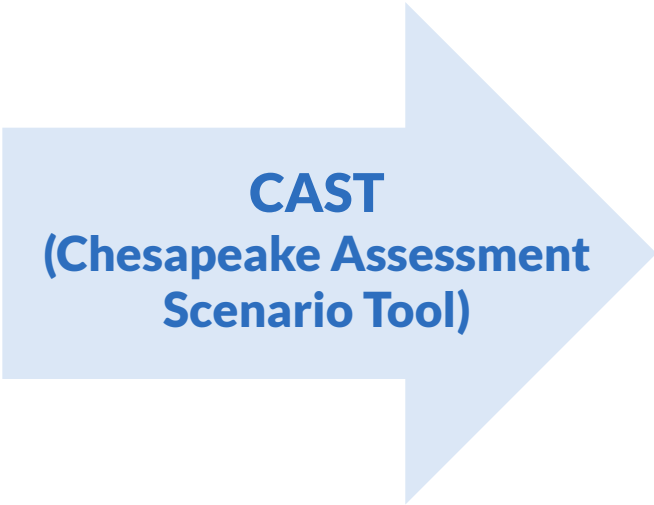


Nutrient & Sediment
Load Reductions
(with least cost \$)


Optimization challenge



**Best
Management
Practices (BMPs)**



CAST
**(Chesapeake Assessment
Scenario Tool)**



Nutrient & Sediment
Load Reductions
(with least cost \$)

Optimization challenge



CAST
(Chesapeake Assessment
Scenario Tool)

Nutrient & Sediment
Load Reductions
(with least cost \$)



Approximately 300 BMP varieties in CAST

Optimization challenge



CAST
(Chesapeake Assessment
Scenario Tool)

Nutrient & Sediment
Load Reductions
(with least cost \$)



Approximately 300 BMP varieties in CAST

non-efficiency BMPs
~120

efficiency BMPs
~180

For example:

Animal waste storage,
Feed additives,
Riparian buffers

For example:

Cover crops,
Infiltration practices,
Barnyard runoff control

Optimization challenge



CAST
(Chesapeake Assessment
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Nutrient & Sediment
Load Reductions
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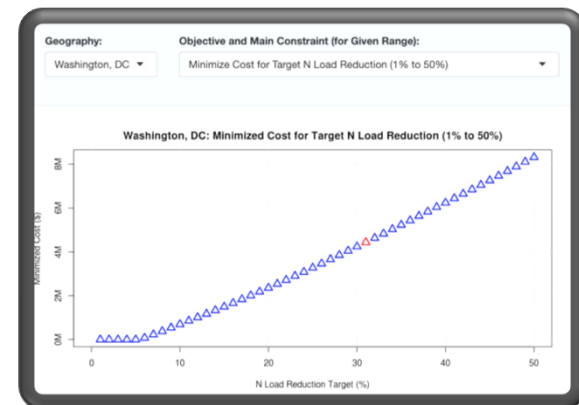
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$$\prod_{G^B \in \mathcal{G}_u^B} \left(1 - \sum_{b \in G^B} \frac{\eta_{u,b}}{\alpha_u} X_{u,b} \right)$$

Current basis for online
tool



Optimization challenge



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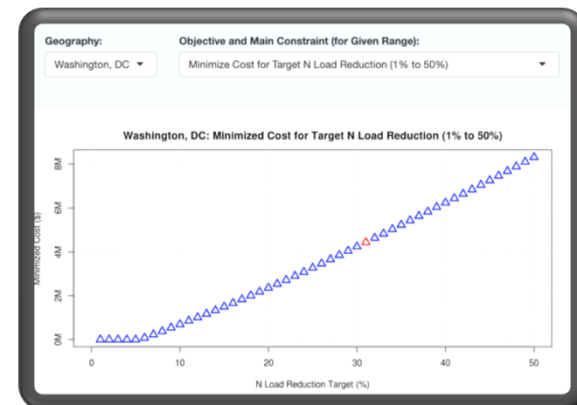
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What optimization
approach will be
effective?

$$\prod_{G^B \in \mathcal{G}_u^B} \left(1 - \sum_{b \in G^B} \frac{\eta_{u,b}}{\alpha_u} X_{u,b} \right)$$

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“The Wall” – what optimization approach will be effective?

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3+ approaches

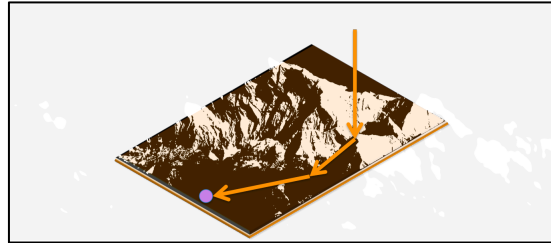


“The Wall” – what optimization approach will be effective?

3+ approaches



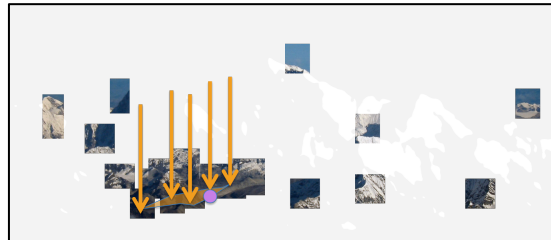
A) “Exact”



B) Surrogate modeling



C) Heuristic



“The Wall” – what optimization approach will be effective?

3+ approaches



A) “Exact”

To decide... to get over “the wall”:

- evaluate mathematical structure (approach depends on “landscape”)
- prototype

B) Surrogate modeling

C) Heuristic

“The Wall” – what optimization approach will be effective?

Evaluating the mathematical structure
of the CAST load function...

$$\mathcal{L} = \sum_{s \in S^*} \left[\sum_{h \in H} \left(\sum_{u \in U_N} \left(\left[\bar{\mathcal{L}}_u^w + \sum_{t \in T} \left((I_{u,t,k(s)} - \bar{I}_{u,t}) * \sigma_{u,t} \right) \right] * \theta_{s,h,u}^* * \alpha_{s,h,u} * \psi_{s,h,u}^{LW} * \psi_{s,h,u}^{SR} \right) * \zeta_{s,h}^{stb} \right) * \psi_{s,h,u}^{RB} + \sum_{u \in U_D} (\mathcal{L}_{s,u} * \psi_{s,u}) \right] + \sum_{s \in S^*} \sum_{h \in H} \mathcal{L}_{s,h,sho}$$

“The Wall” – what optimization approach will be effective?

Approximately 300 BMP varieties in CAST

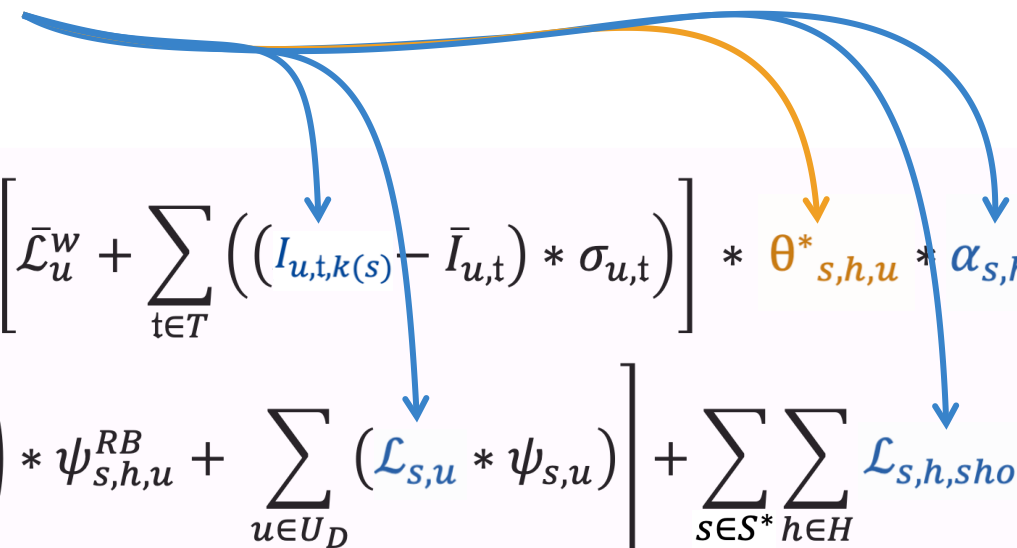
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“The Wall” – what optimization approach will be effective?

Approximately 300 BMP varieties in CAST



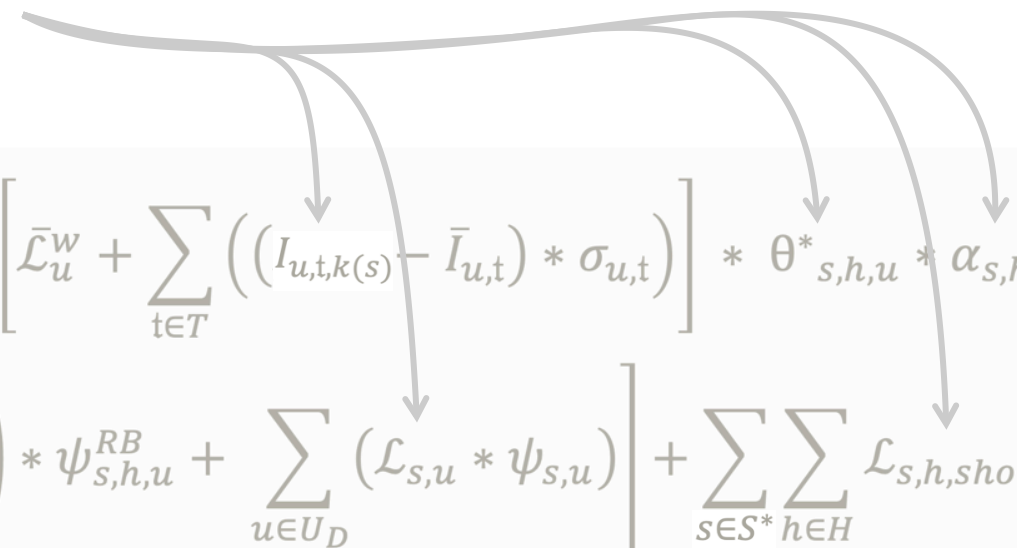
The diagram shows a blue line originating from the text 'Approximately 300 BMP varieties in CAST'. From this line, four arrows point to specific terms in the equation below:

- A blue arrow points to the term $I_{u,t,k(s)}$ in the inner sum.
- A blue arrow points to the term $\mathcal{L}_{s,u}$ in the sum over $u \in U_D$.
- An orange arrow points to the term $\theta^*_{s,h,u}$.
- A blue arrow points to the term $\mathcal{L}_{s,h,sho}$ in the final double sum.

$$\mathcal{L} = \sum_{s \in S^*} \left[\sum_{h \in H} \left(\sum_{u \in U_N} \left(\left[\bar{\mathcal{L}}_u^w + \sum_{t \in T} \left((I_{u,t,k(s)} - \bar{I}_{u,t}) * \sigma_{u,t} \right) \right] * \theta^*_{s,h,u} * \alpha_{s,h,u} * \psi_{s,h,u}^{LW} * \psi_{s,h,u}^{SR} \right) * \zeta_{s,h}^{stb} \right) * \psi_{s,h,u}^{RB} + \sum_{u \in U_D} (\mathcal{L}_{s,u} * \psi_{s,u}) \right] + \sum_{s \in S^*} \sum_{h \in H} \mathcal{L}_{s,h,sho}$$

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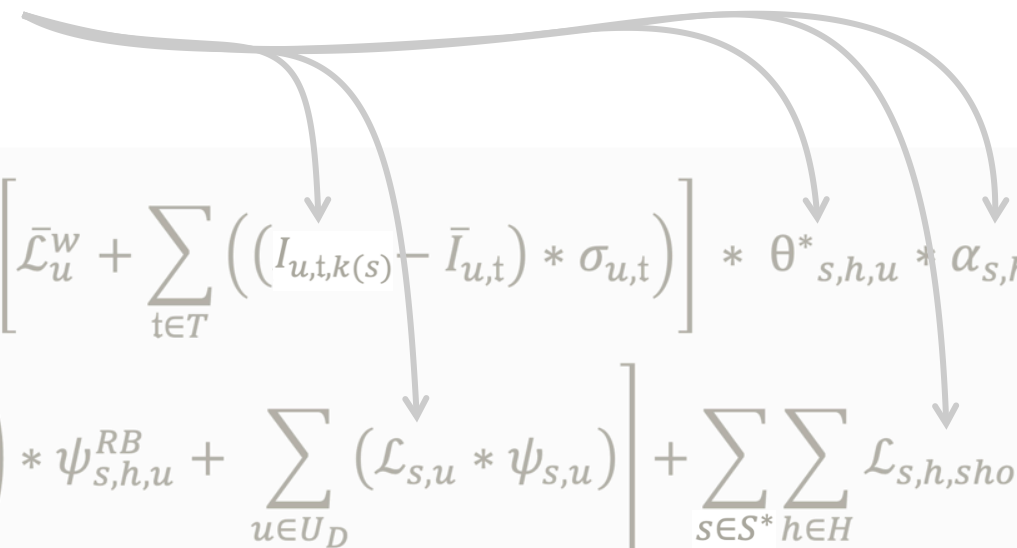

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1) We are revealing the problem Landscape

- High dimensional
- Non-linear
- Non-convex
- Generally non-separable

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1) We are revealing the problem Landscape

- High dimensional
- Non-linear
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2) We are composing a report:

- Elucidation of the CAST mathematical structure
- Optimization models and algorithmic approaches

Outline

Optimization challenge (“The Wall”) update

Online tool updates

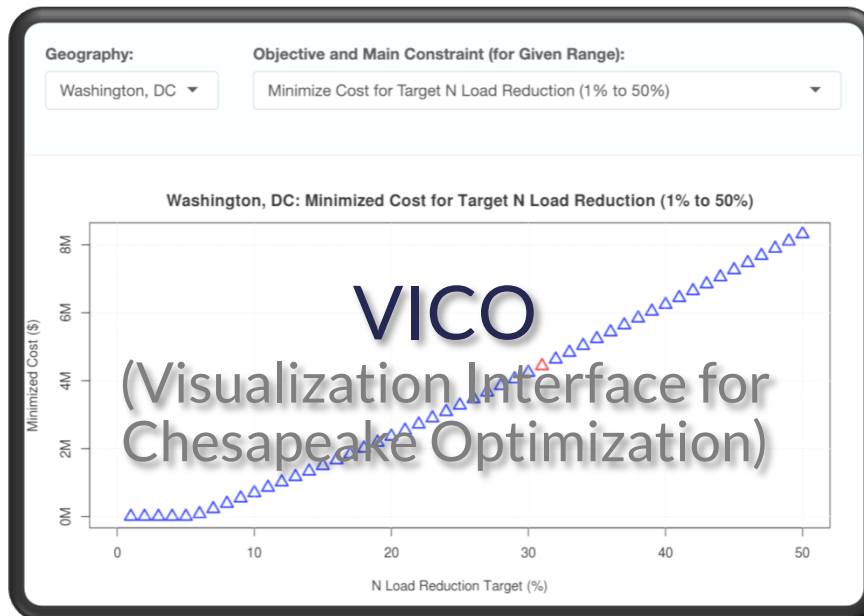
Ongoing development & planned updates

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we had the first Beta release of a working,
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Load reduction and cost tradeoffs for counties in watershed

Acres of efficiency BMPs to achieve load reduction at near least-cost

39,400 solutions (cost, load, BMPs)

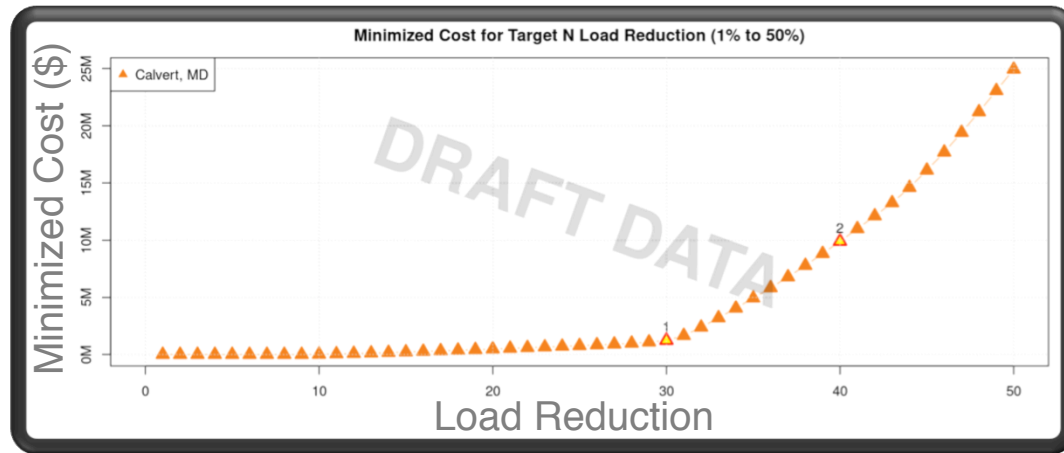
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Where do things stand now?

Visualization Interface

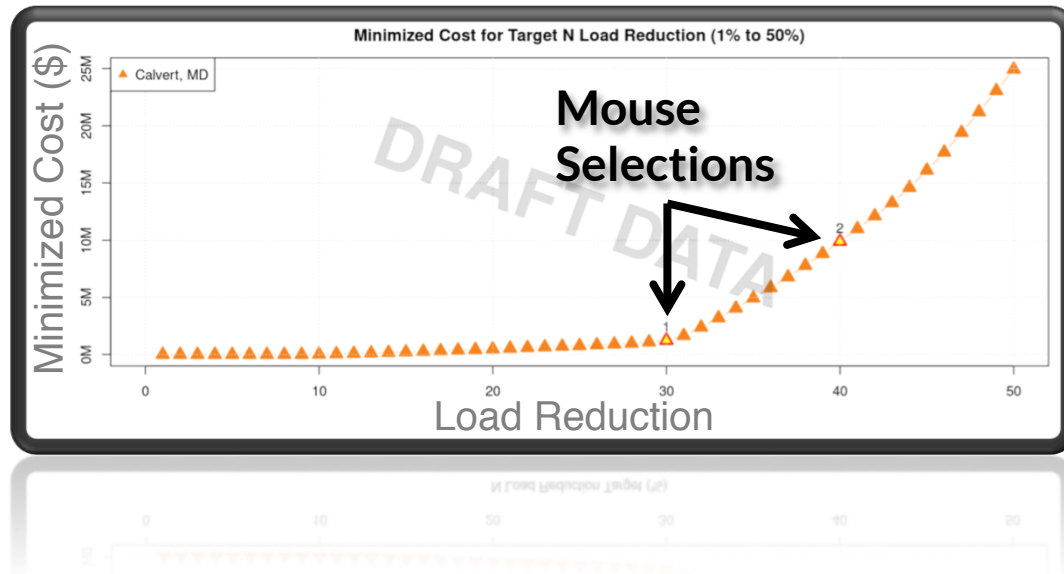
Cost vs. Load tradeoff
for a given county



Visualization Interface

Allows comparisons

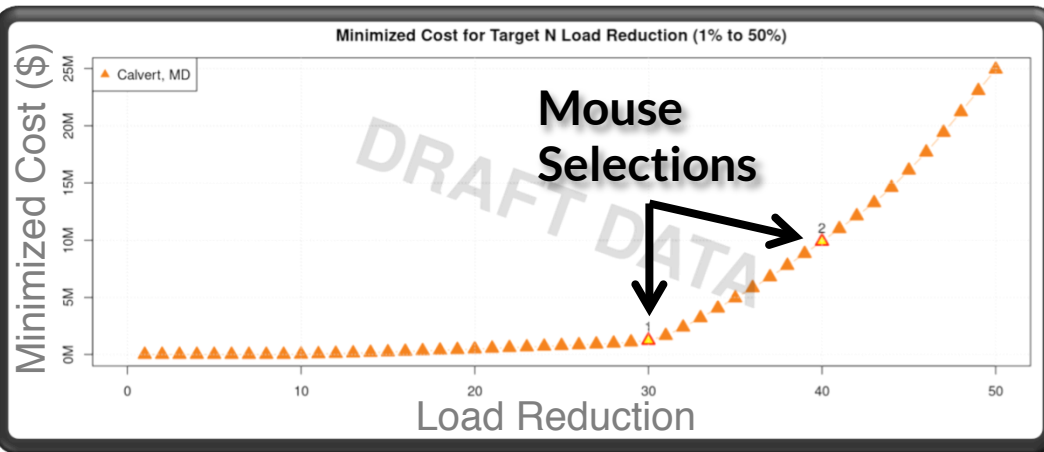
- between two points on the same county curve



Visualization Interface

Allows comparisons

- between two points on the same county curve



Calvert, MD
N load reduction ≥ 30% (=208,700 lb), Cost = \$1,236,398.91

Calvert, MD
N load reduction ≥ 40% (=278,260 lb), Cost = \$9,903,748.22

Efficiency BMP

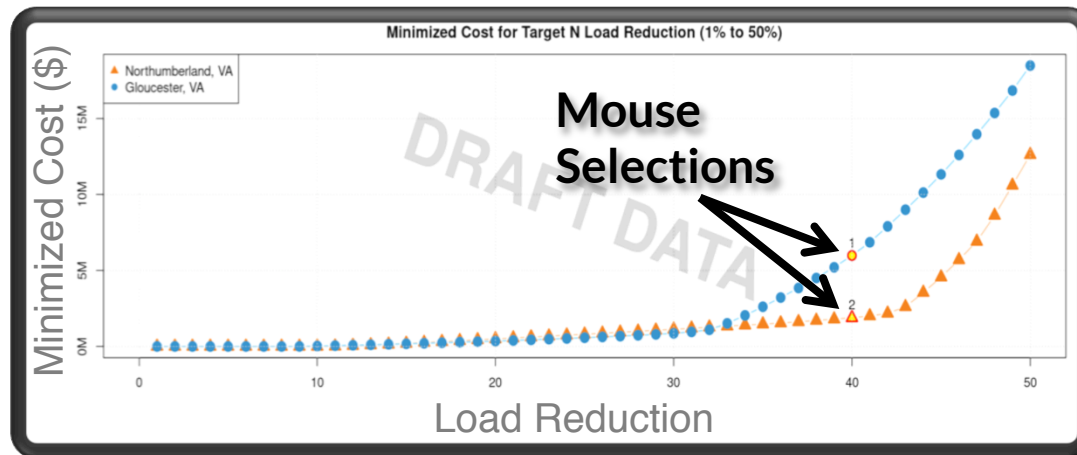
Bioswale: 0.0 at \$989.19 total annualized cost per unit	
Bioswale: 4,811.1 at \$989.19 total annualized cost per unit	
Cover Crop: Traditional Rye Early Drilled: 13,827.6 at \$68.04 total annualized cost per unit	
Cover Crop: Traditional Rye Early Drilled: 13,865.3 at \$68.94 total annualized cost per unit	
Forest Harvesting Practices: 362.1 at \$64.01 total annualized cost per unit	
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Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain: 0.0 at \$1,248.94 total annualized cost per unit	
Infiltration Practices w/ Sand, Veg. - A/B soils, no underdrain: 2,641.8 at \$1,248.94 total annualized cost per unit	
Manure Incorporation Low Disturbance Early: 7,900.2 at \$17.34 total annualized cost per unit	
Manure Incorporation Low Disturbance Early: 7,005.2 at \$17.34 total annualized cost per unit	
Manure Incorporation Low Disturbance Late: 0.0 at \$17.34 total annualized cost per unit	
Manure Incorporation Low Disturbance Late: 2,808.8 at \$17.34 total annualized cost per unit	
Manure Injection: 0.0 at \$74.60 total annualized cost per unit	
Manure Injection: 5,547.2 at \$74.60 total annualized cost per unit	
Nutrient Management N Timing: 0.0 at \$33.75 total annualized cost per unit	
Nutrient Management N Timing: 1,177.1 at \$33.75 total annualized cost per unit	
Nutrient Management Plan High Risk Lawn: 22,685.8 at \$0.00 total annualized cost per unit	
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Off Stream Watering Without Fencing: 0.0 at \$29.53 total annualized cost per unit	
Off Stream Watering Without Fencing: 1,192.4 at \$29.53 total annualized cost per unit	
Precision Intensive Rotational/Prescribed Grazing: 0.0 at \$18.83 total annualized cost per unit	
Precision Intensive Rotational/Prescribed Grazing: 3,133.7 at \$18.83 total annualized cost per unit	
Soil Conservation and Water Quality Plans: 5,618.6 at \$1.94 total annualized cost per unit	
Soil Conservation and Water Quality Plans: 5,652.1 at \$1.94 total annualized cost per unit	
Tillage Management Continuous High Residue: 13,865.3 at \$0.00 total annualized cost per unit	
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Water Control Structures: 5,852.1 at \$17.74 total annualized cost per unit	
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Acres

Visualization Interface

Allows comparisons

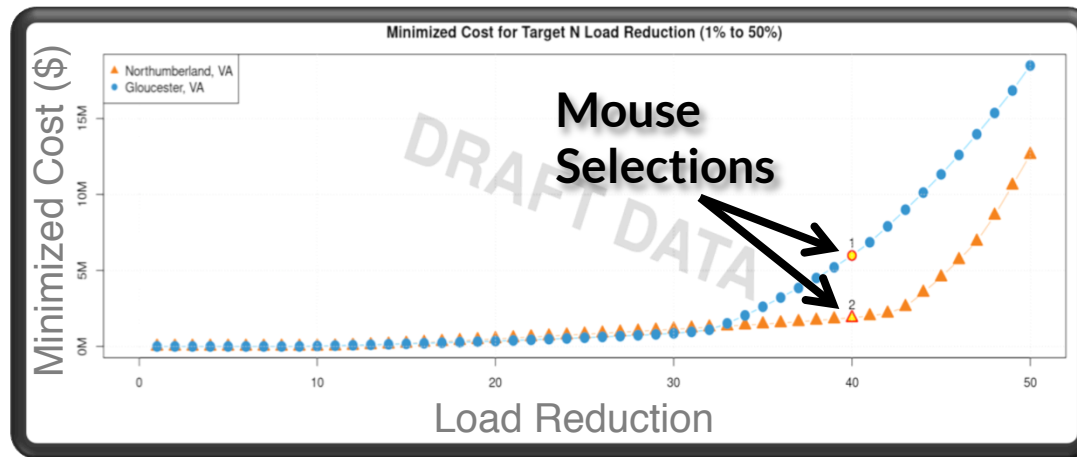
- between two points on the same county curve
- between a point for one county and a point for another county



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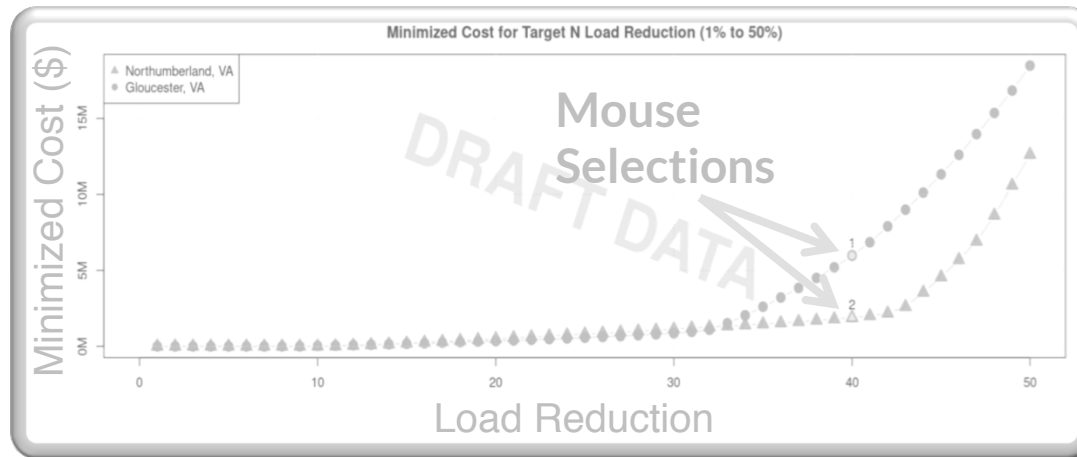


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Downloadable BMP input file(s) for selected point(s)



Download(s)

Data tables (.txt) of BMP implementation acres for selected point(s), including delineation by land-river segment, load source, and agency.

↓ Point 1 - Gloucester, VA

↓ Point 2 - Northumberland, VA

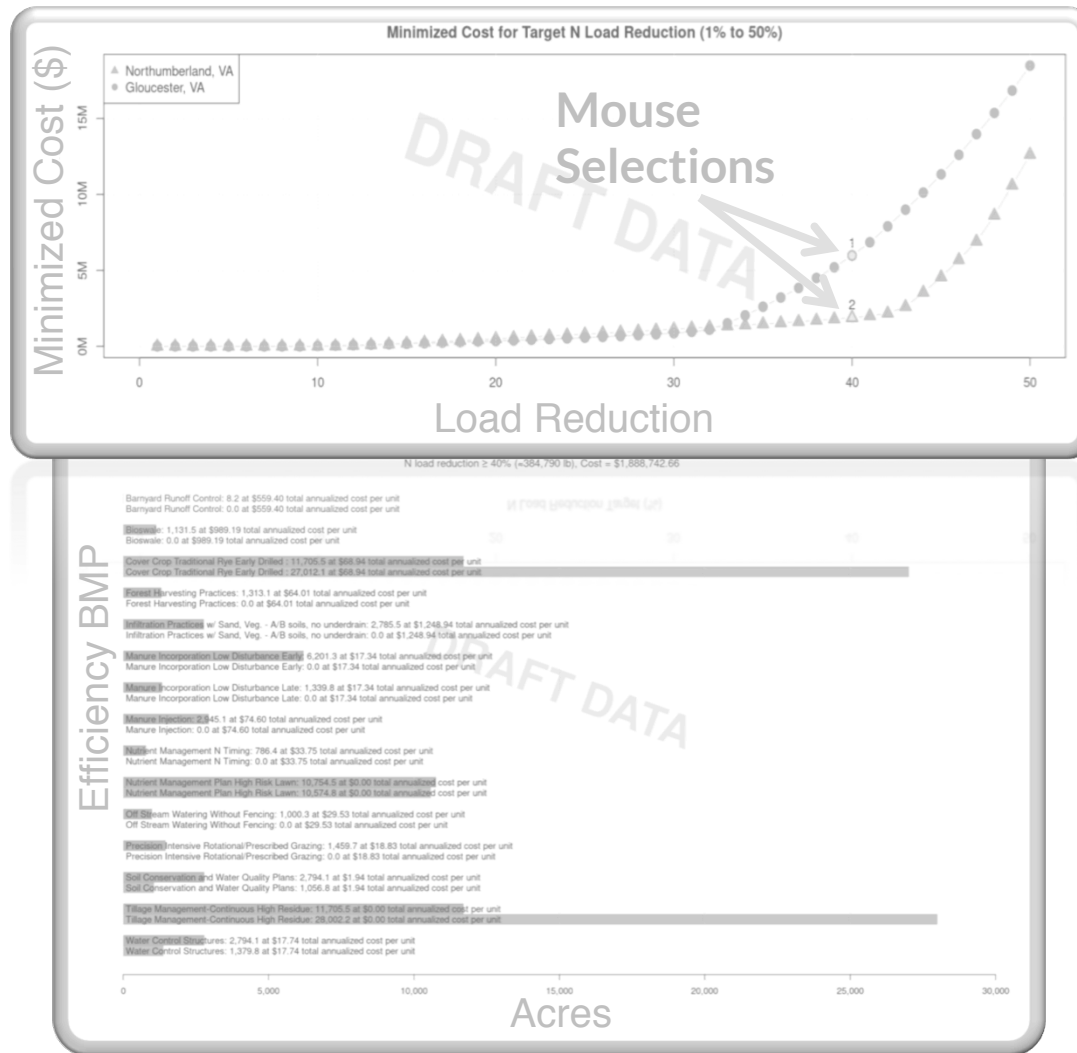
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Downloadable BMP input file(s) for selected point(s) cost/load solution

- Load reduction in pounds in addition to percentages
- Fixed an issue when switching data points
- Other graphical improvements



Optimization Engine

Using updated CAST source data

Outputting additional table as CAST-formatted BMP inputs

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In the next week or so:

- Fixing issue with mapping between load source groups and load sources available for BMP implementation
- Including delineations between federal and non-federal agency acres, as in CAST

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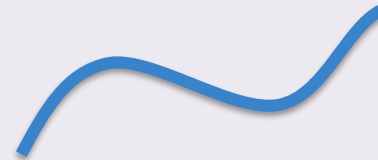
Online tool updates

Ongoing development & planned updates

Ongoing development

1

Efficiency BMP representation:



Nonlinear

- same load calculation as in CAST

vs.



Linear

- solve faster
- facilitate more solution exploration

2

Land conversion BMP model

3

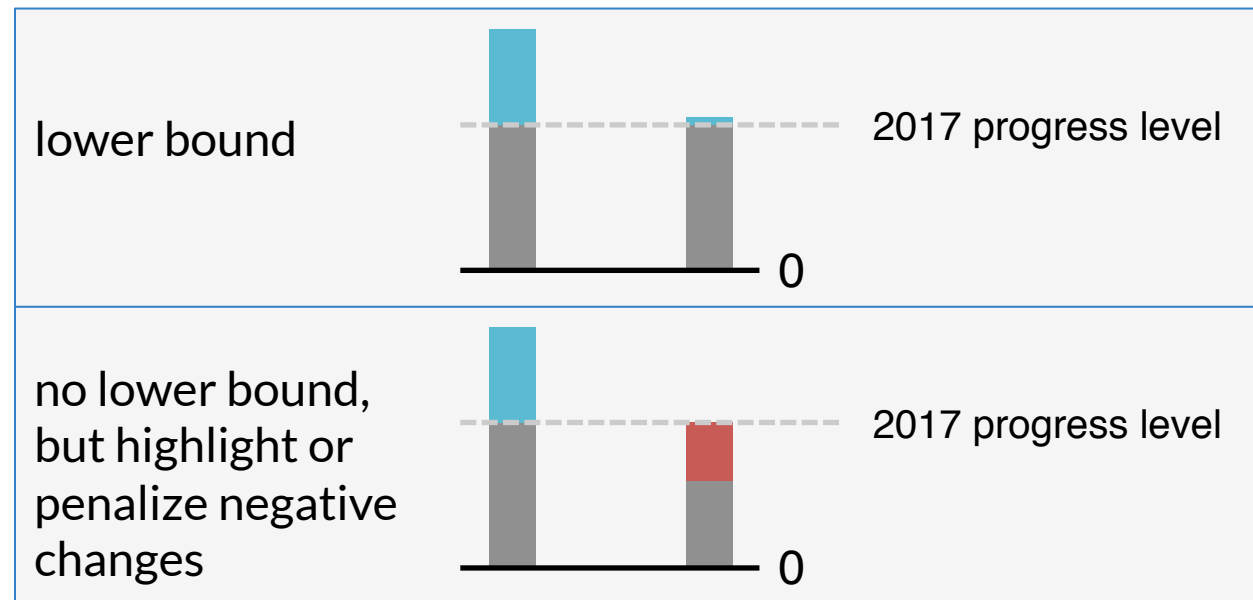
Larger geographies

Planned updates for January

1

Base loads and BMPs other than 2010 no-action (e.g. 2017 progress)

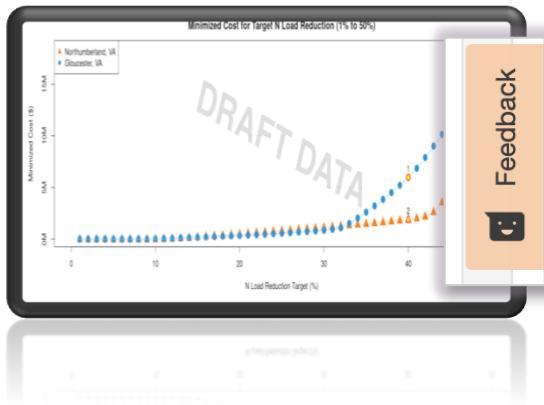
How to handle existing BMP acres?



2

Structural software improvements

Will continue to be shaped by feedback

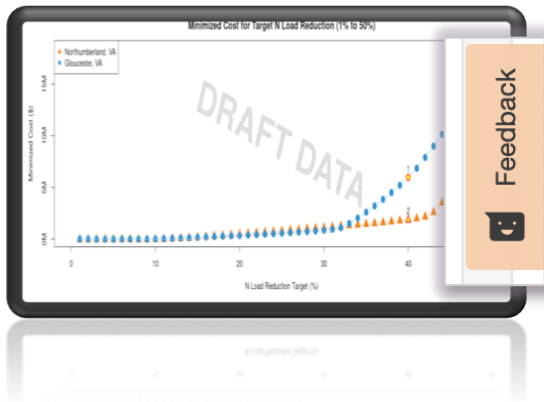


Check it out!

<https://shiny-apps.chesapeakebay.net/vico/>

...and email me (Danny), at:
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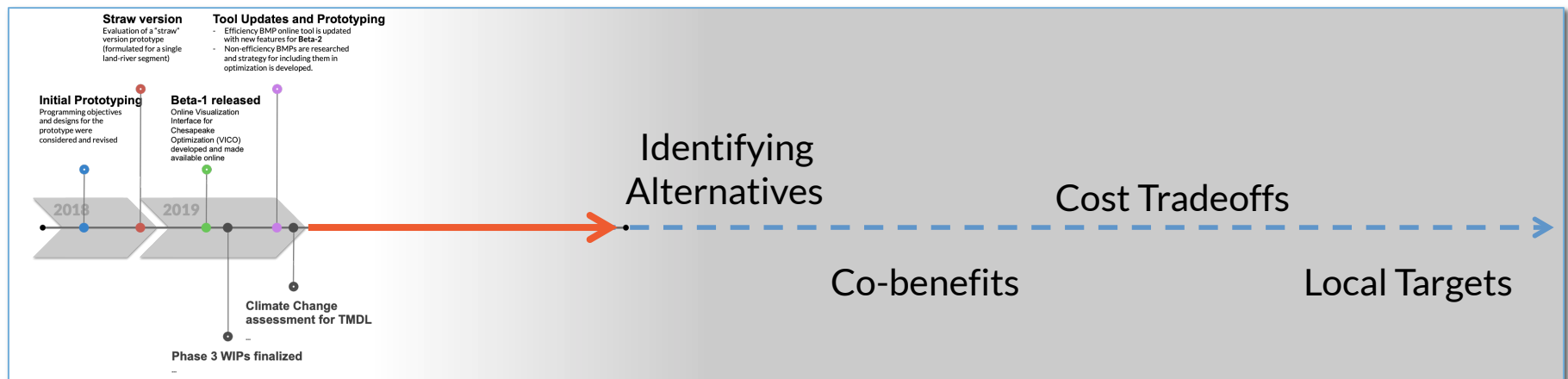
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Best Management Practices (BMPs)

[illegible]

Light blue – dirt and gravel

Pink – shore

Red - animal

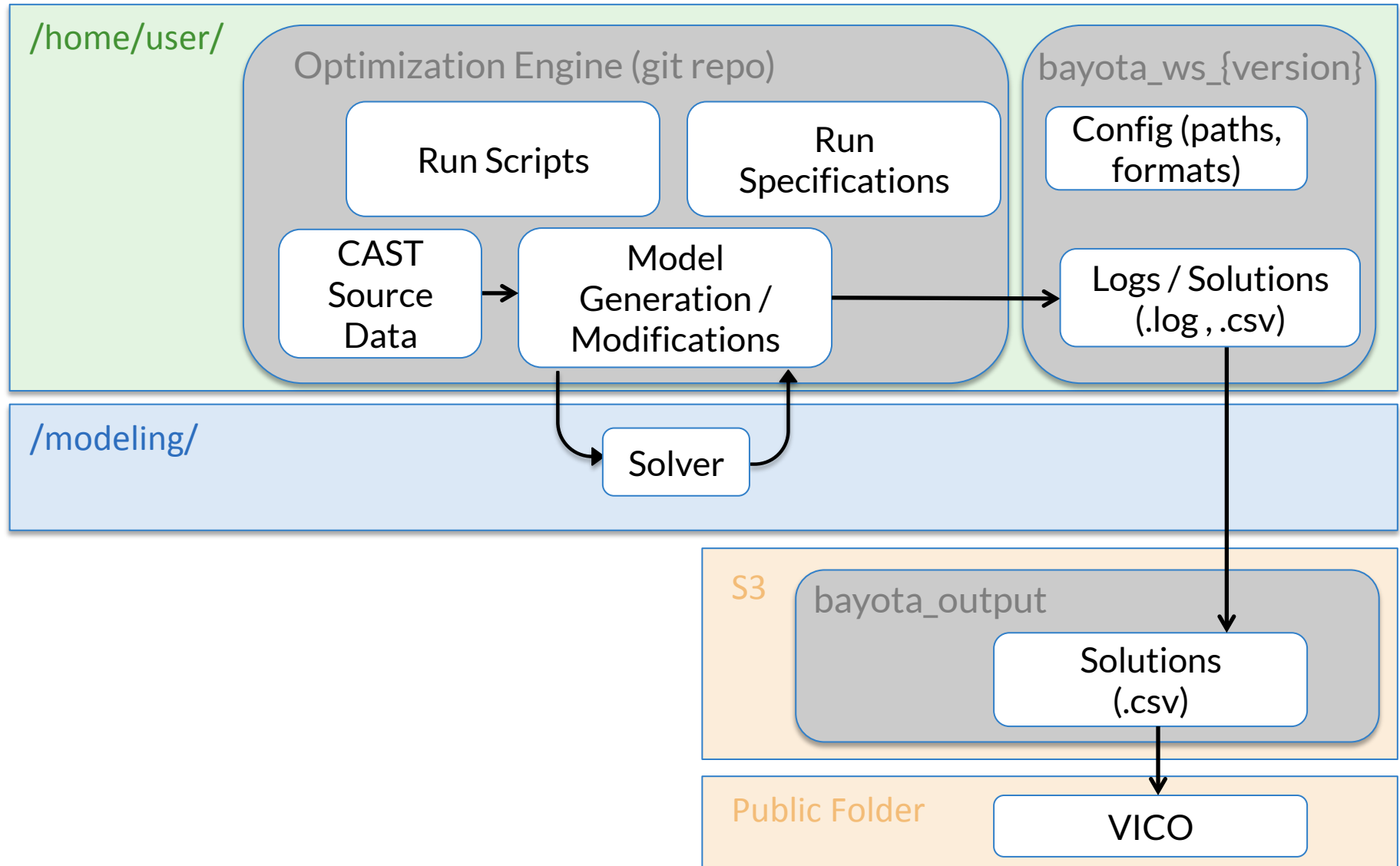
Green – Land use change

Yellow – Load reduction

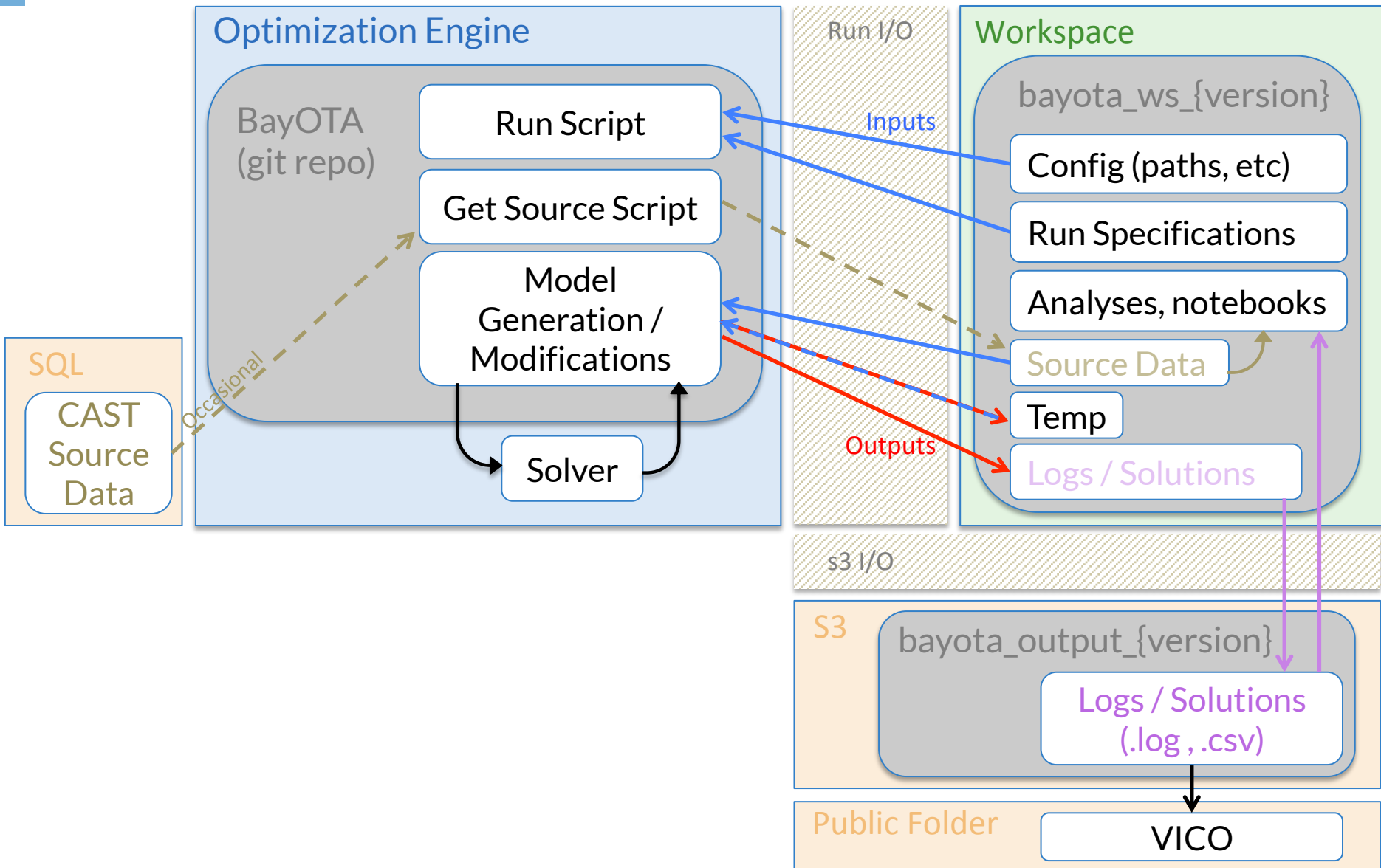
Teal – stream

Orange - Efficiency

Beta-1 Version components



Beta-2 Version components



Planned version components

