Optimization Tool Development

February 6, 2018

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Description: The project goal is to facilitate cost-effective reductions of nutrient loads entering the Chesapeake Bay from the watershed by developing an optimization module for the Chesapeake Assessment Scenario Tool (CAST).

Status (Phase 1): developing an optimization plan

Outline

- **The vision: a “scenario optimization tool” for the Chesapeake Assessment Scenario Tool (CAST)**
- **What is the current phase of development?**
- **How will a prototype tool utilize information from CAST?**
- **Next steps and moving forward**

Overview

Motivation:

Of all possible types and combinations of feasible Best Management Practices (BMPs), which mix(es) of BMPs will allow us to meet the target loads at the lowest total cost?

Tools:

- **Chesapeake Assessment Scenario Tool (CAST)**
- **Scenario Optimization Tool**

Chesapeake Assessment Scenario Tool (CAST)

A "web-based nitrogen, phosphorus and sediment load estimator"

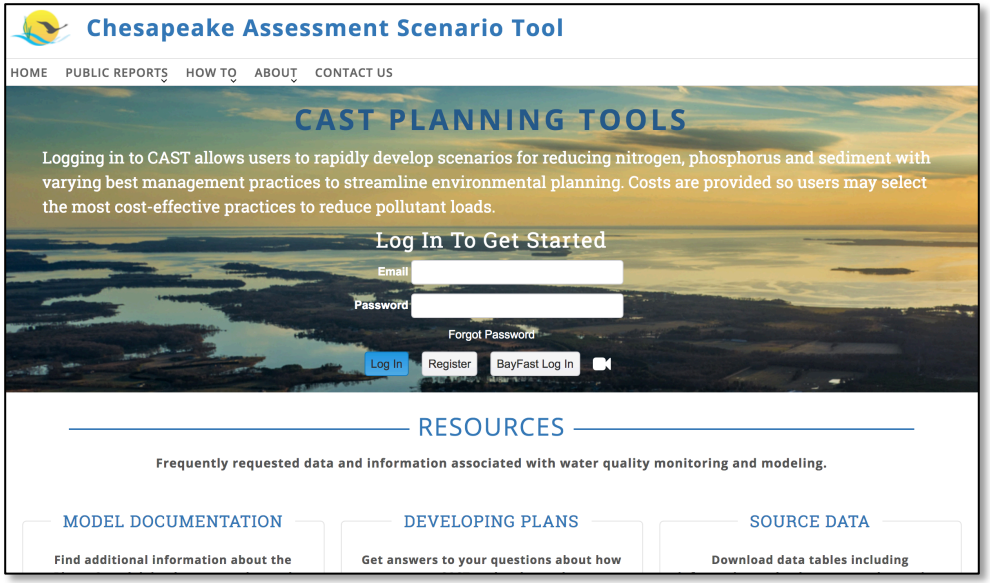
Originally developed in 2011, but has undergone substantial changes over the years

Users specify:

- **A geographical area (e.g. a county)**

  (& other restrictions, such as "agencies")

- **Best Management Practices (BMPs) to apply on that area**



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- **The cost of the scenario.**

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Load Sources
Cost profiles

BMP effects on
• loads • other BMPs

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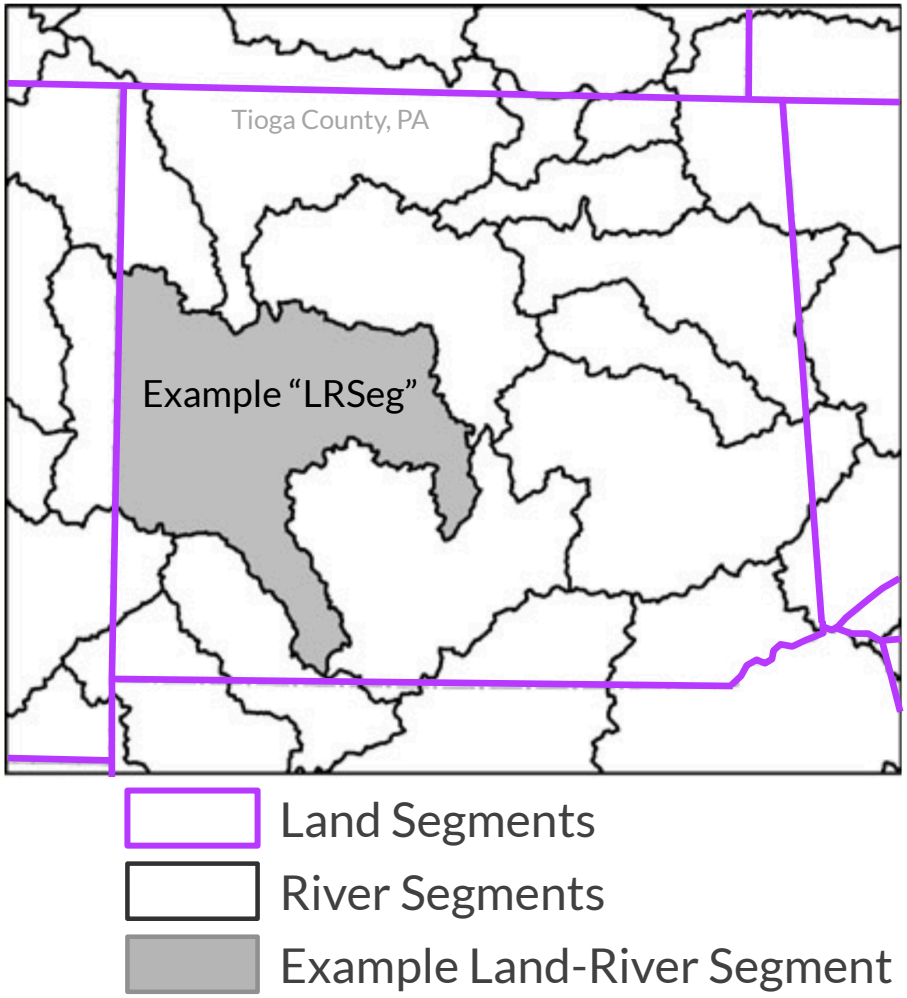
Best Management Practices (BMPs) in CAST

BMPs are applied at the scale of a land-river segment



Land-River segments are the intersection of River segments with Land segments (and are contained within counties)

Figure modified Shenk and Linker, 2013

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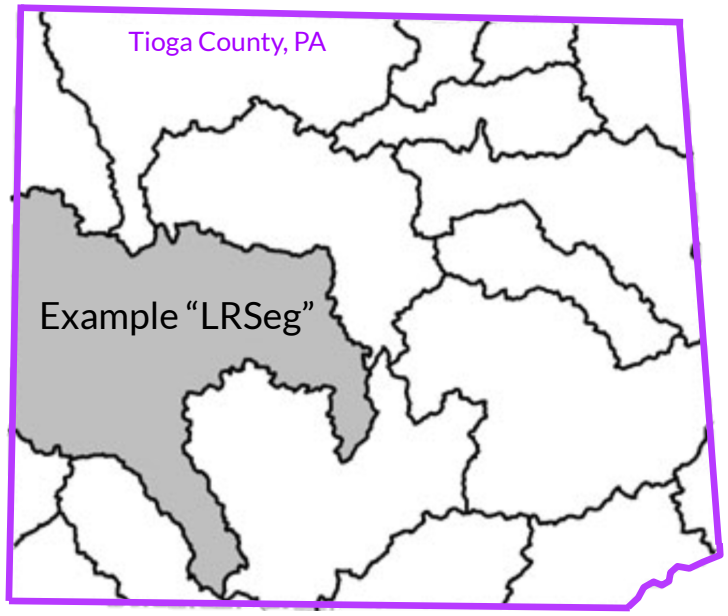


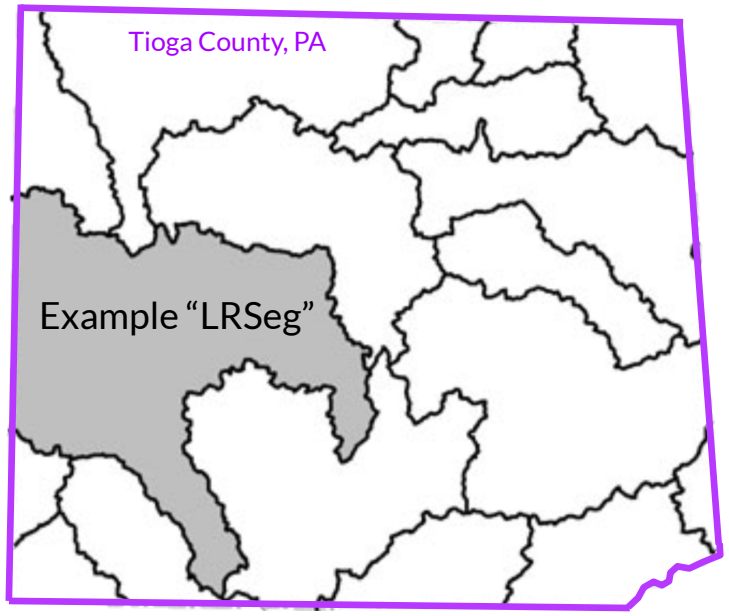
Example Land-River Segment

- Land-River segments are the intersection of River segments with Land segments (and are contained within counties)
- Acres of a county-applied BMP are distributed among the Land-River segments
- 2,057 total modeled land-river segments
  - 1,933 are inside the Bay watershed
  - 124 are outside (can still affect credited BMPs when distributed throughout a county)

Figure modified Shenk and Linker, 2013

Best Management Practices (BMPs) in CAST

There are different BMP candidate spaces within a county



Within the entire county:

- Number of animals for each animal type
- Tons of manure produced by each animal type

Within each LRseg:

- Acres of land (partitioned among 12 agencies)
- Miles of roads
- Miles of stream/shoreline
- Number of septic systems

Example Land-River Segment

Figure modified Shenk and Linker, 2013

Best Management Practices (BMPs) in CAST

There are a variety of BMP constraints and interactions

- Load source changes
- Mutually exclusive BMP spaces
- Transfer of manure tons between counties

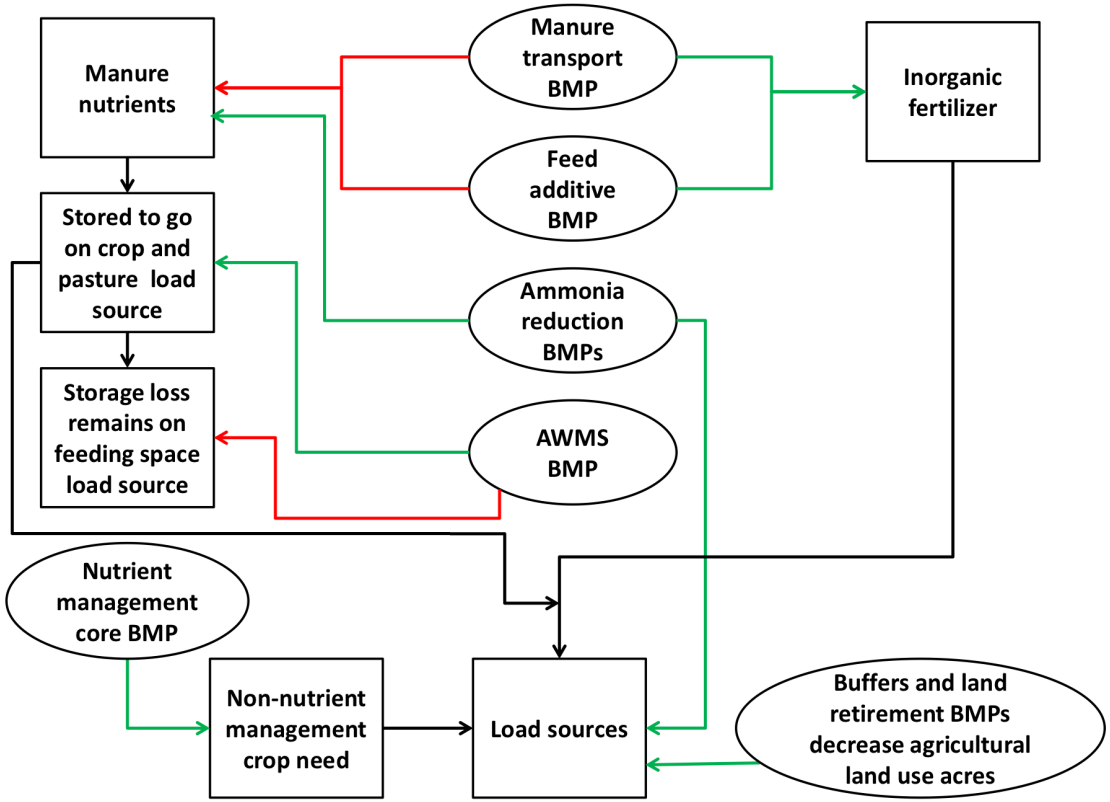
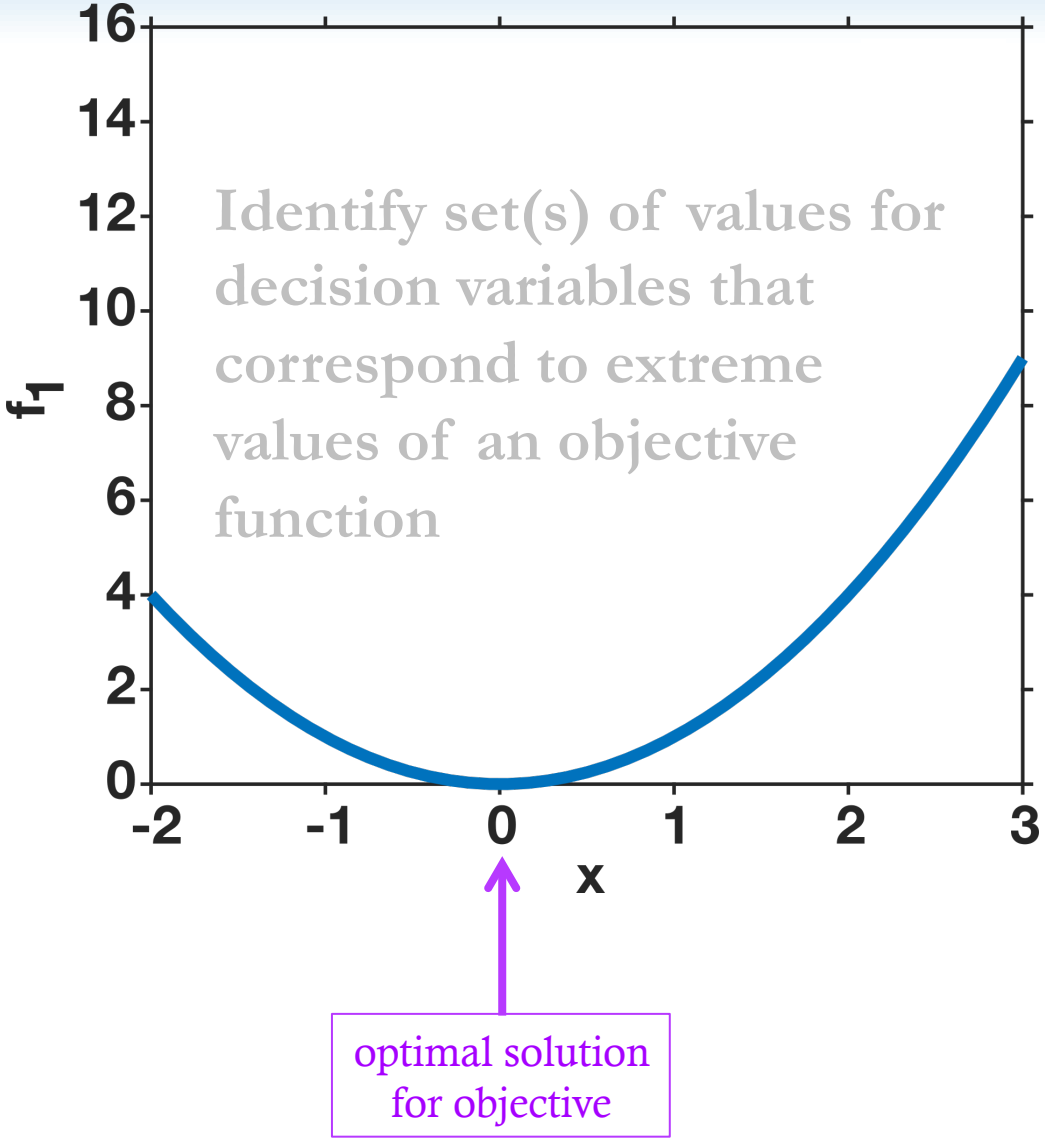


Image from CAST documentation - 4.11.0

What is meant by "Optimization"?



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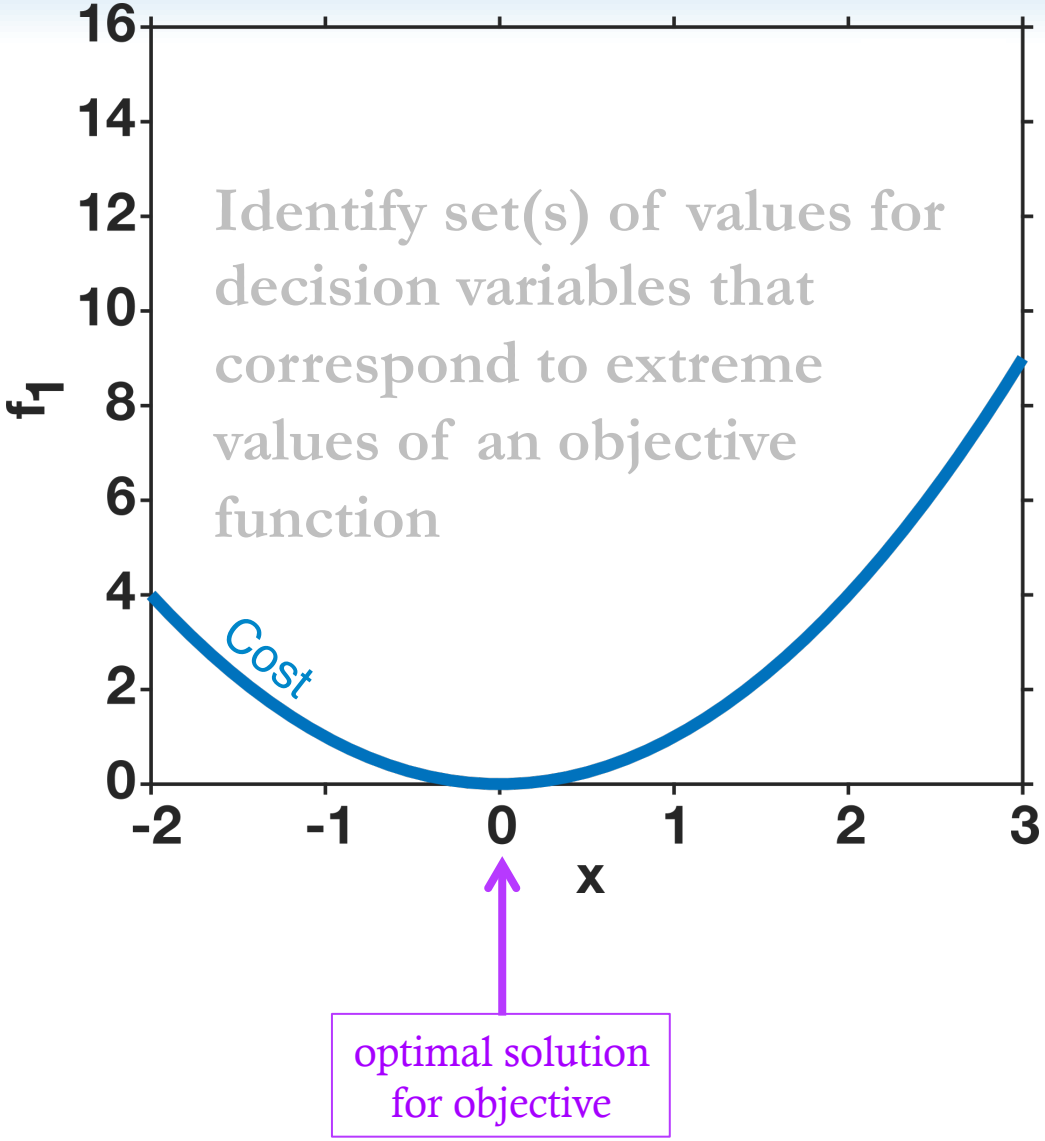

- Minimum cost is the "Extreme value" desired for CAST scenarios

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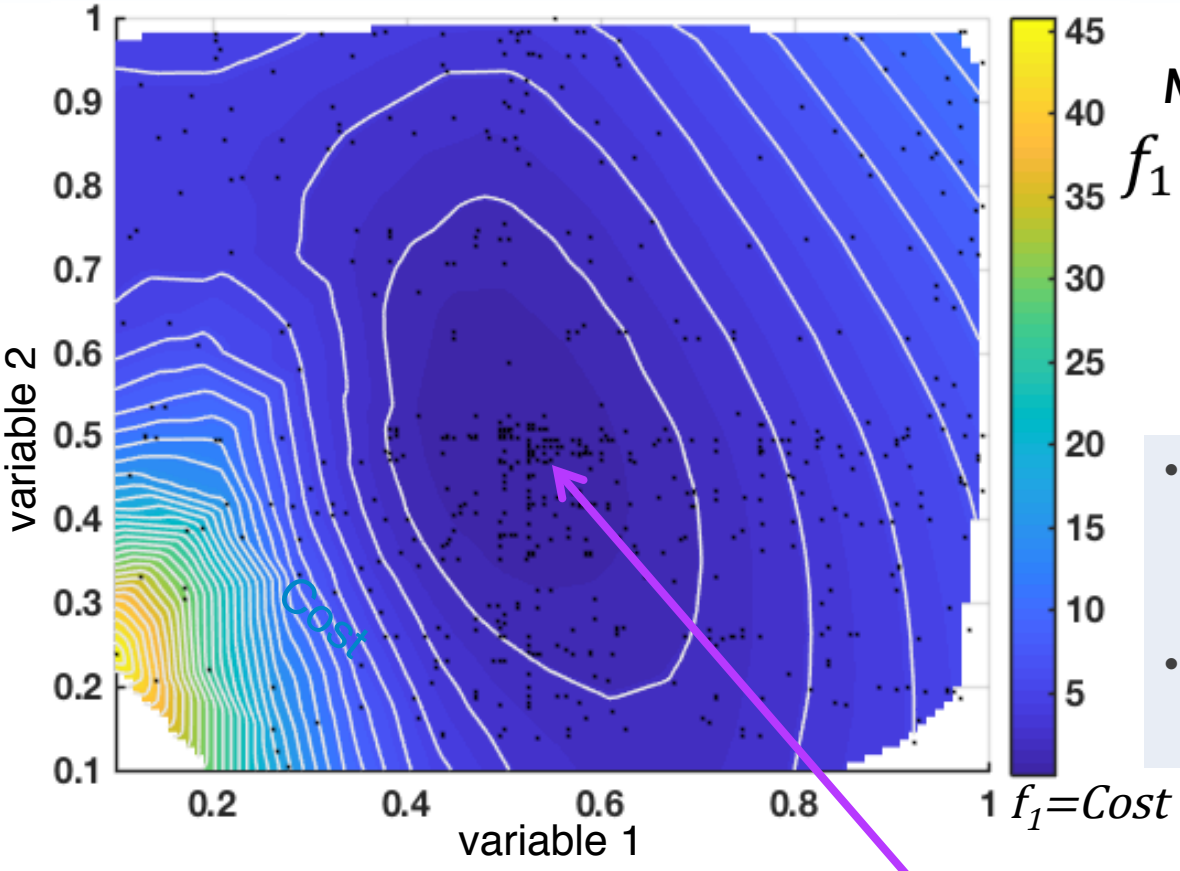

Objective:

Minimize

$$f_1 = CAST_{cost}(x_1, x_2 \ldots x_n)$$

- Each variable represents the amount for a (Geo, Agency, Load Source, BMP) coordinate
- Various algorithms can be used to identify optimal solutions

Current Phase

Investigate and Develop an Optimization Plan

Learn about CAST (uses, algorithms, and data/input/output structures)

Consider:

- objectives and designs for a Phase 2 prototype
- suitable algorithms (or combinations)

Identify model simplifications (reduced parameter sets)

Design an efficient interface between CAST and the proposed optimization software

Optimization Description

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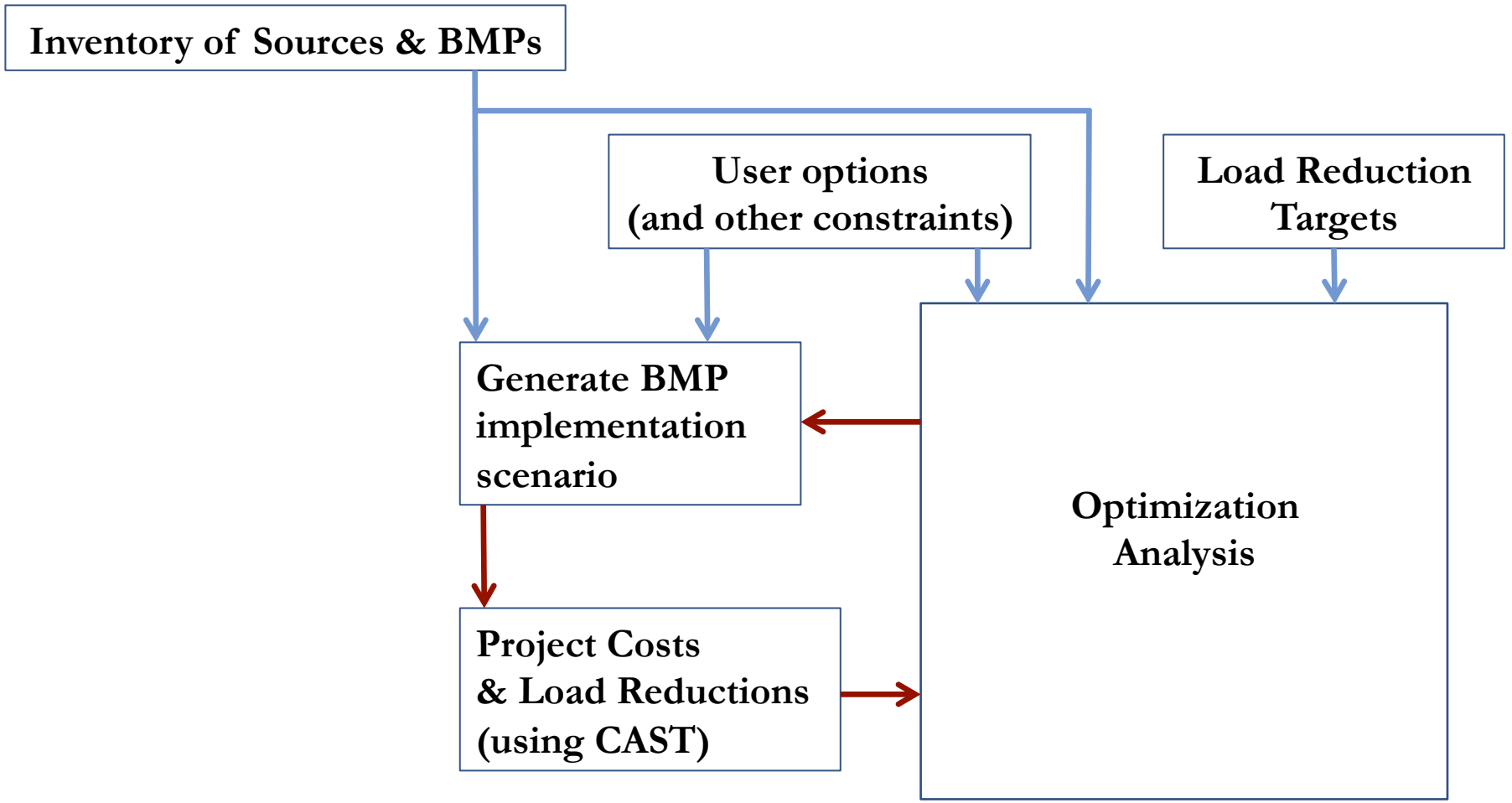
Basic Constraints:

- Scale/region of scenario (and/or agencies)
- Nitrogen and Phosphorous delivered load reductions ≥ load targets
- BMP'd acres ≤ available acres (by segment and land-use)
  - BMP'd roads ≤ available miles
  - BMP'd shorelines ≤ available miles
  - BMP'd animals ≤ available animal counts

Other Constraints:

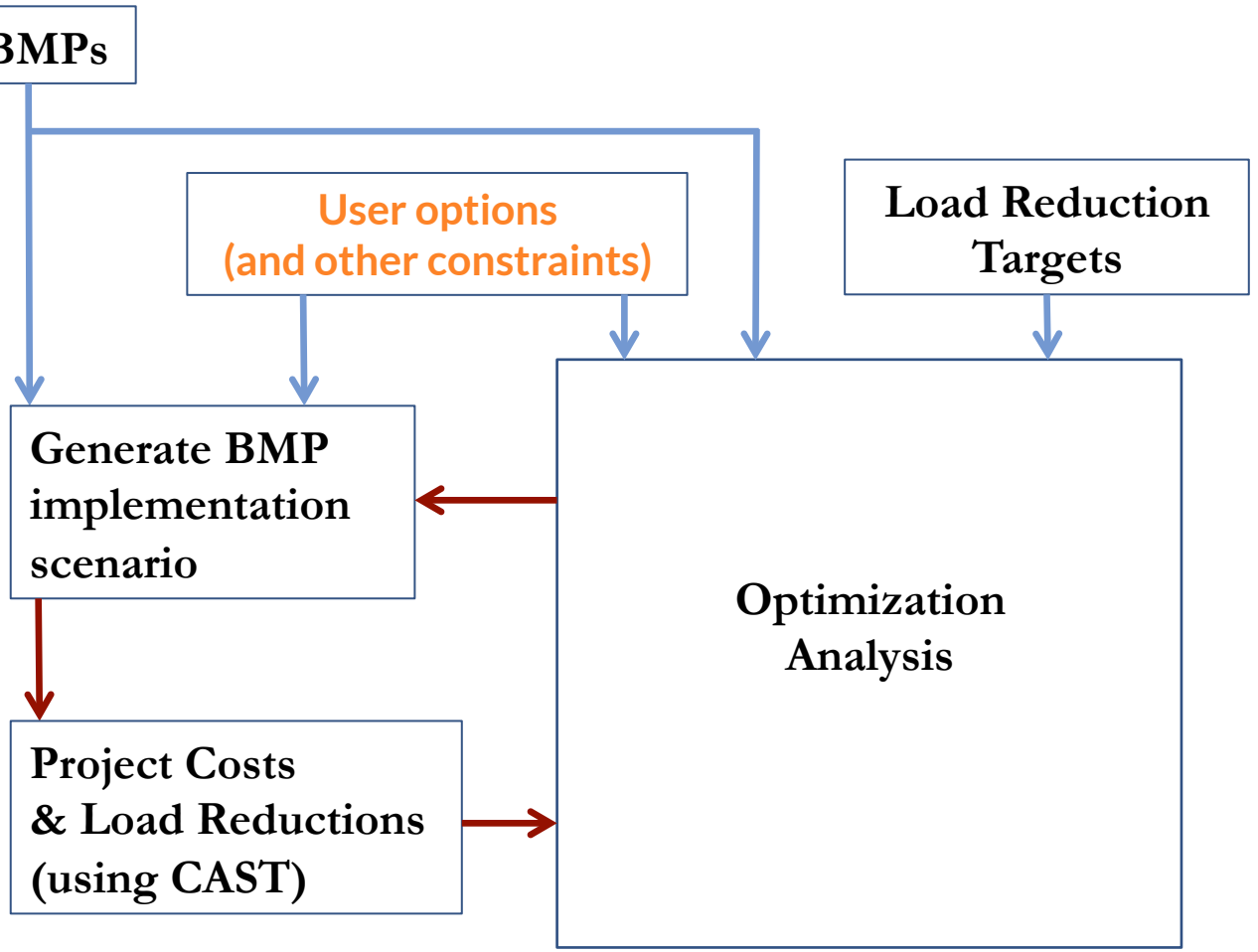
- BMP constraints, for example:
  - agricultural land retirement ≤ *X* acres
  - cover crop oats ≥ *X* % of agricultural acres
- Land use restrictions for certain BMPs
- Capital limitations for certain sectors?

Optimization Tool Sandbox



Optimization Tool Sandbox

- Land-river segments and load sources included in the scenario
- Pre-BMP acres eligible for BMP application on each segment-source
- BMPs feasible for each segment-source



A complete set of possibilities is generated

Inventory of Sources & BMPs

User options (and other constraints)

Generate BMP implementation scenario

- Land-river segments and load sources included in the scenario
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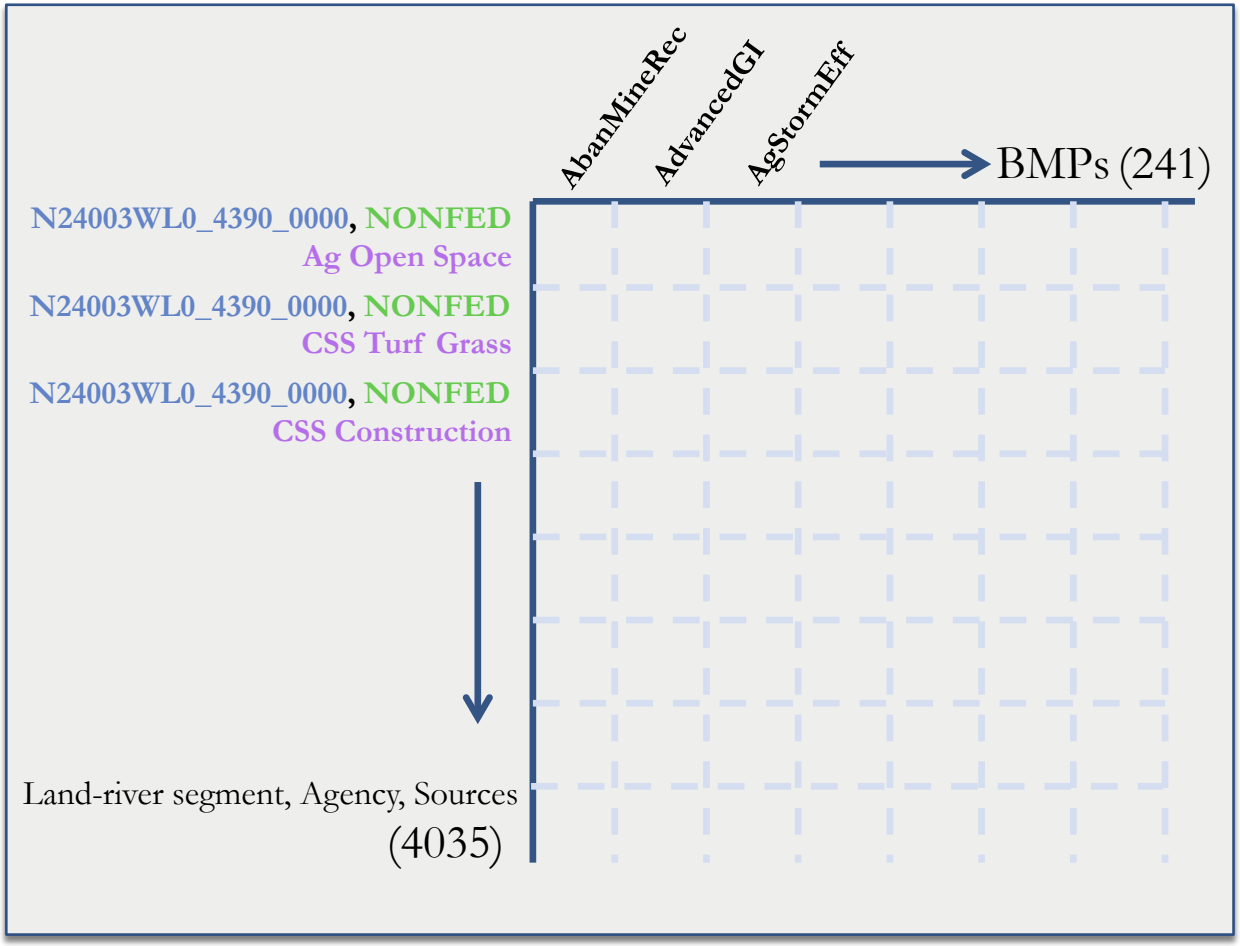
Include:

- **All land river segments, sources for geography**
- **All BMPs**



Allowable Source-BMP pairs are identified

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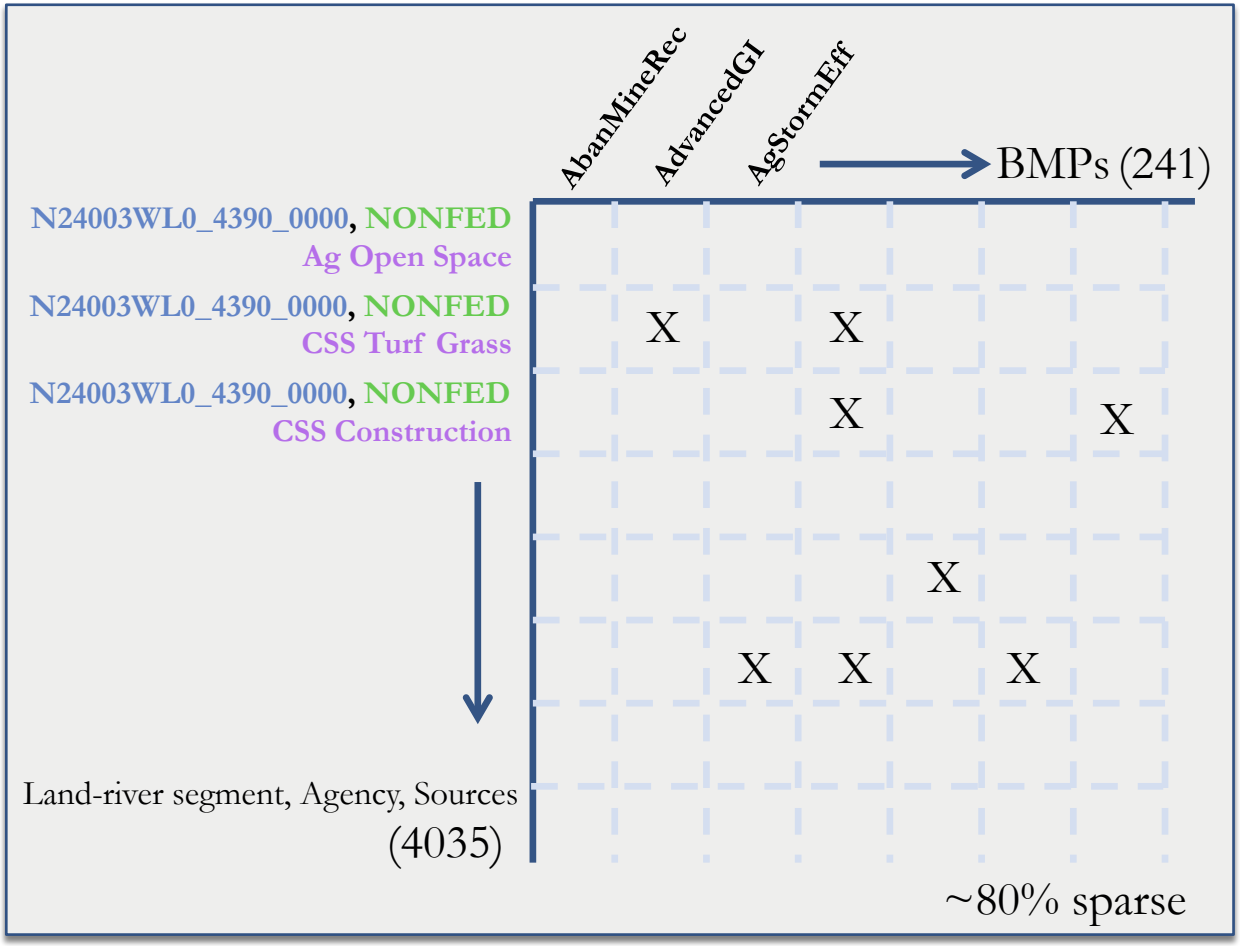
Maximum number of knobs to turn:
~ 200,000 - Anne Arundel County
~ 2 million - Maryland



Values for each allowable Source-BMP pair

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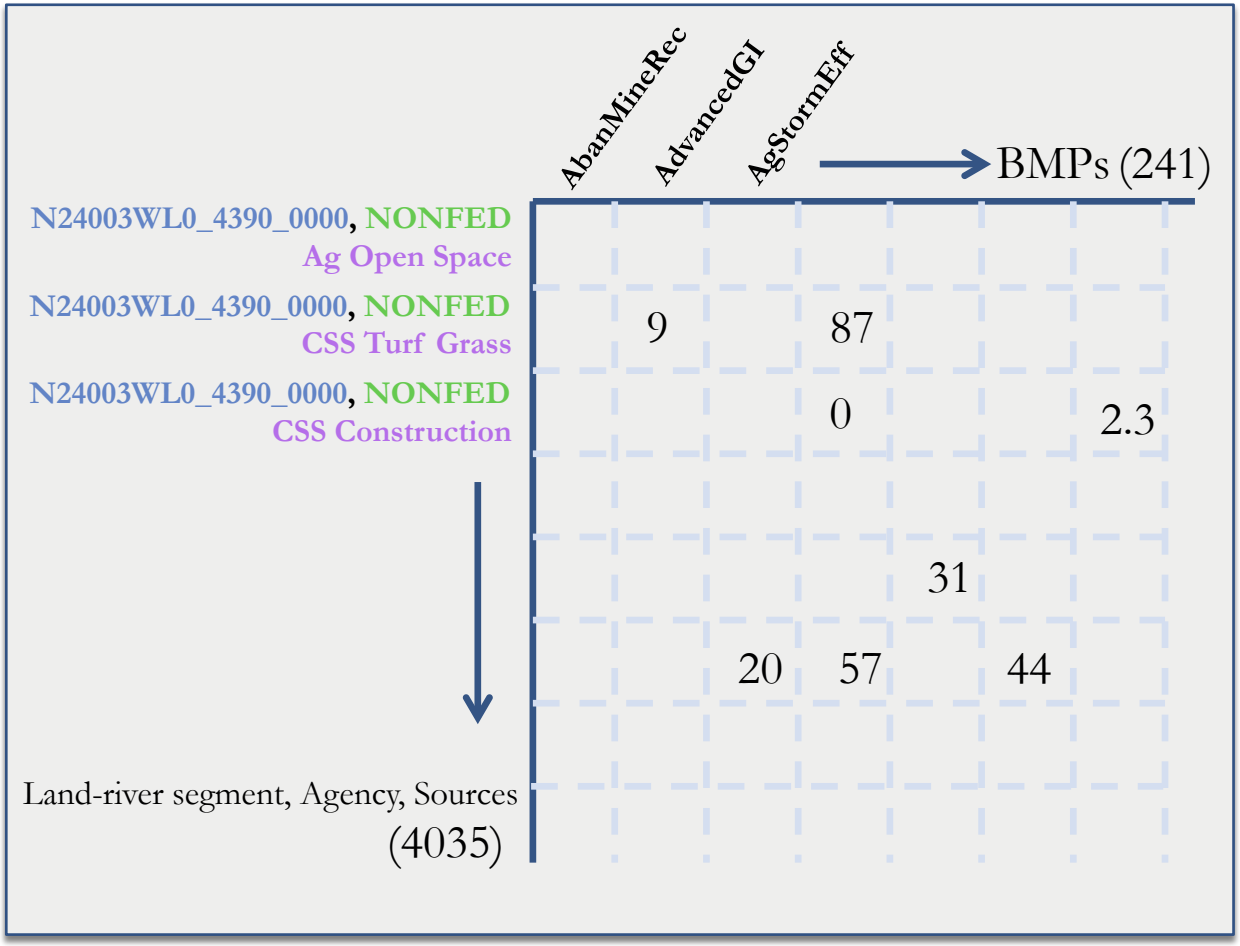
Basic constraints determine value bounds, e.g.

- **Pre-BMP acres**
- **Miles of available roads**



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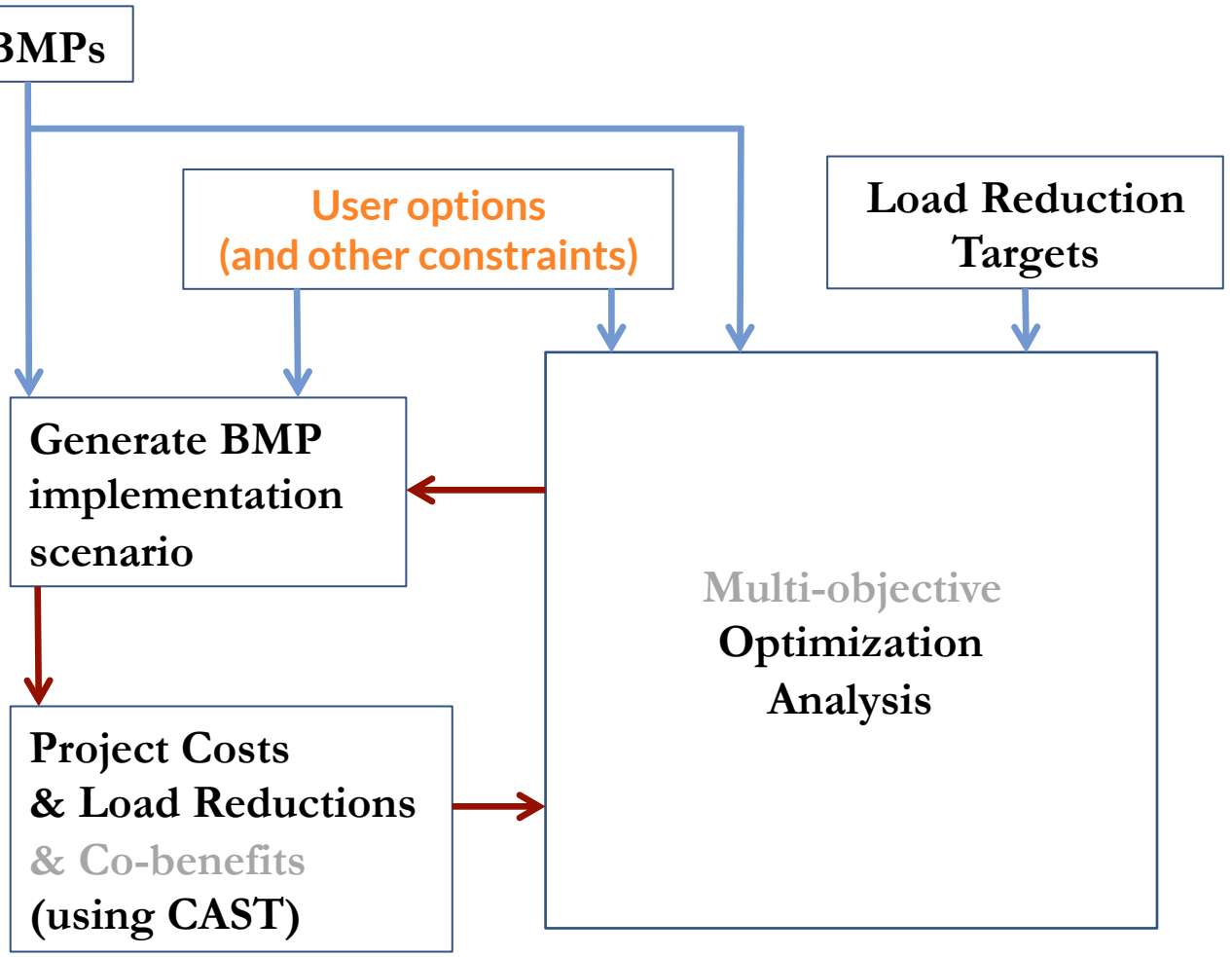

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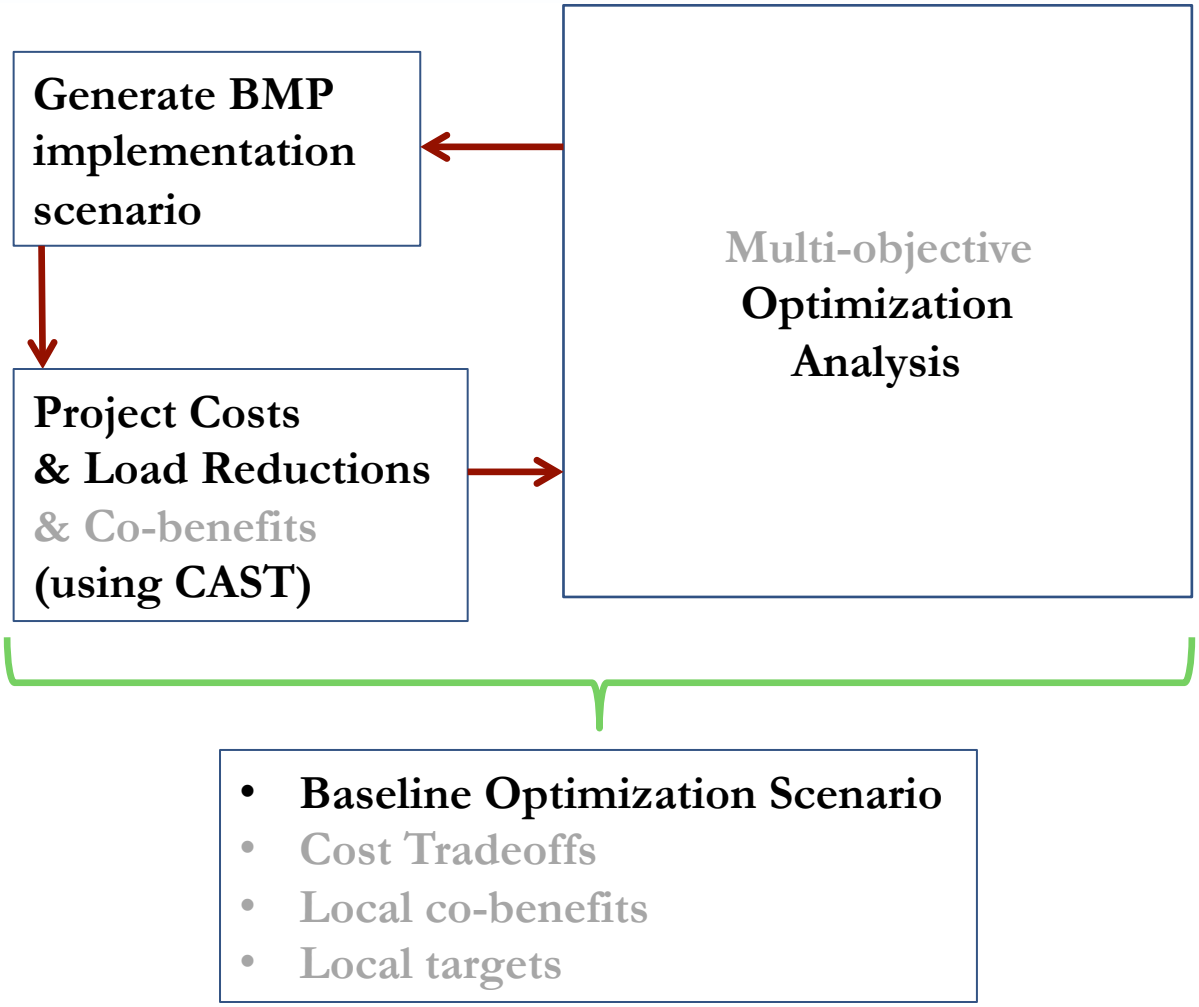
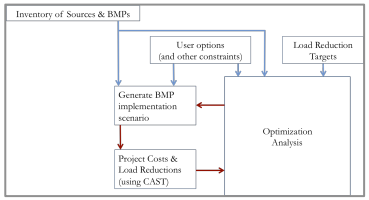


Looking Forward

Sandbox



Identifying Alternatives

Cost Tradeoffs

Baseline Optimization Prototype

Co-benefits

Local Targets

Next Steps

Phase 1: Investigate and Develop an Optimization Plan

Continue developing a prototype in python

Continue learning about CAST (uses, algorithms, and data/input/output structures)

Refine optimization objectives, constraints, user needs

Continue considering suitable algorithms and tool designs for Phase 2 prototype

User Interface

What does a user want to be able to do/see?

Select geographic region of interest and land use types

- Geographic region by State, County, In/Out of CBWS, Land-river segment
- Land Use types by agency, sector, and base conditions

Select BMP constraints

- ideas: exclude certain BMPs, max/min acreage of certain BMPs,

See and compare objective attributes of nondominated solutions

- load reductions
- cost
- co-benefits

See the set of BMP assignments for each solution

- by land use, segment, state, sector
- in categories or individually, and in acreage or percent

Looking Forward

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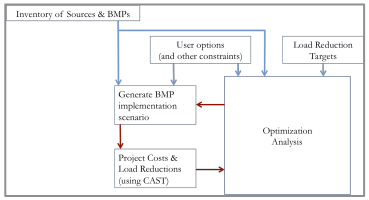

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Questions

Other constraints?

Other objectives?

Departures from existing scenarios, with given costs

Computational resources/speed