

# Optimization Applied to Strategies for Achieving the Chesapeake Bay TMDL

PRESENTED BY:

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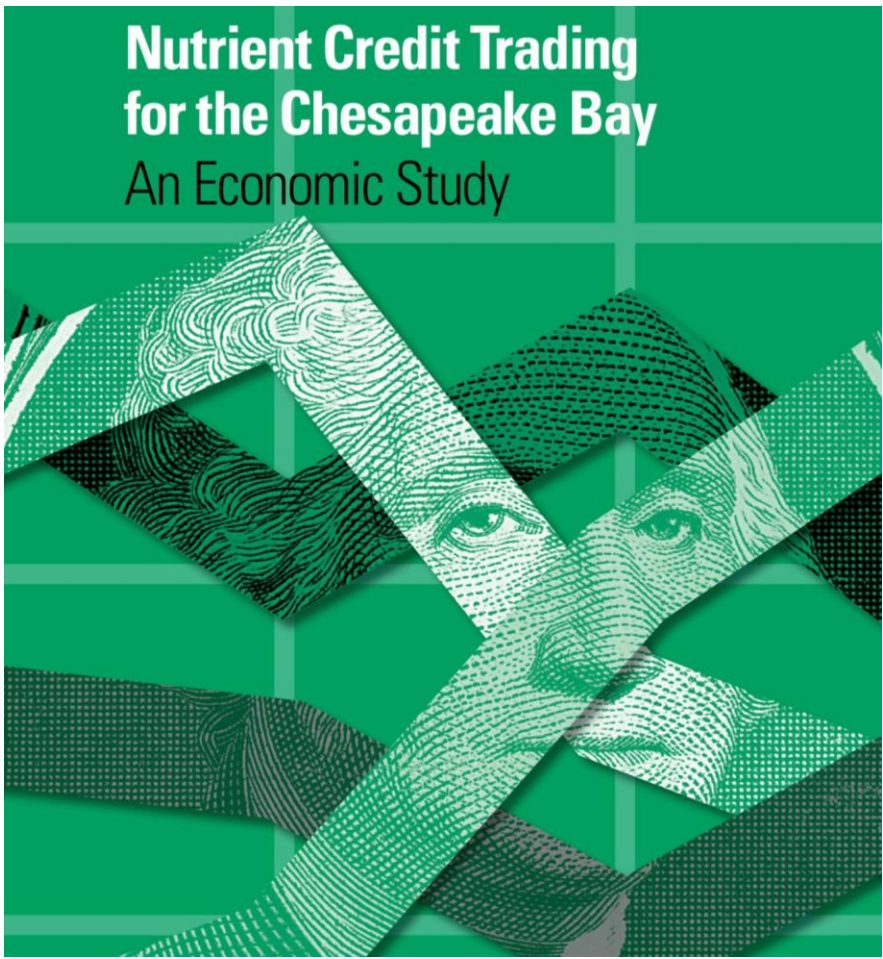
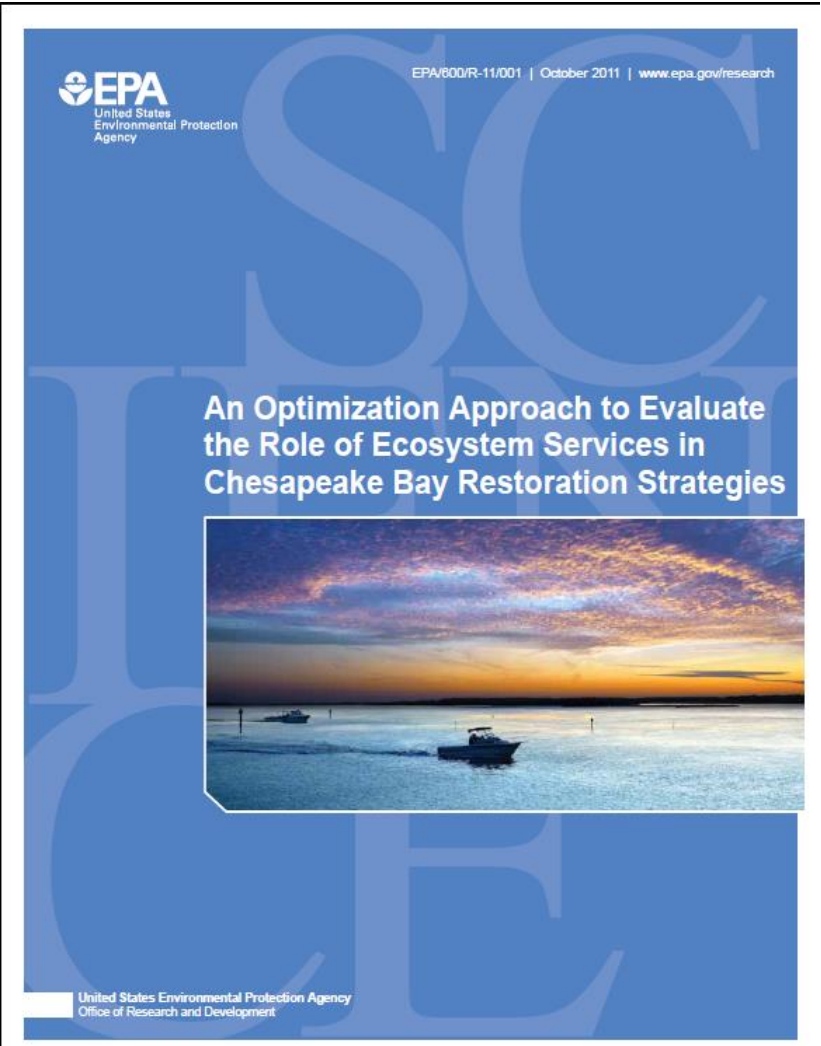
STAC Workshop

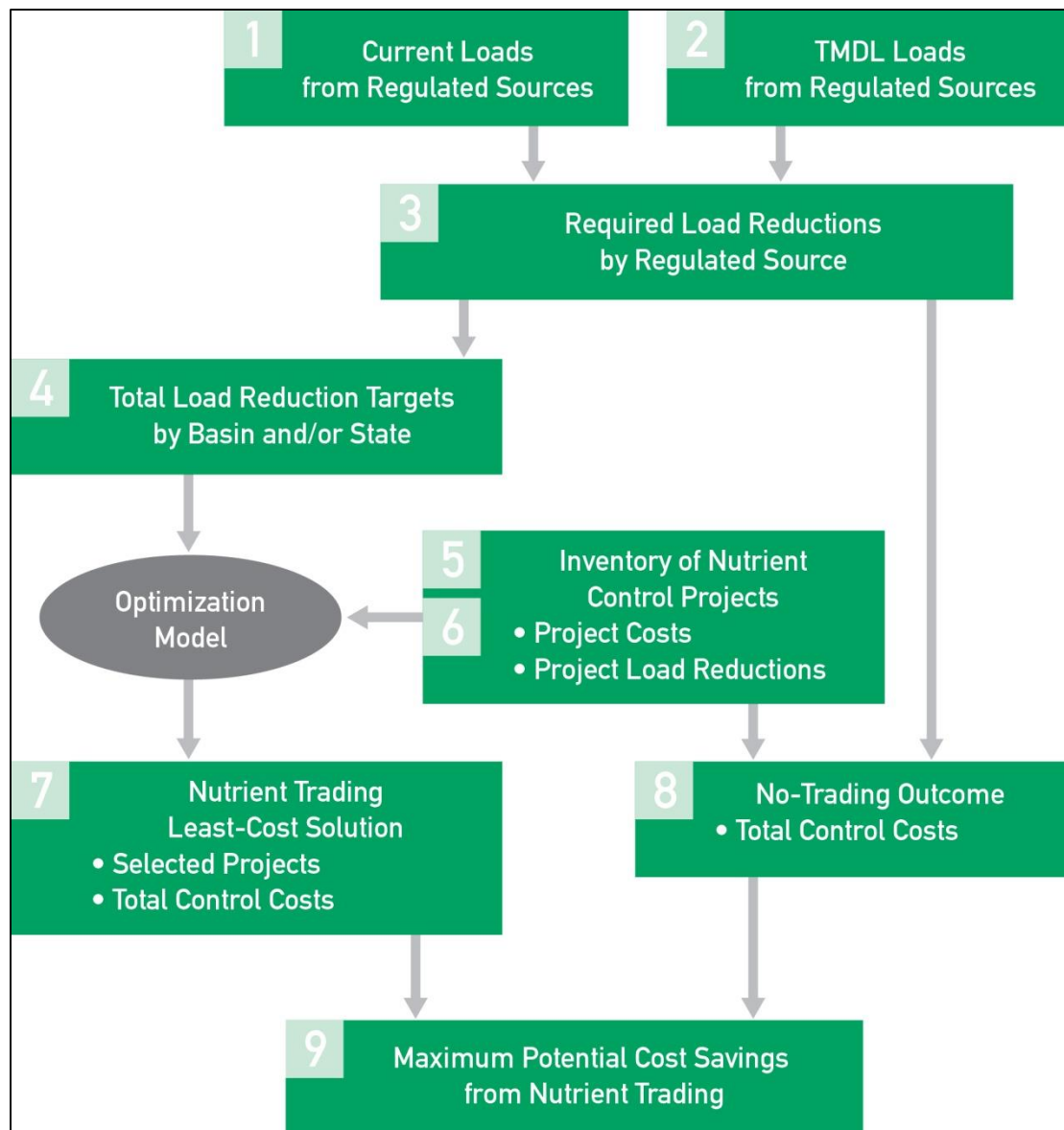
Annapolis, MD

## Overview

- Objective: Describe an optimization modeling system developed for the Chesapeake Bay watershed to evaluate alternative strategies for achieving the TMDL
- Model development was funded through projects for USEPA (Office of Research and Development and the National Center for Environmental Economics) and for the Chesapeake Bay Commission

# Studies for EPA and Chesapeake Bay Commission





## Analytical Framework

- 9 step process to
- identify the least-cost solution for achieving the TMDL load limits
  - estimate cost savings compared to non-optimized approaches

# Key Inputs for Developing the Framework

- Bay Program's Chesapeake Bay Watershed Model (CBWM) Phase 5.3.2
  - **Watershed network and segmentation**—linked network of ~2,500 “land-river segments”
  - **Land use/cover**—30 land use categories, which we regroup into 3 crop, 2 pasture, and 2 urban categories
  - **Baseline (2010) delivered loads**— annual N and P loads delivered to the Bay's tidal waters from each land use in each land-river segment
  - **BMP nutrient removal rates**—for selected agricultural and urban stormwater best management practices (BMPs)
  - **Baseline (2010) acres of BMP implementation**—by land-river segment

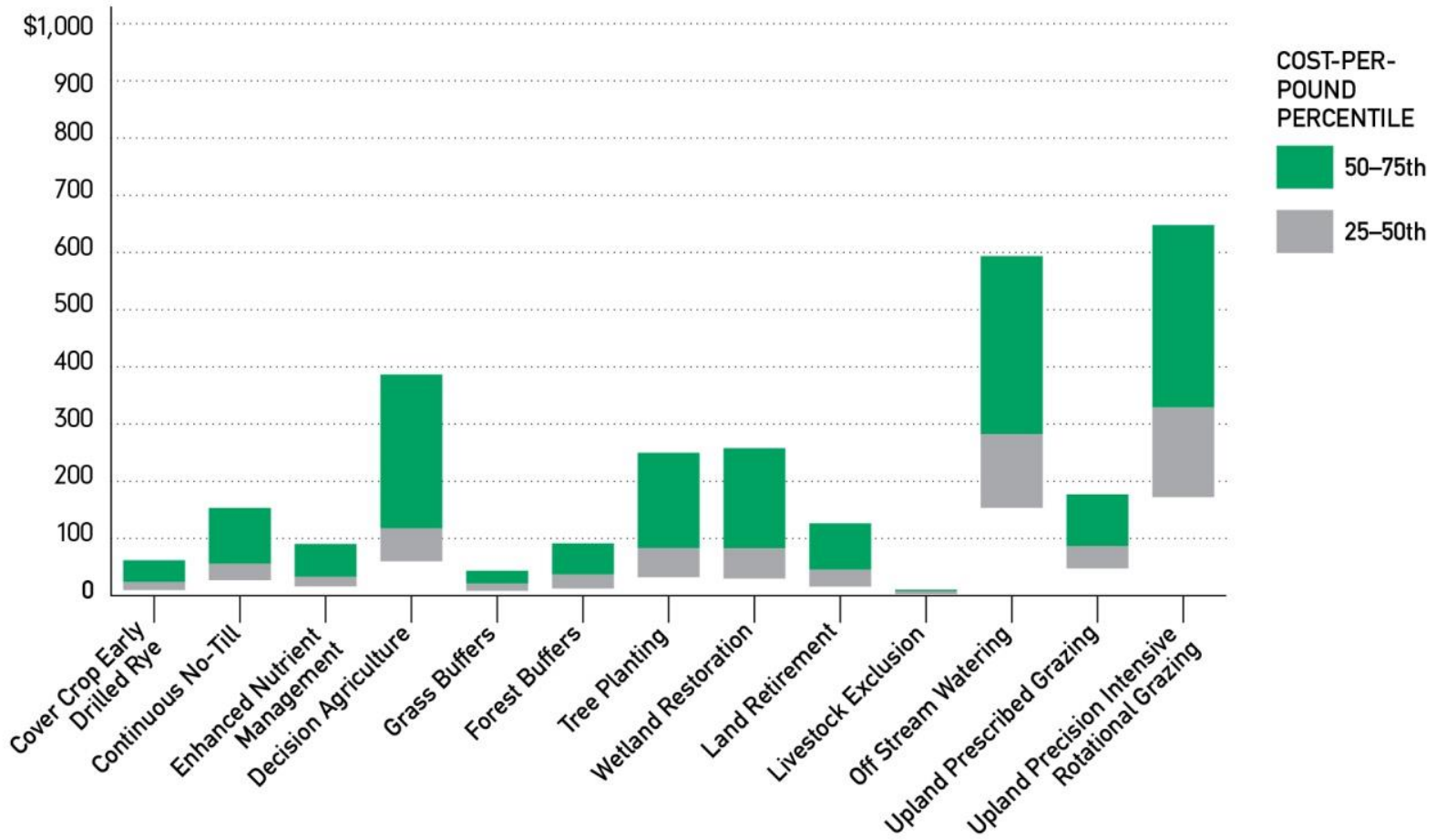
# Control Projects, Load Reductions, and Annual Costs

- **Significant Point Sources**
  - Multiple DISCRETE (16) tiers of wastewater treatment at 475 “significant” municipal and industrial facilities
  - Annualized costs (capital and O&M) and nutrient removal estimates based on EPA’s ongoing cost analysis of the Bay TMDL
  
- **Agricultural and Urban Stormwater BMPs**
  - Annualized unit costs (\$/acre/yr) based on EPA’s cost analysis of the Bay TMDL
    - based on a detailed review and summary of existing studies and data sources
    - includes land, installation, and O&M costs

# Cost-Effectiveness of Agricultural BMPs for N Removal

## AGRICULTURAL BMPs

Cost per pound of NITROGEN reduced per year



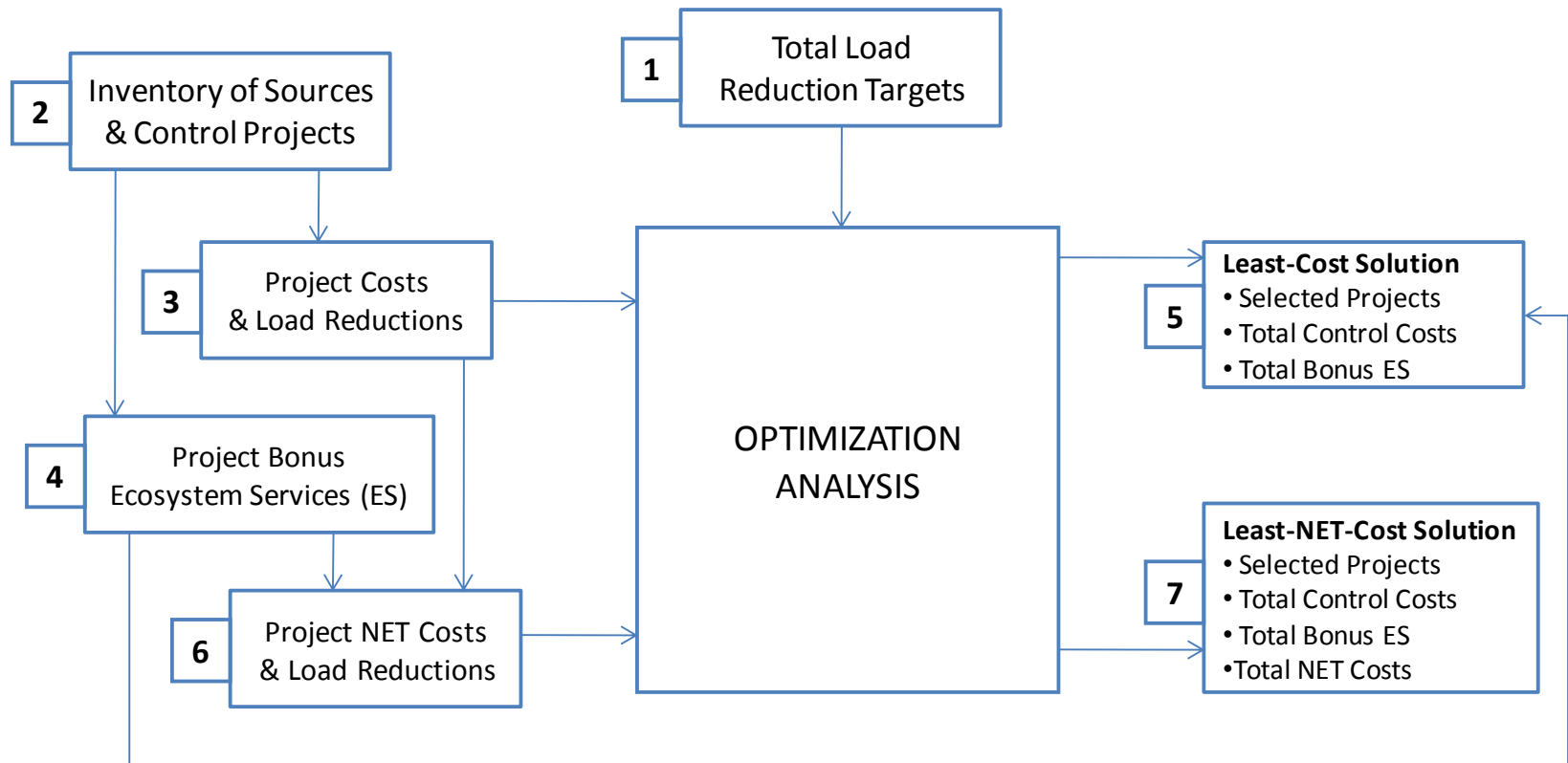
# Optimization Problem

- Objective: Minimize total costs of nutrient controls by selecting
  - Number of acres of each BMP in each land-use category and land river segment (continuous) ~1.6 million variables
  - Treatment technology upgrades at each significant point source facility (discrete)
- Constraints:
  - N and P delivered load reductions  $\geq$  TMDL targets
    - By basin OR by state OR by basin-state
  - BMP'd acres  $\leq$  available acres (by land-use and LR segment)
  - Additional:
    - Agricultural land conversion BMPs  $\leq$  X acres (by land-use and LR segment)

# Optimization Approach

- Need algorithm to solve mixed discrete-continuous linear optimization problem
  - Mixed Integer Linear Programming (MILP)
  - To avoid non-linearities, each feasible BMP combination was treated like a separate BMP with its own removal efficiency
- Solved using a branch-and-bound search method implemented in GAMS
  - Bay-wide model runs usually take  $\leq 20$  minutes to solve

# Expanding Model to Include a Co-Benefits Objective



# Ecosystem Services Co-Benefits of Practices

BMPs	Monetized Ecosystem Services				Non-monetized Ecosystem Services	
	Carbon Sequestration & Reduced GHG Emissions	Non-waterfowl Hunting	Duck Hunting	Air Quality	Brook Trout Habitat	Wetland Water Storage
<b>Urban Stormwater</b>						
Extended Detention	•					
Bioretention	•			•		
Grass Buffer	•			•		
Forest Buffer	•			•		
Wetlands	•			•		•
<b>Agriculture</b>						
Forest Buffers	•	•			•	
Grass Buffers	•					
Conversion to Forest	•	•			•	
Natural Revegetation	•	•			•	
Wetland Restoration	•	•	•		•	•
No-till	•					
Reduced Fertilizer Application	•					

# Optimization Problem

- Objective: Minimize total NET costs of nutrient controls

*NET Cost of BMP<sub>i</sub> = Cost of BMP<sub>i</sub>*

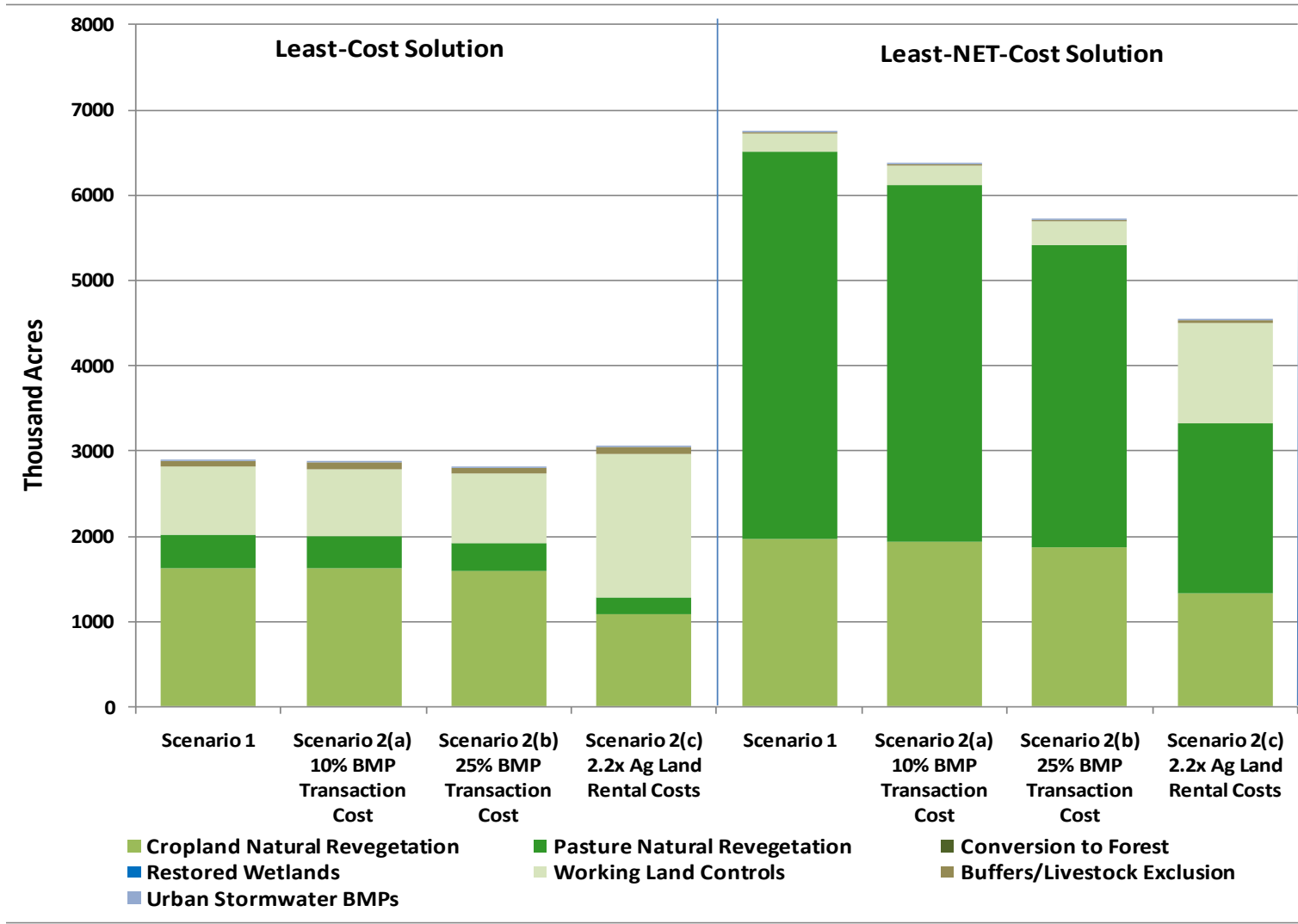
*–  $\beta_1$  \* Co-Benefit1 of BMP<sub>i</sub>*

*–  $\beta_2$  \* Co-Benefit2 of BMP<sub>i</sub>*

*–  $\beta_3$  \* Co-Benefit3 of BMP<sub>i</sub>*

- $\beta$ 's are weights that convert non-monetary benefit units to dollars (e.g., value per ton of carbon sequestered)
- All variables and constraints are the same as in the cost-minimization problem

# Comparative Results with Co-Benefits Included



# Thank you

- Questions?