Modeling Workgroup Meeting Quarterly Review
October 2023

Optimization Update

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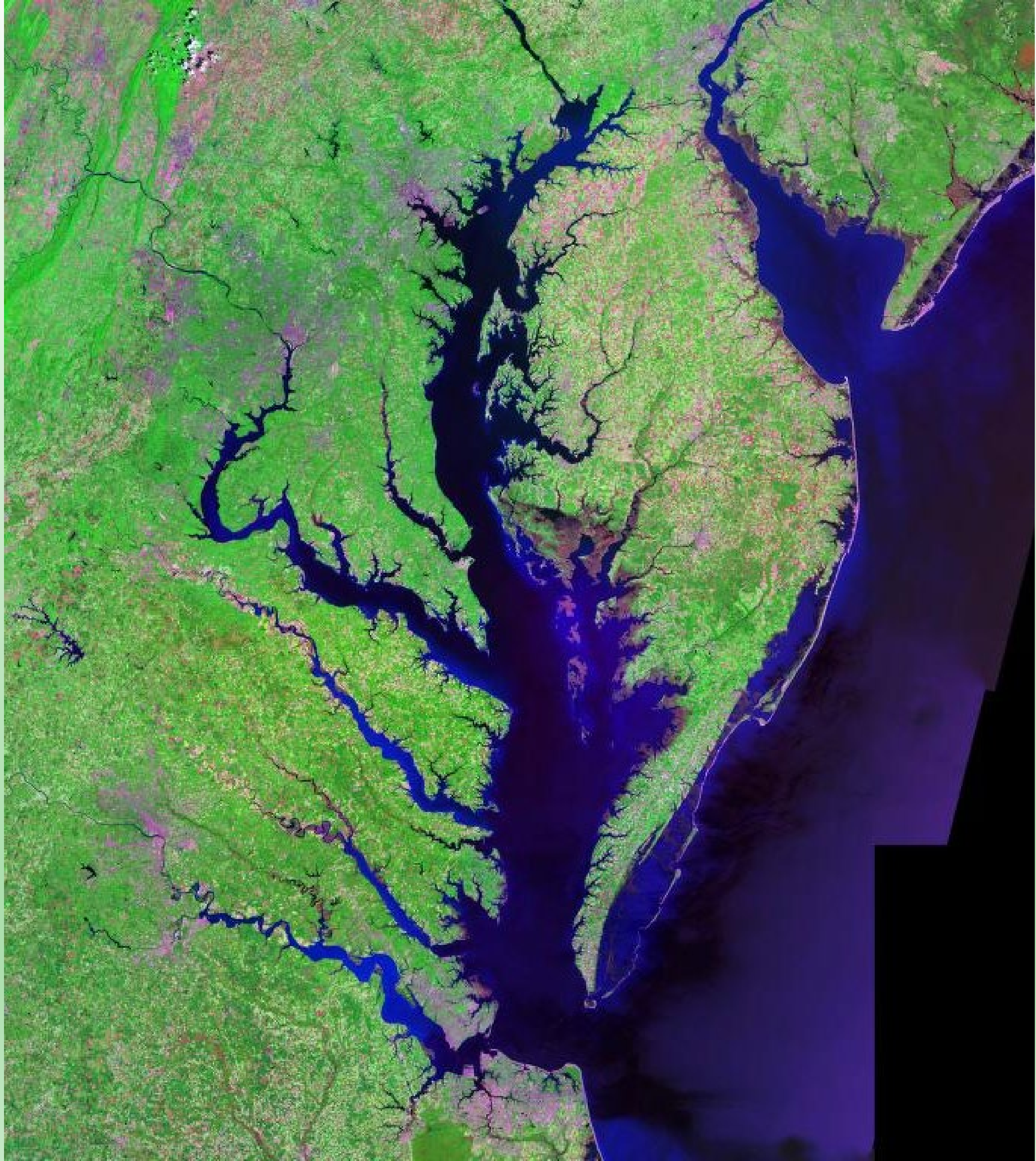
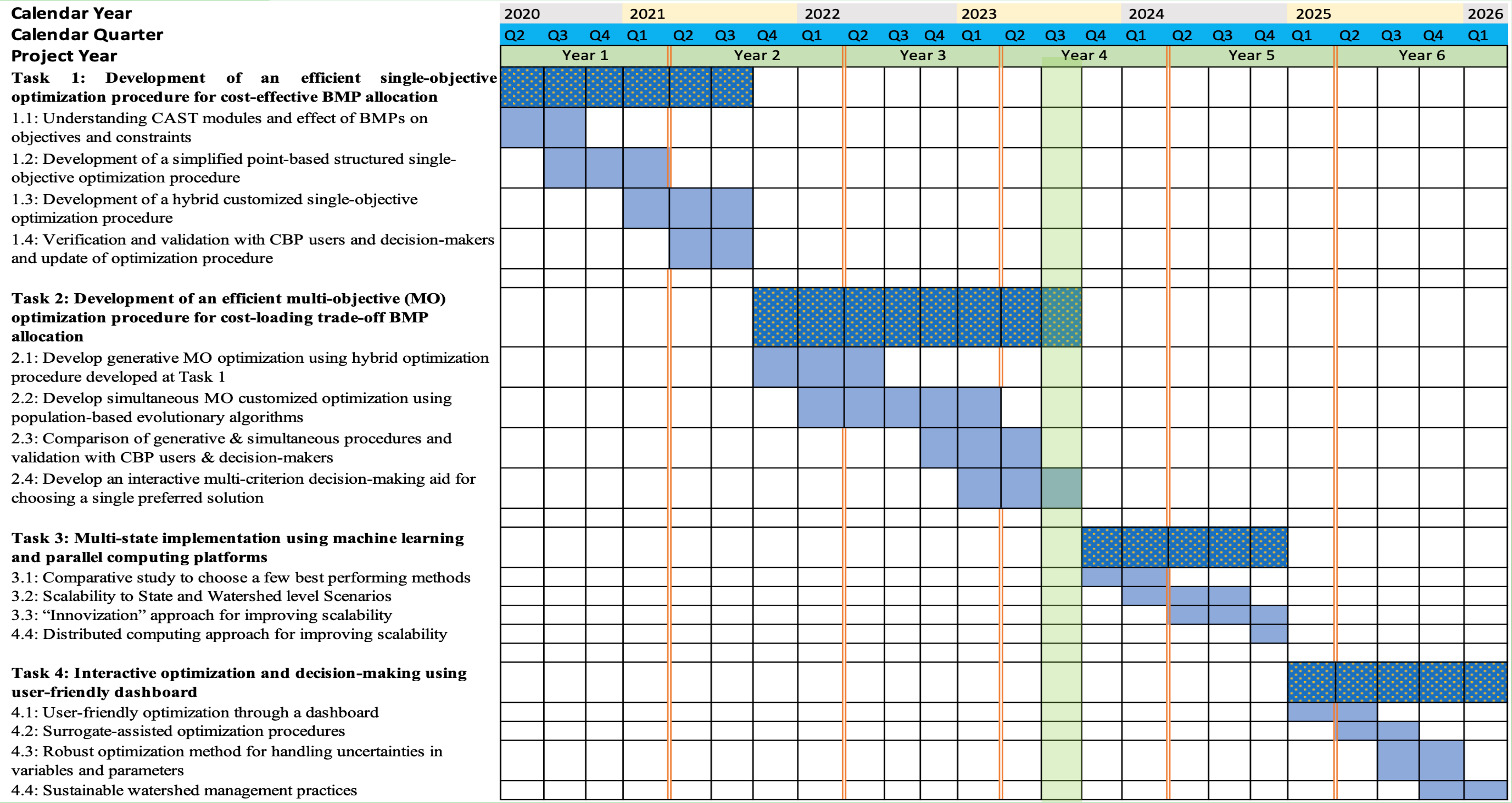
MICHIGAN STATE UNIVERSITY



AGENDA

1	Timeline
2	Overview
3	Reoptimization-validation WV
4	Examining “innovization” strategies beyond WV: Virginia
5	Multi-criteria decision-making
6	Next steps
7	2024 Chesapeake Bay Optimization Webinars

Timeline of the Project



We are here

Task 2: Development of an efficient multi-objective (MO) optimization procedure for cost-loading trade-off BMP allocation

2.1: Develop generative MO optimization using hybrid optimization procedure developed at Task 1

2.2: Develop simultaneous MO customized optimization using population-based evolutionary algorithms

2.3: Comparison of generative & simultaneous procedures and validation with CBP users & decision-makers

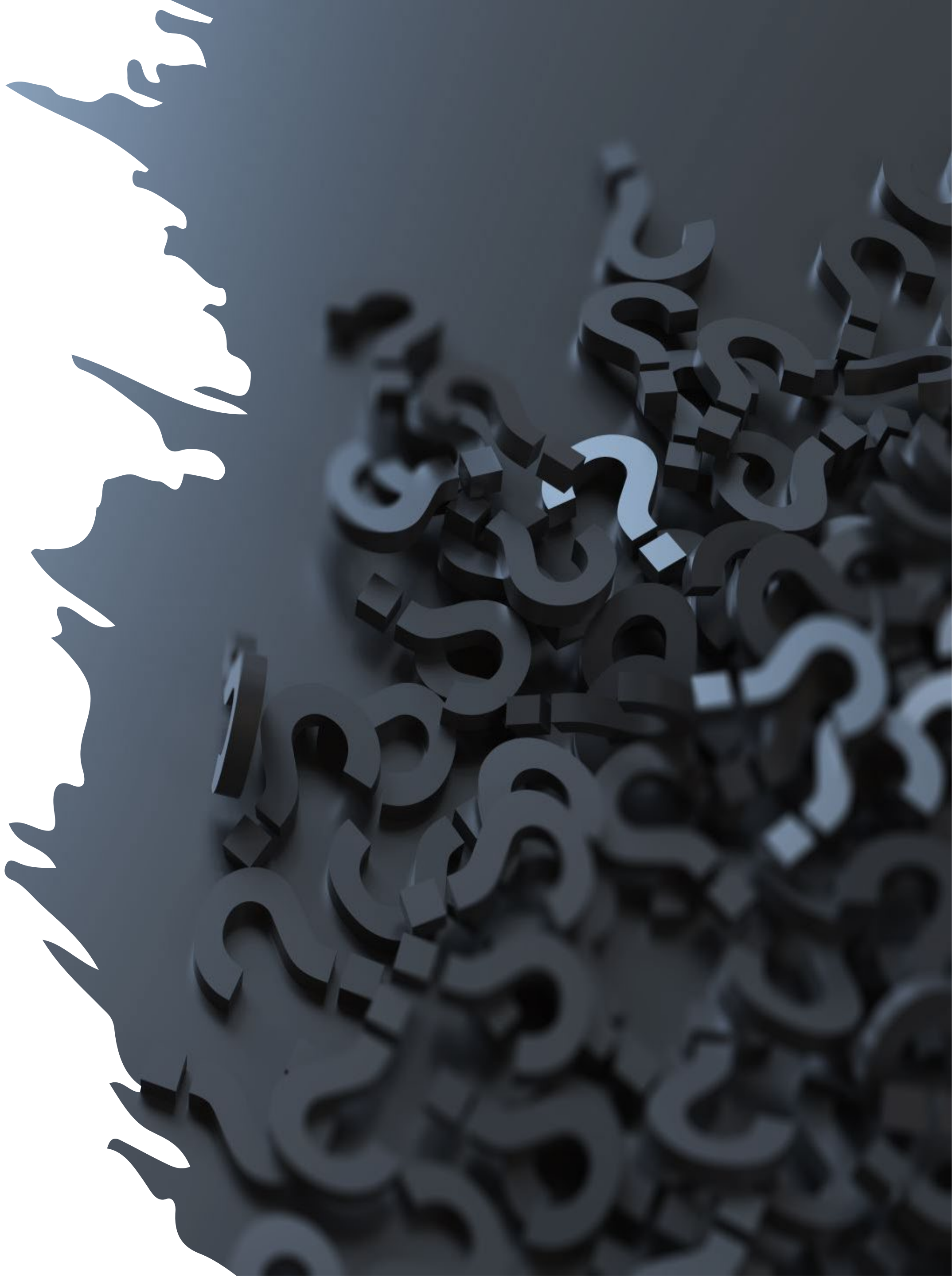
2.4: Develop an interactive multi-criterion decision-making aid for choosing a single preferred solution

Timeline of the Project


OVERVIEW

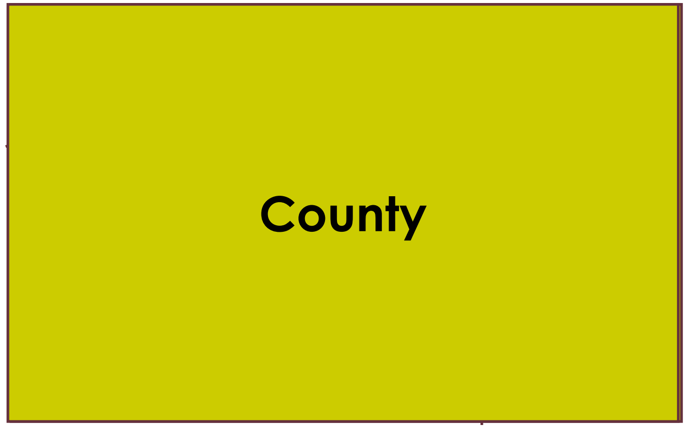
Problem Statement

One of the most challenging issues for a real-world optimization problem is the ***Search Space Complexity*** (variables and constraints), especially for the CBW management problem.



Problem Significance (Search Space Complexity)

- Each county on average has 10 land-river segments,
- Each landriver segment can accept up to 200 BMPs options
- Each landriver segment has 50 land use options
- Making the overall search space for a county to have about $(50 * 200)^{10} = 10^{40}$ **solutions**.
- Highly constrained: ~**100 000 constraints**.
- High-dimensional: more than **2 million variables** at the watershed level



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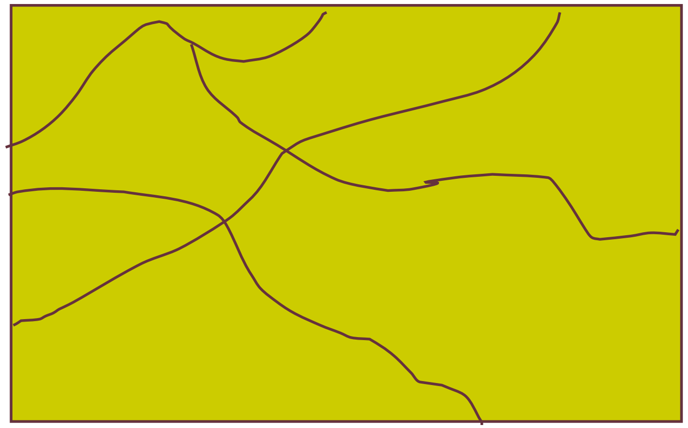

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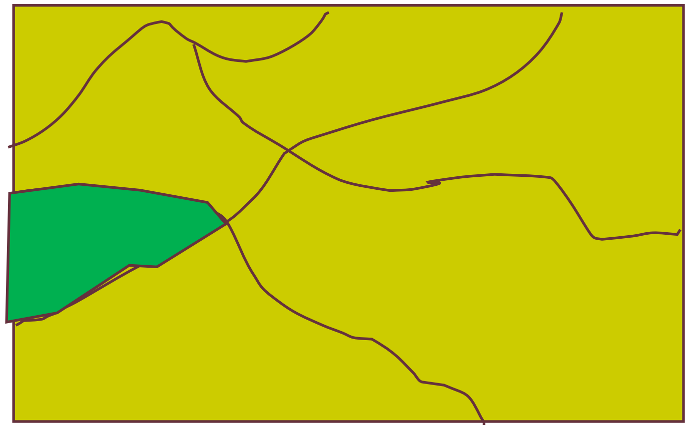

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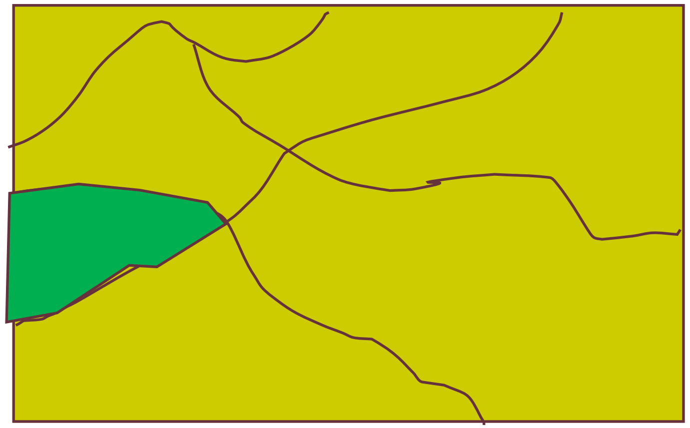

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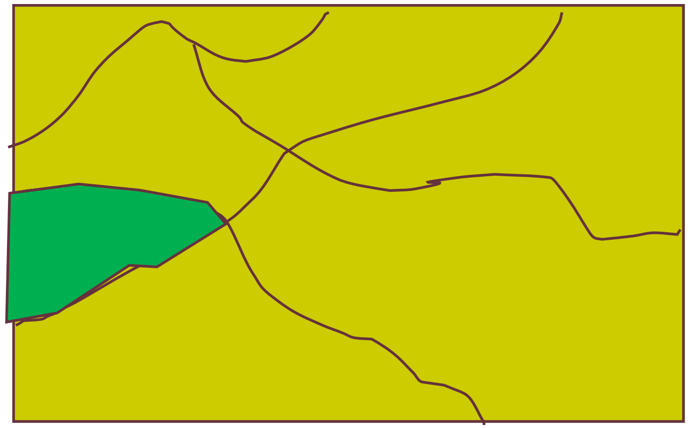

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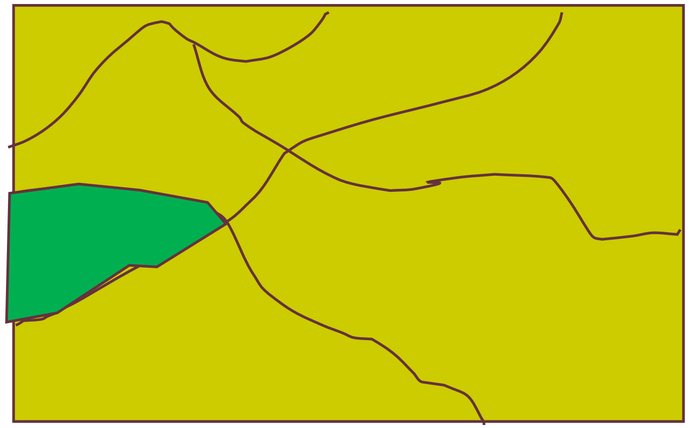
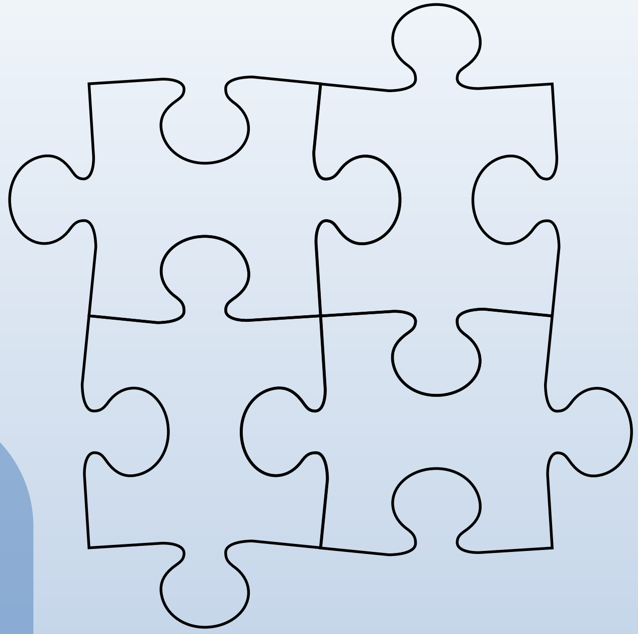


Thousands of BMP implementation scenarios can be evaluated and compared.

Beating the "Curse of Dimensionality"



- ❑ Due to the **large dimension of the problem**, there is **no off-the-shelf optimization algorithm** capable of handling this problem.
- ❑ Therefore, we developed a **customized optimization** approach **to speed up computational time and reduce the size of optimization variables** to make the problem solvable in a reasonable time frame.

Proposed Solution Approach

1. **Employ an Initial Local Search on a Math Model (for efficient BMPs only)**

   to reduce the computational time associated with running watershed model (Discussed in previous presentations using IPOPT)

2. **Employ a Multi-obj. Optimization algorithm using CAST**

   to find a number of trade-off Pareto solutions (Discussed in previous presentations)

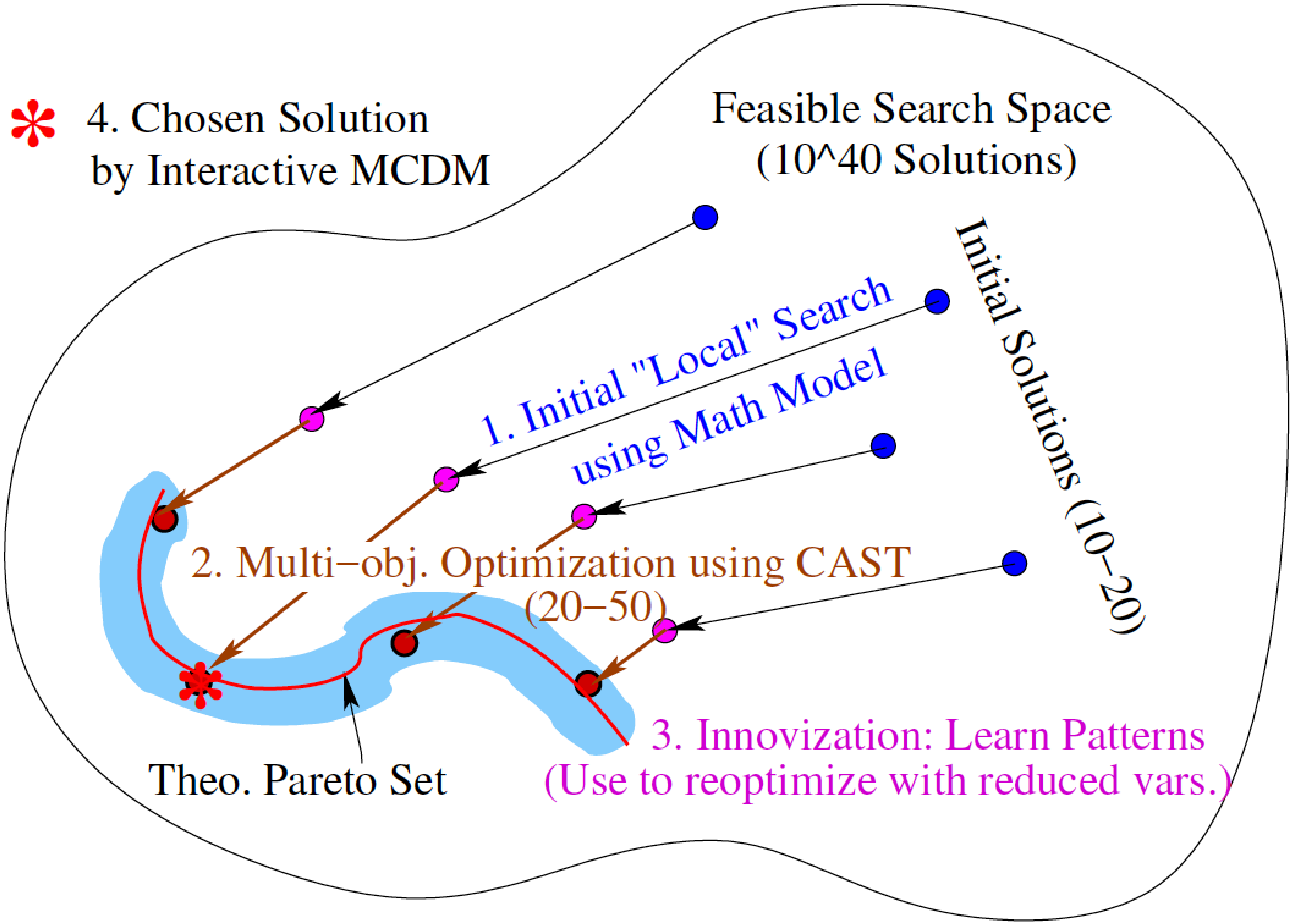
3. **Innovization: Learning Patterns**

   to learn patterns from Pareto solutions for re-optimization with reduced number of variables (Discussed here)

4. **Multi-Criterion Decision-making (MCDM)**

   to choose a single preferred solution (Discussed here)

Overall Approach



Innovation through Optimization

The major problem we are facing is **the large number of optimization variables.** These variables originate from three major components:

- Type of BMPs
- BMP implementation location
- Size of BMPs

Innovization

By understanding **the common characteristics of the group of BMPs or locations of implementation**, we can reduce the number of BMPs and ultimately **reduce the total number of variables**.

Study Area

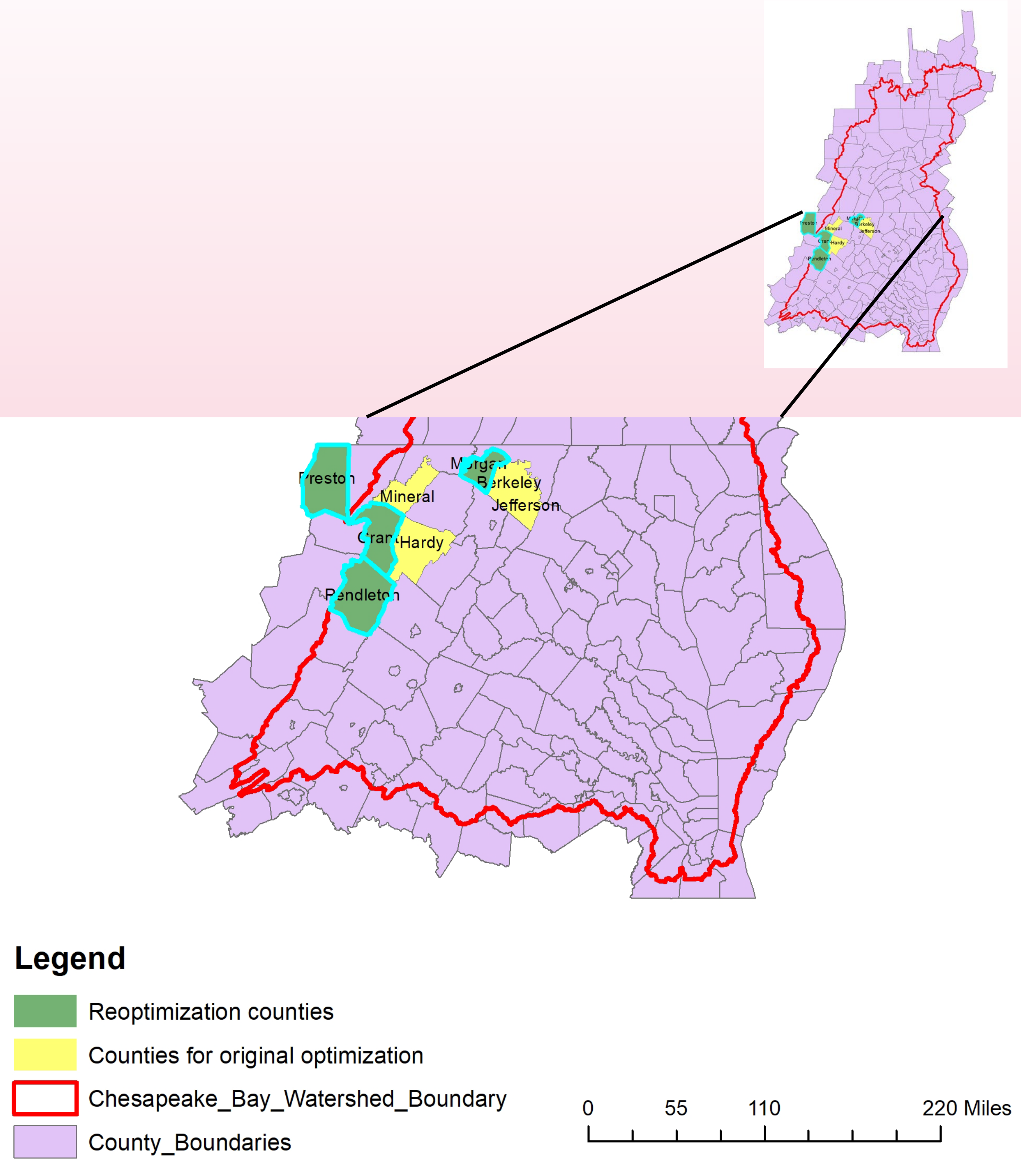
The number of variables and constraints depends on **the scale of the county or state** under study.

West Virginia

Four county: 65,260 variables (Berkeley, Jefferson, Mineral, and Hardy)

Entire state: the number of variables is about **153,818.**

For any optimization algorithm, these numbers are regarded as substantial and computationally challenging.



Innovization in CPB

Ranking Conservation Practices

Discover the top-rated conservation practices and how to implement them!

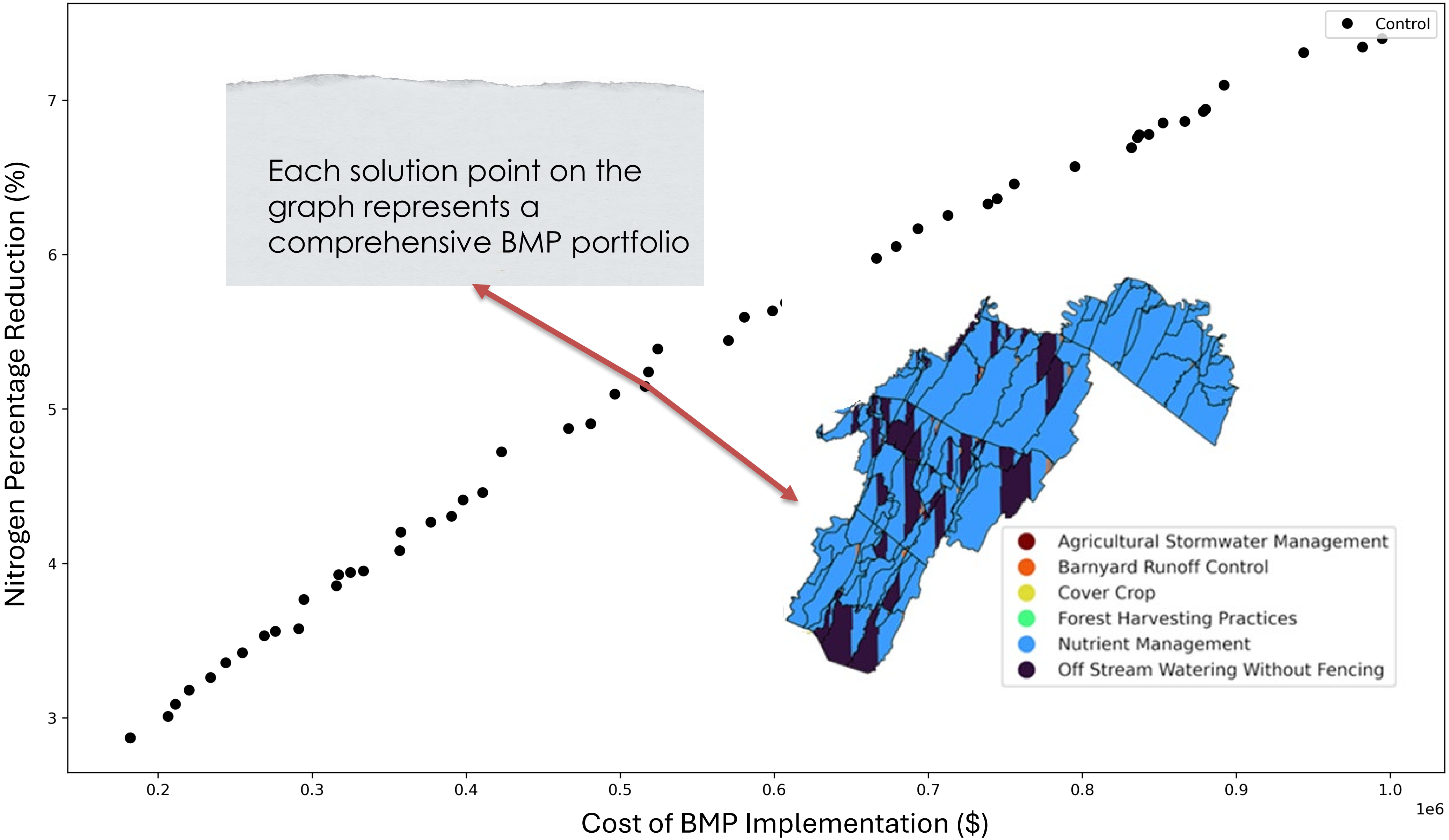
Use different ranking strategies to **identify the top 10 ranked BMPs** by the optimization algorithm.

- implementation acreages
- maximum allowable acreages
- nitrogen reduction per dollar spent

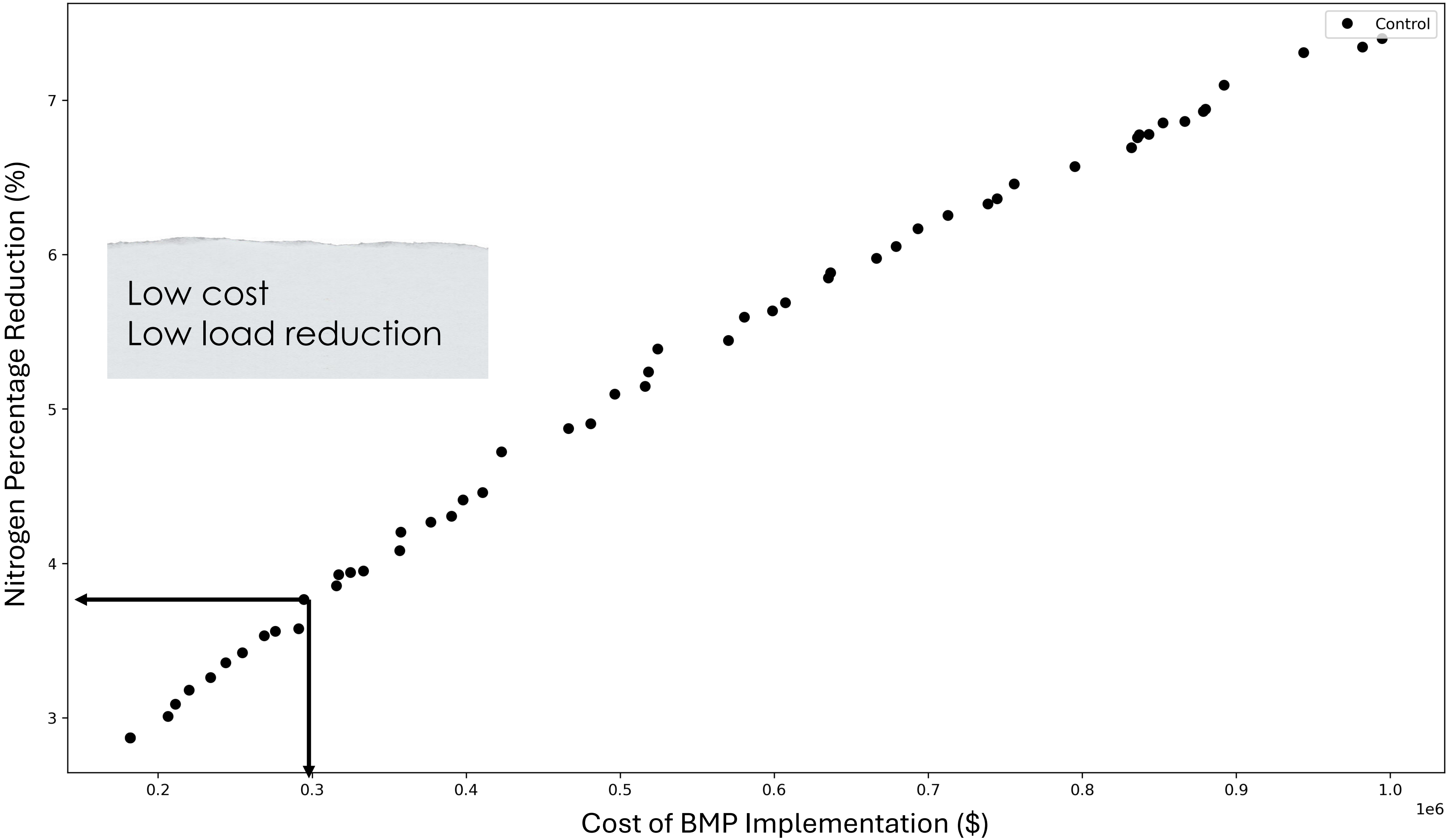
Four counties for the **initial testing** of the innovization algorithm: **(Berkeley, Mineral, Hardy, and Jefferson)** of West Virginia

The results from these new strategies **(top 10 BMPs**) were compared against the **original optimization** algorithm (**200 BMPs**) in these counties.

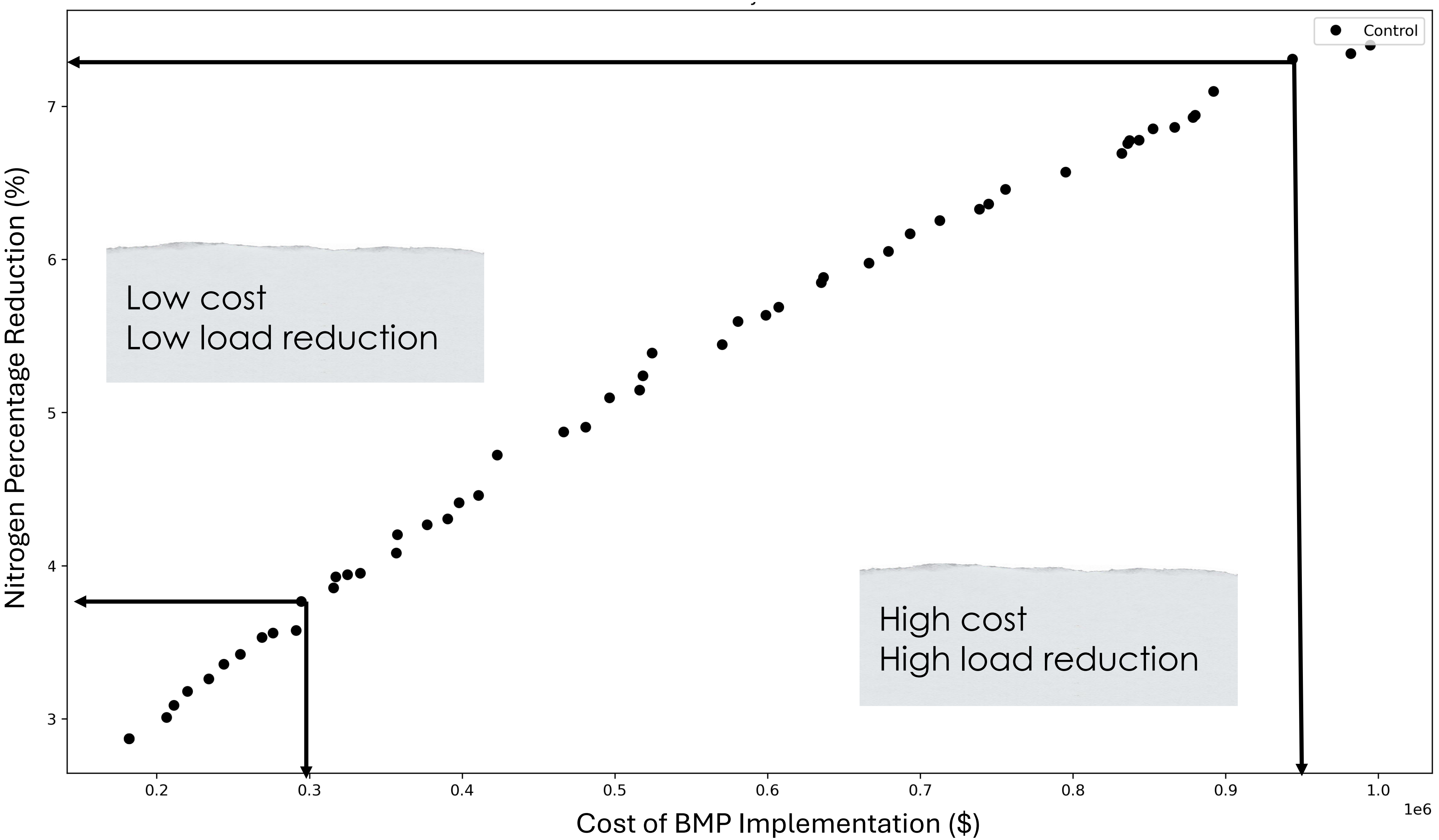
Original Optimization



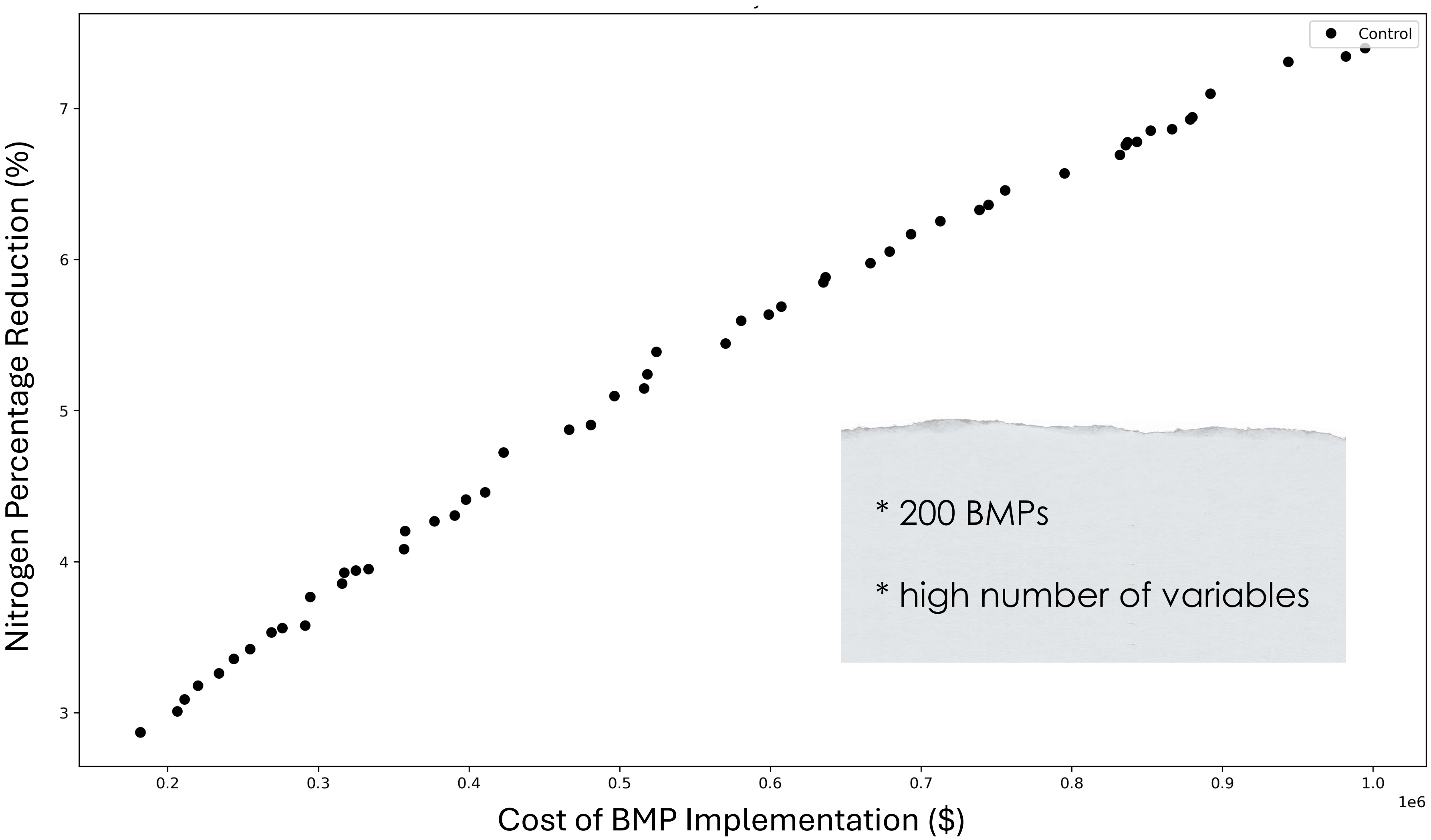
Original Optimization



Original Optimization



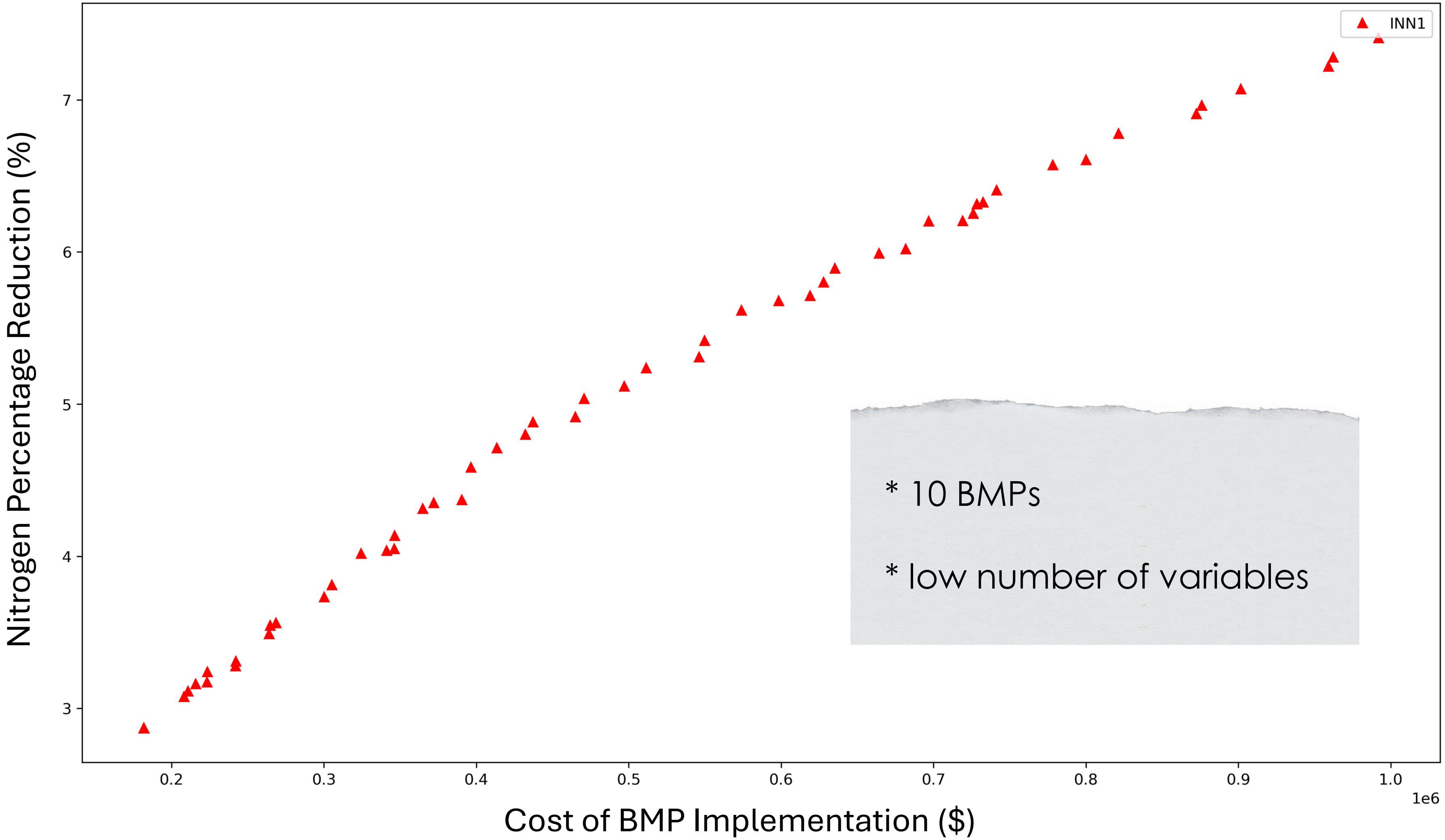
Original Optimization
Berkeley, Hardy, Jefferson, and Mineral Counties



* 200 BMPs

* high number of variables

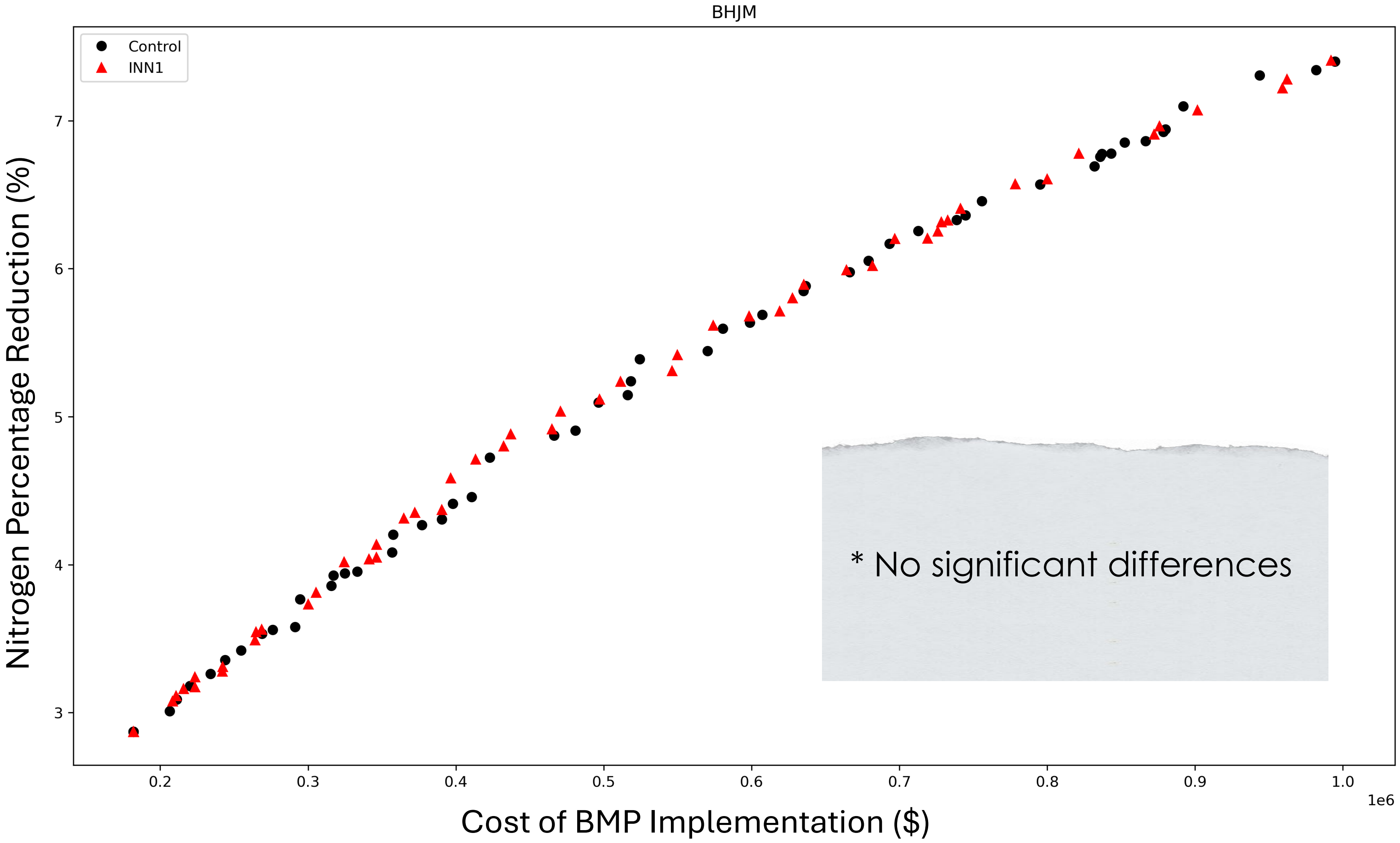
Innovized Optimization
Berkeley, Hardy, Jefferson, and Mineral Counties



* 10 BMPs

* low number of variables

Compare Original vs. Innovized Optimization
Berkeley, Hardy, Jefferson, and Mineral Counties



Innovization-for efficiency BMPs-

By reducing the number of BMP from about **200 types of efficient BMPs to only 10 BMPs,** the size of the problem was significantly reduced.

The innovizaed approach can reduce the number of variables by **about 96%,** which is a promising result.

Reoptimization-Validation

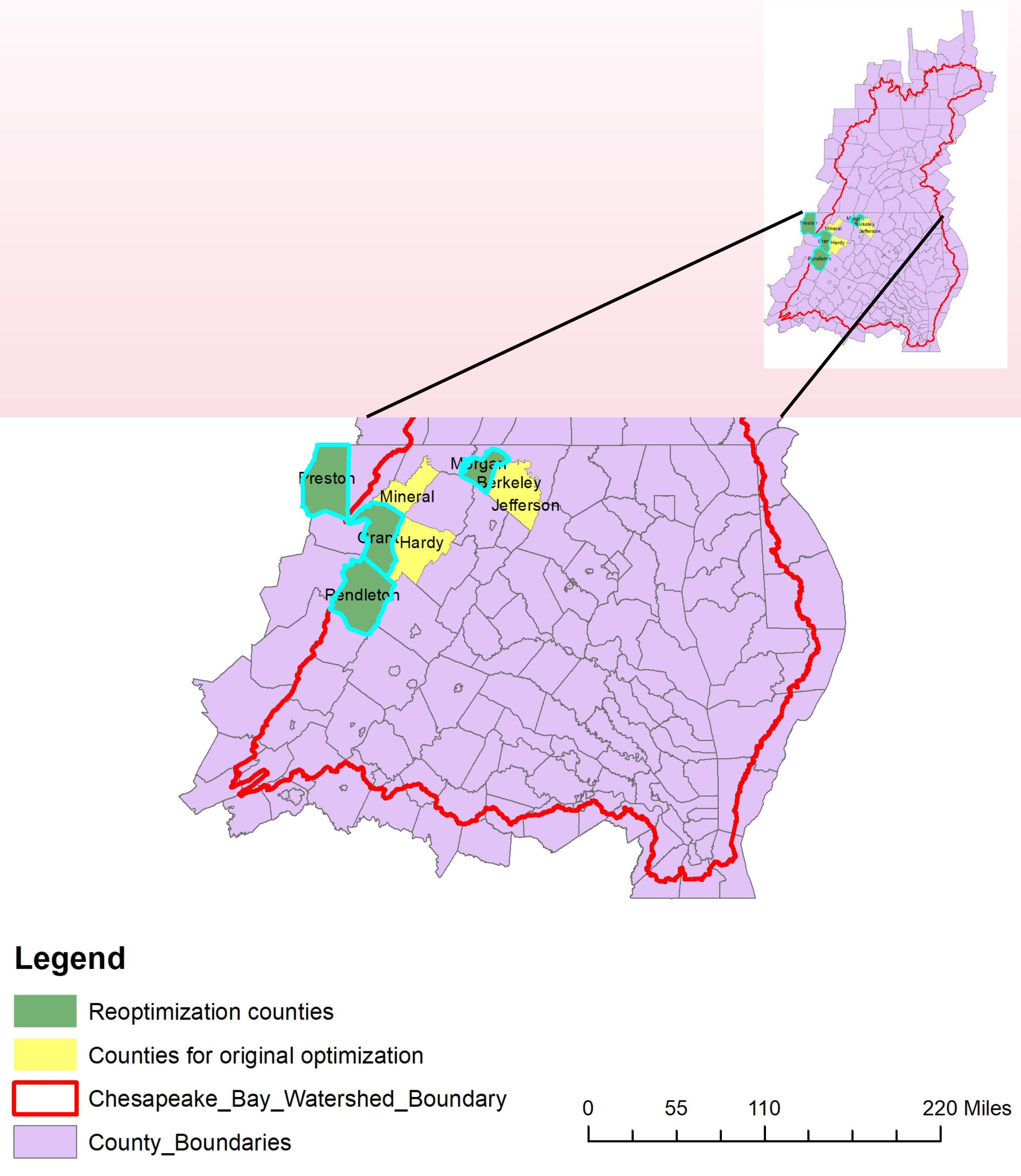
Reoptimization

Evaluate the performance of original innovization technique other counties

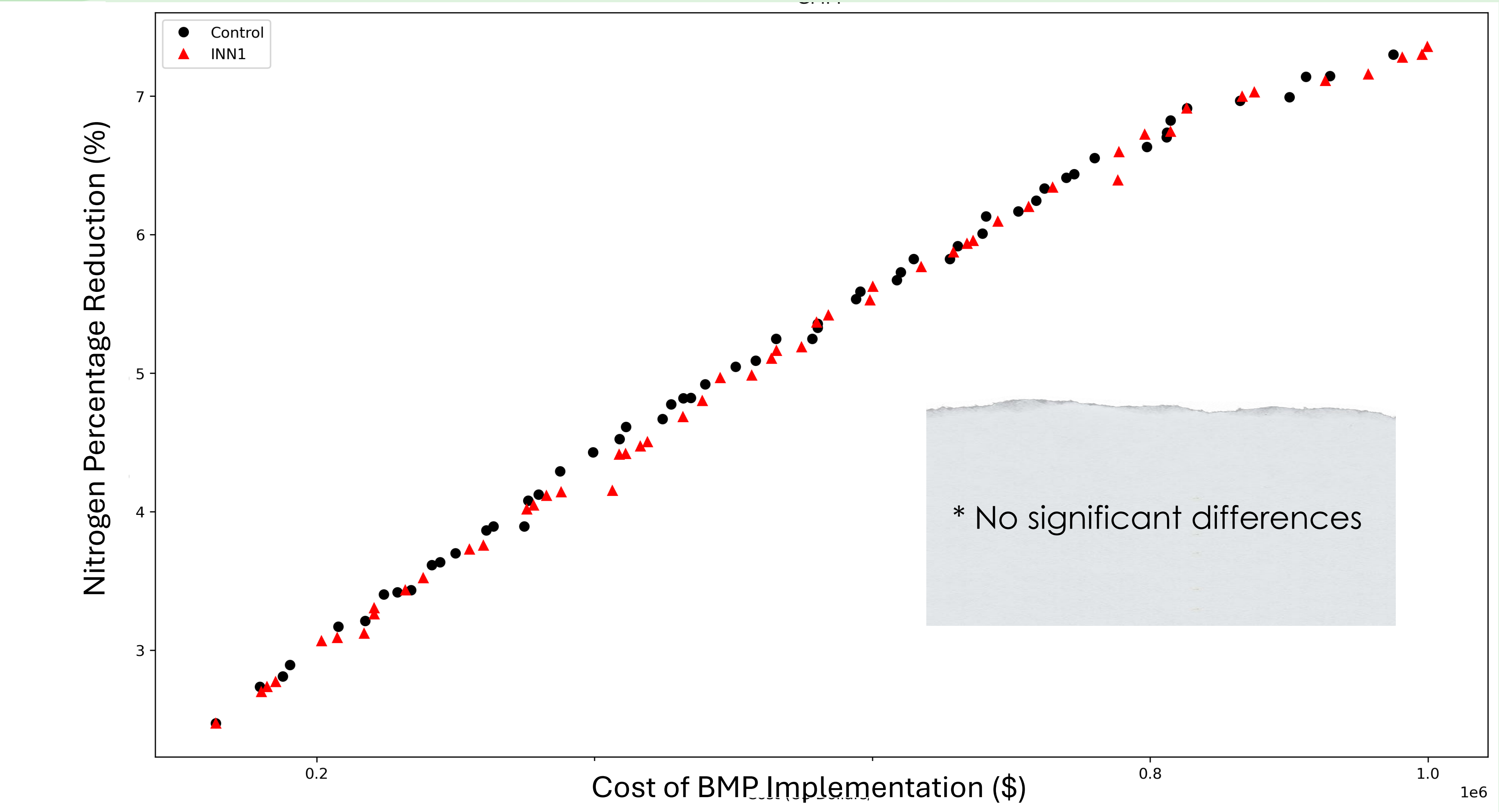
West Virginia

Four counties: 71,661 variables (Grant, Morgan, Pendleton, and Preston)

The best innovization strategy (10 BMPs) outperforms the control (>200 BMPs).



Reoptimization
Compare Original vs. Innovized Optimization
Grant, Morgan, Pendleton, and Preston Counties



Innovization effectiveness

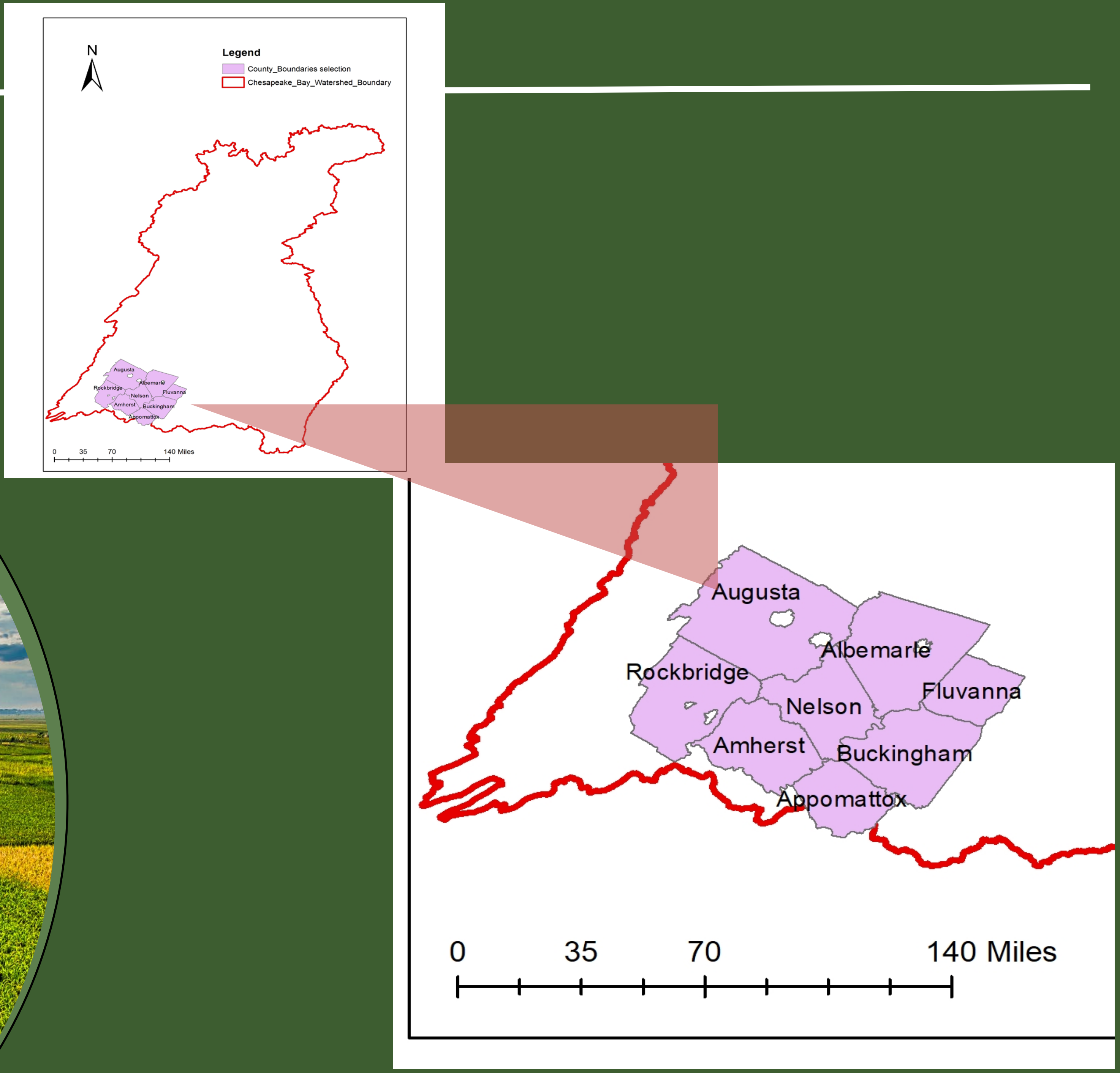
The results of this study show that innovization technique is an effective approach to significantly reducing the size of the optimization problem.

This reduction in variables enhances computational efficiency without sacrificing solution quality

Extract critical knowledge allow for solving similar problems without performing any new optimization.

From West Virginia to Virginia: Innovization Strategies

Study Area



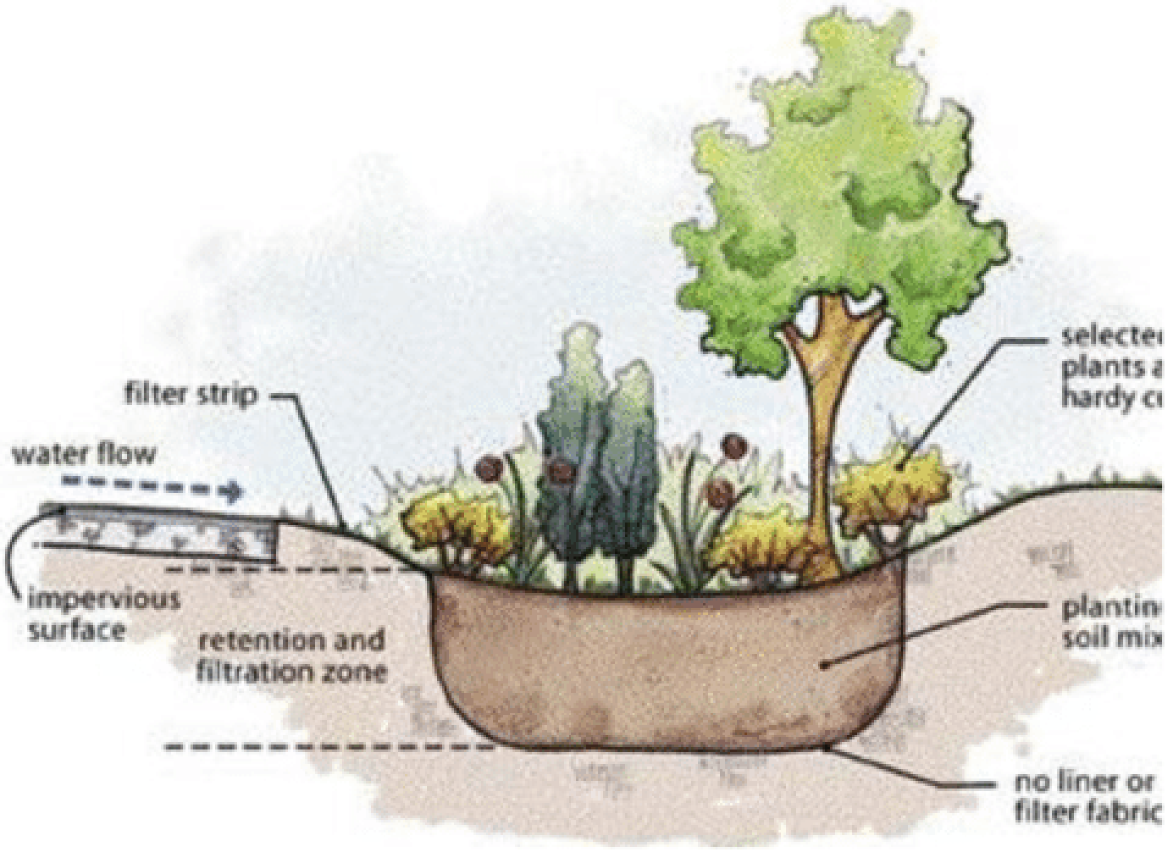
N
Legend
County_Boundaries selection
Chesapeake_Bay_Watershed_Boundary
0 35 70 140 Miles
Augusta
Albemarle
Rockbridge
Fluvanna
Nelson
Amherst
Buckingham
Appomattox
0 35 70 140 Miles

Combinations of Optimization Scenarios

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E) →	
Experiment 2	Only Land Conversion BMPs (LS) →	(LS) first, then (E)
Experiment 3	Only Animal Manure (AM) →	(AM) first, then (E)
Experiment 4	Only Manure Transport (MT) →	(MT) first, then (E)

1

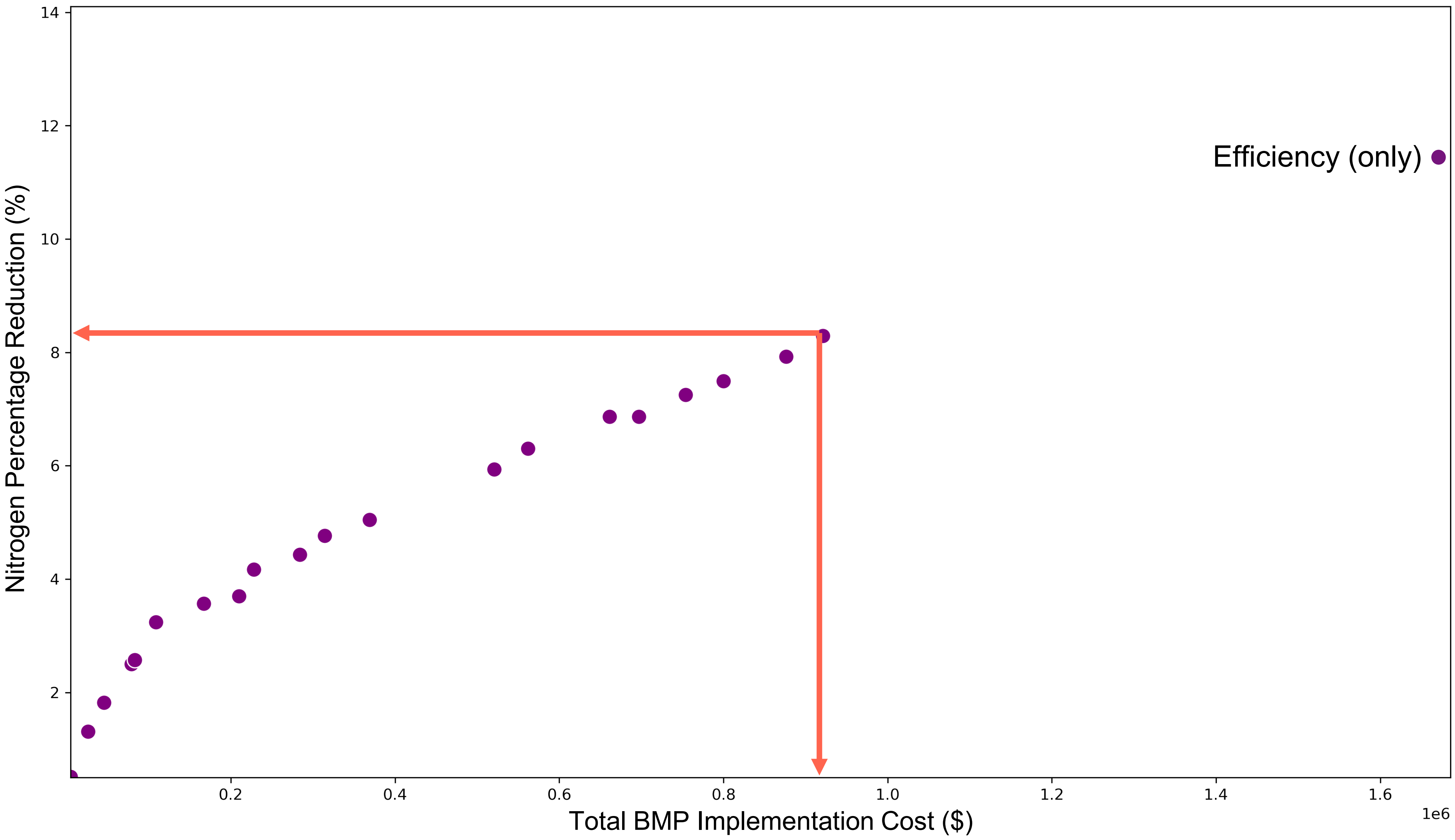
Efficiency BMPs



1

Efficiency BMPs (Nelson)

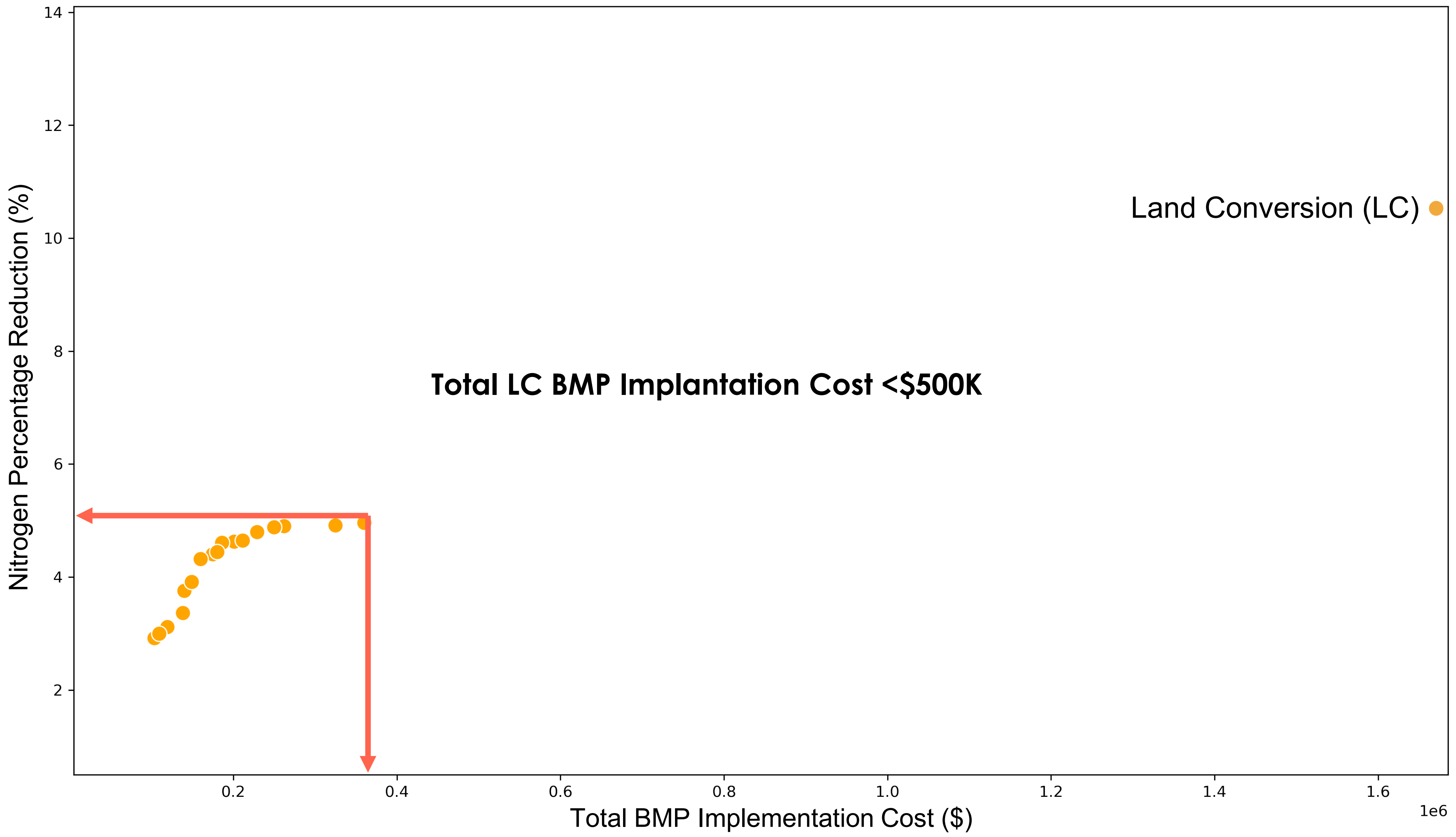
	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E) →	



Efficiency (only)
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
14
12
10
8
6
4
2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

2 Land Conversion BMPs (Nelson)

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E) →	
Experiment 2	Only Land Conversion BMPs (LS) →	(LS) first, then (E)



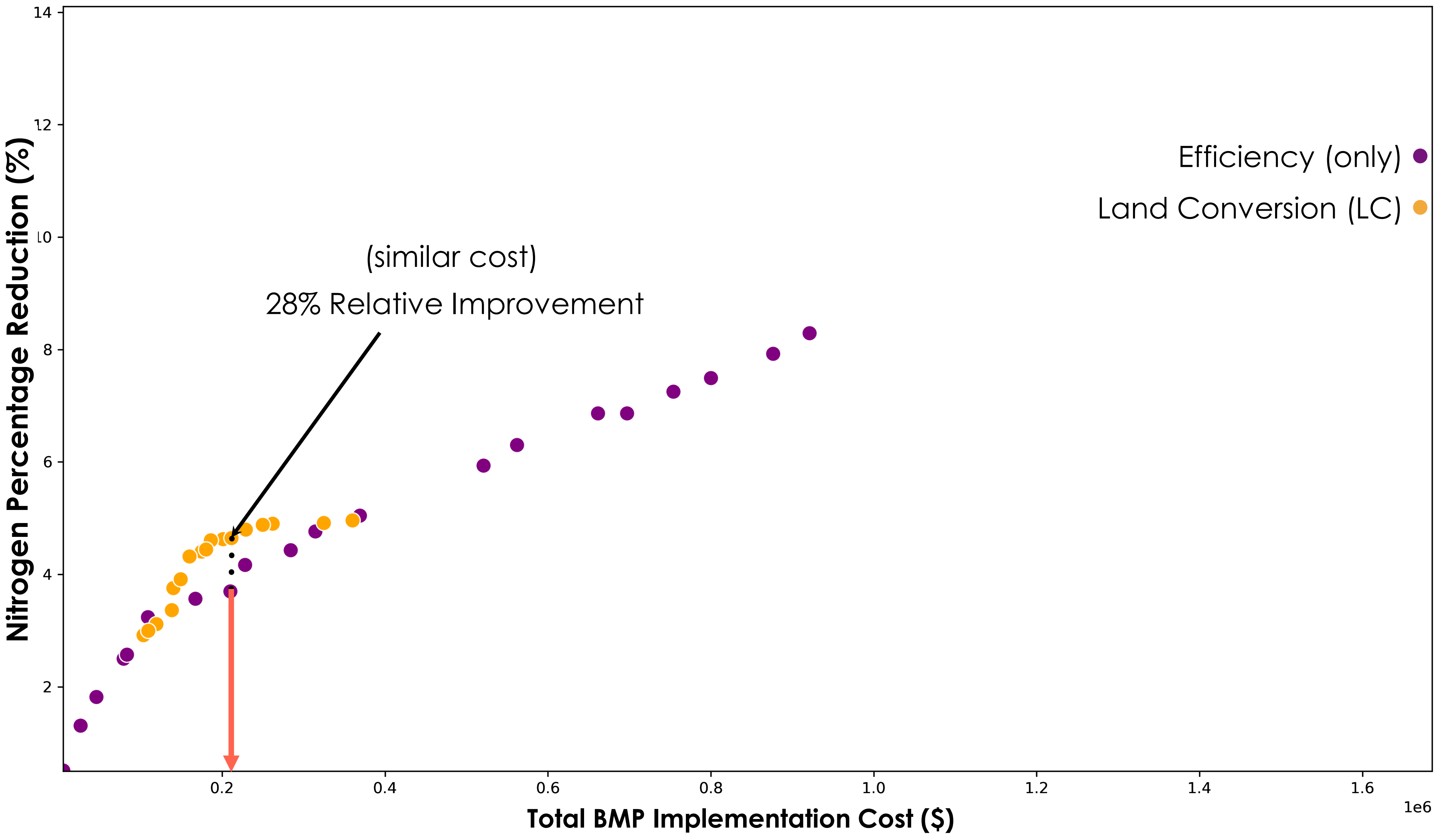
Land Conversion (LC)
Total LC BMP Implantation Cost <$500K
Nitrogen Percentage Reduction (%)
14
12
10
8
6
4
2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1e6
Total BMP Implementation Cost ($)

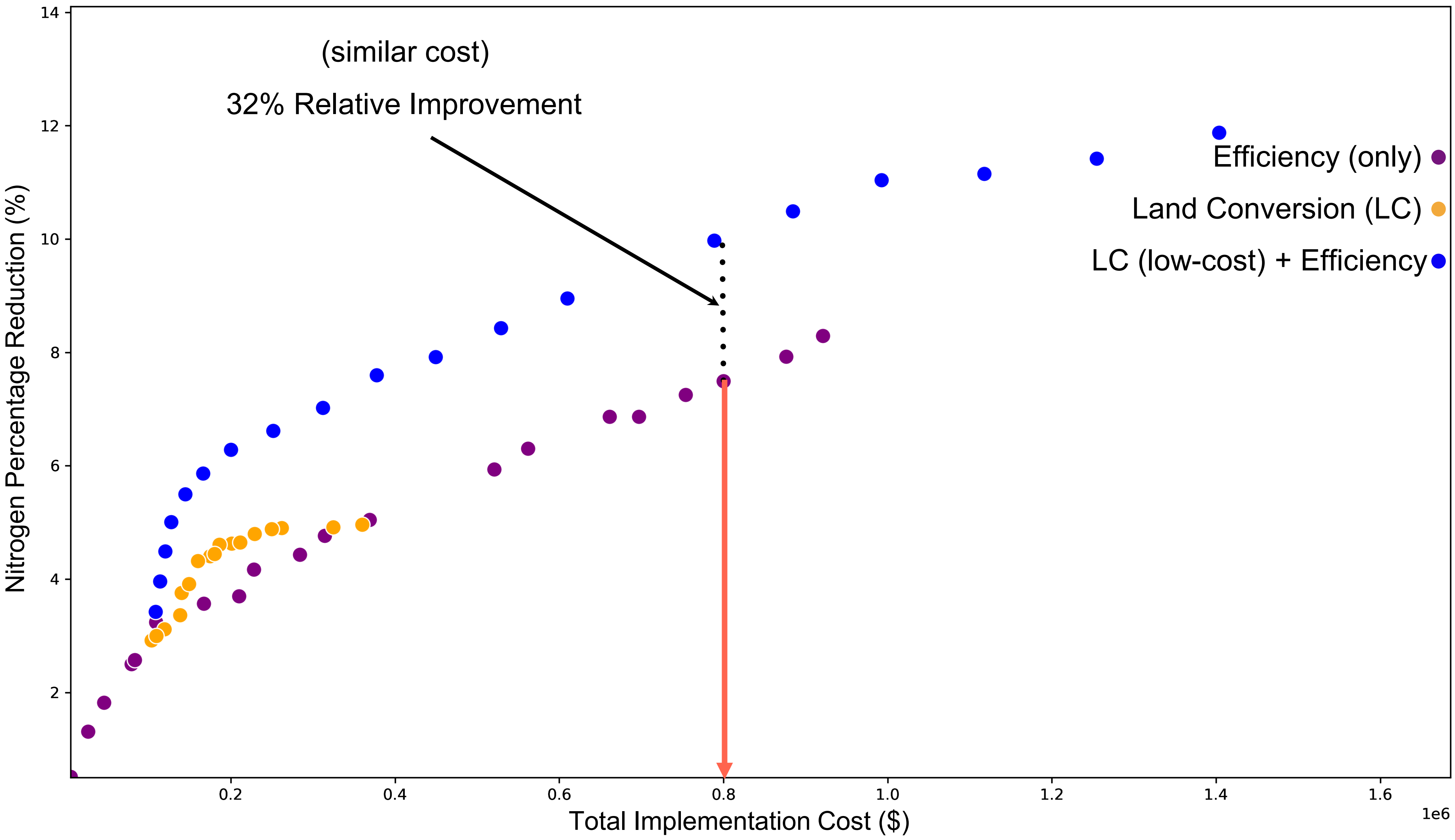
2 Land Conversion and then Efficiency BMPs (Nelson)

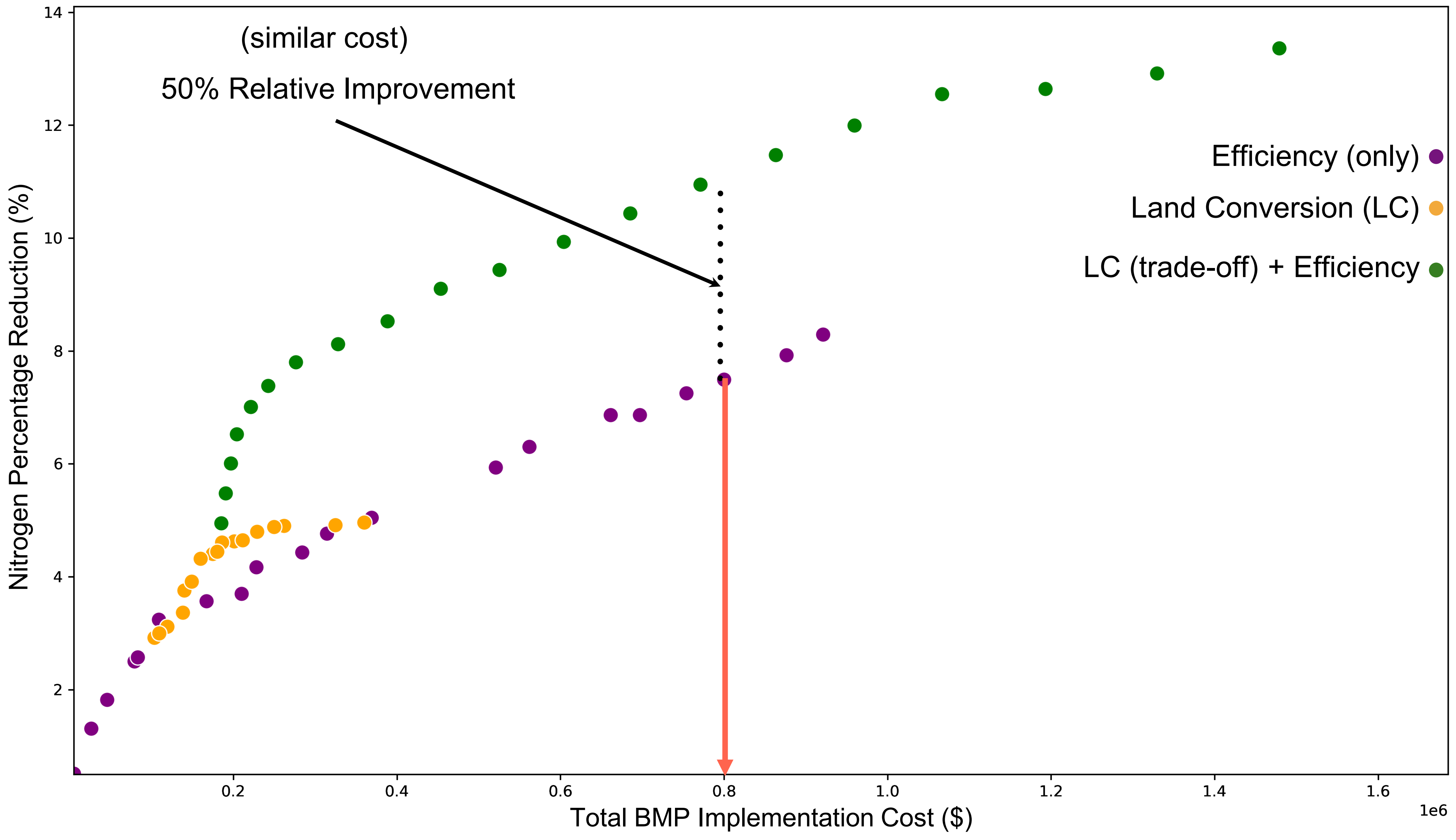
	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E)	
Experiment 2	Only Land Conversion BMPs (LS)	(LS) first, then (E)

Total LC BMP Implantation Cost <$500K

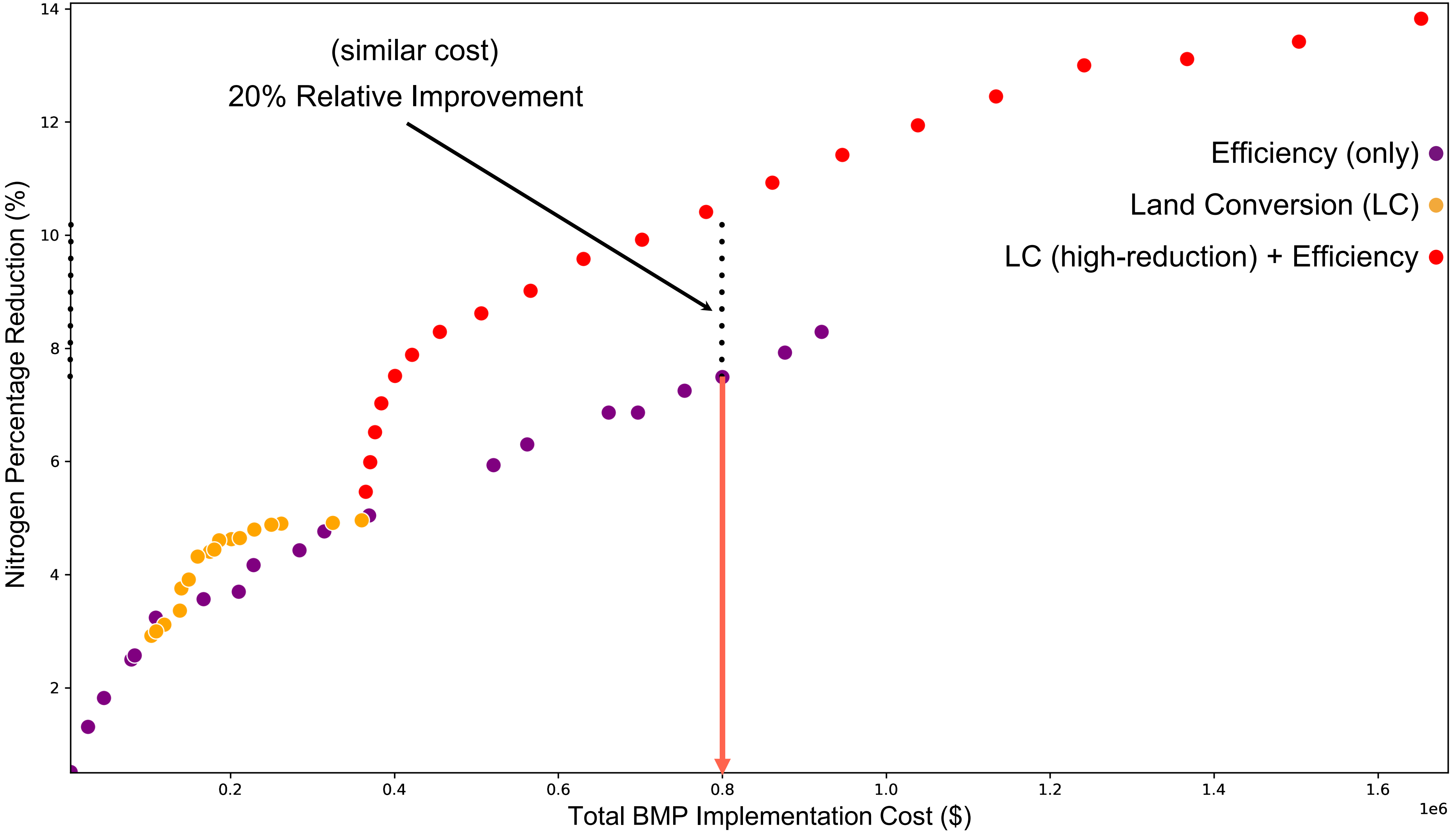
Comparison of optimization solutions from Efficiency and Land conversion BMPs

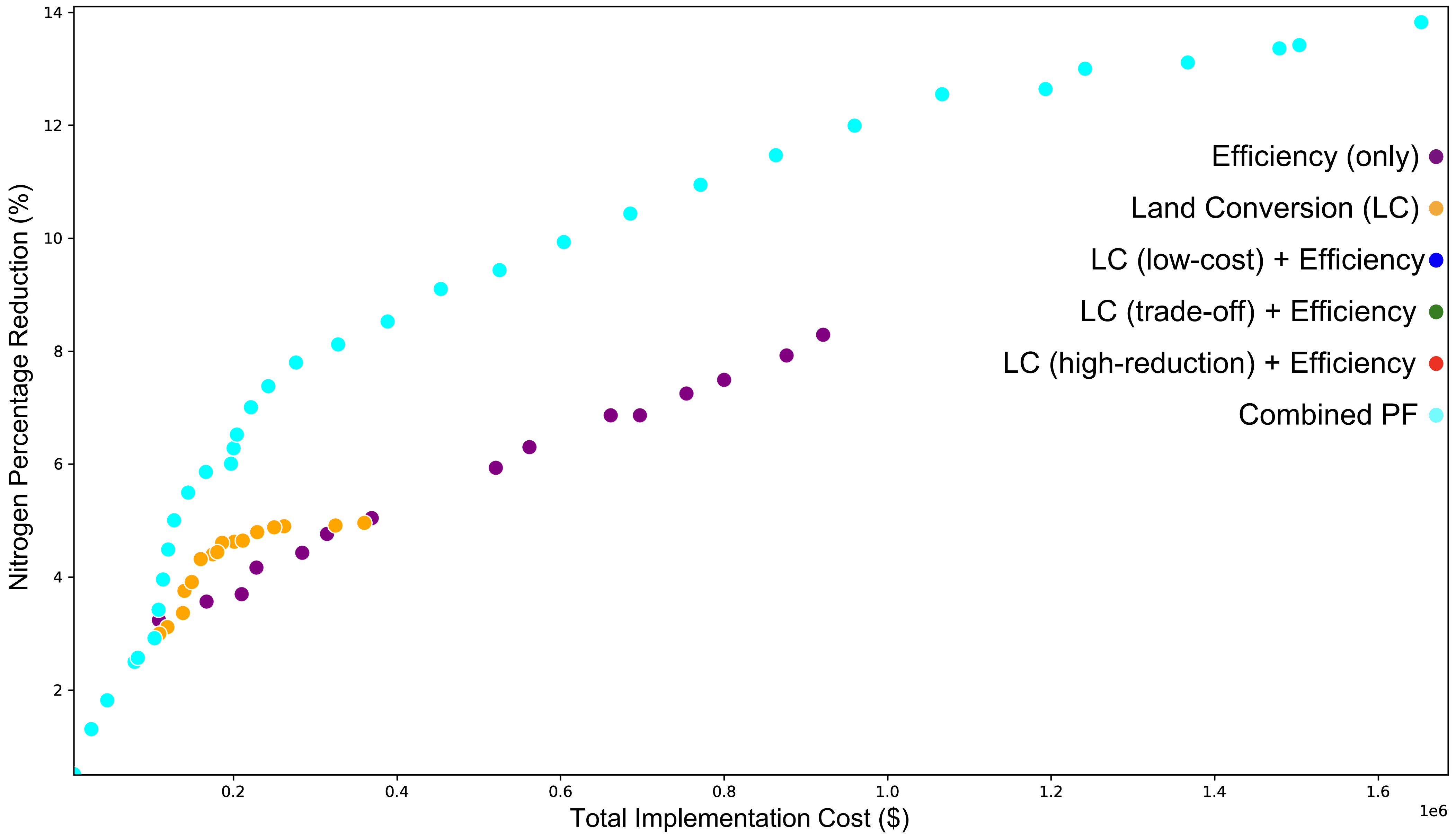



(similar cost)
32% Relative Improvement
Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
Nitrogen Percentage Reduction (%)
Total Implementation Cost ($)
1e6
14
12
10
8
6
4
2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6



(similar cost)
50% Relative Improvement
Efficiency (only)
Land Conversion (LC)
LC (trade-off) + Efficiency
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
14
12
10
8
6
4
2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6


(similar cost)
20% Relative Improvement
Efficiency (only)
Land Conversion (LC)
LC (high-reduction) + Efficiency
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
14
12
10
8
6
4
2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6



Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF
Nitrogen Percentage Reduction (%)
Total Implementation Cost ($)
1e6
14
12
10
8
6
4
2
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

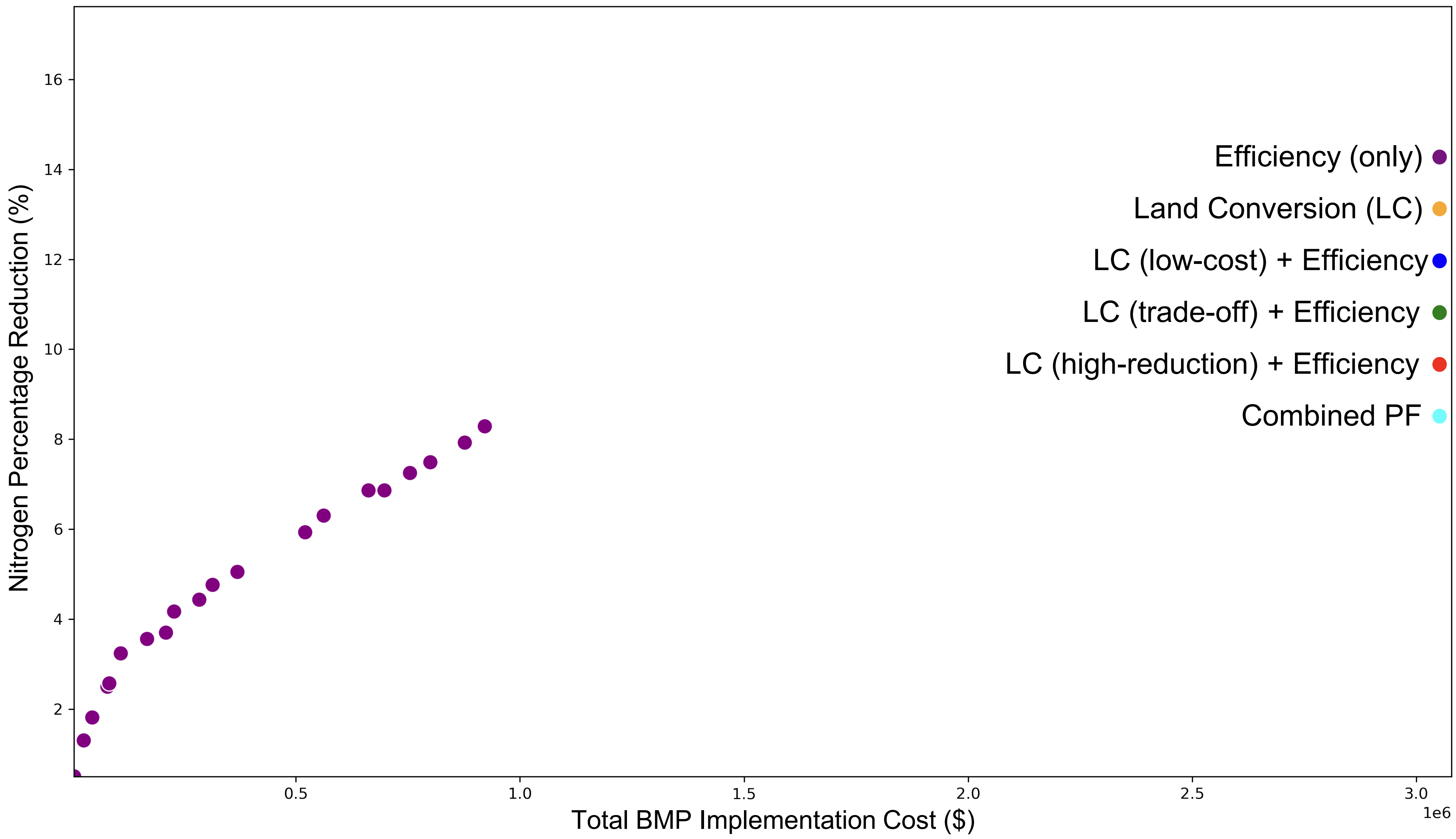
2

Land Conversion BMPs (Nelson)

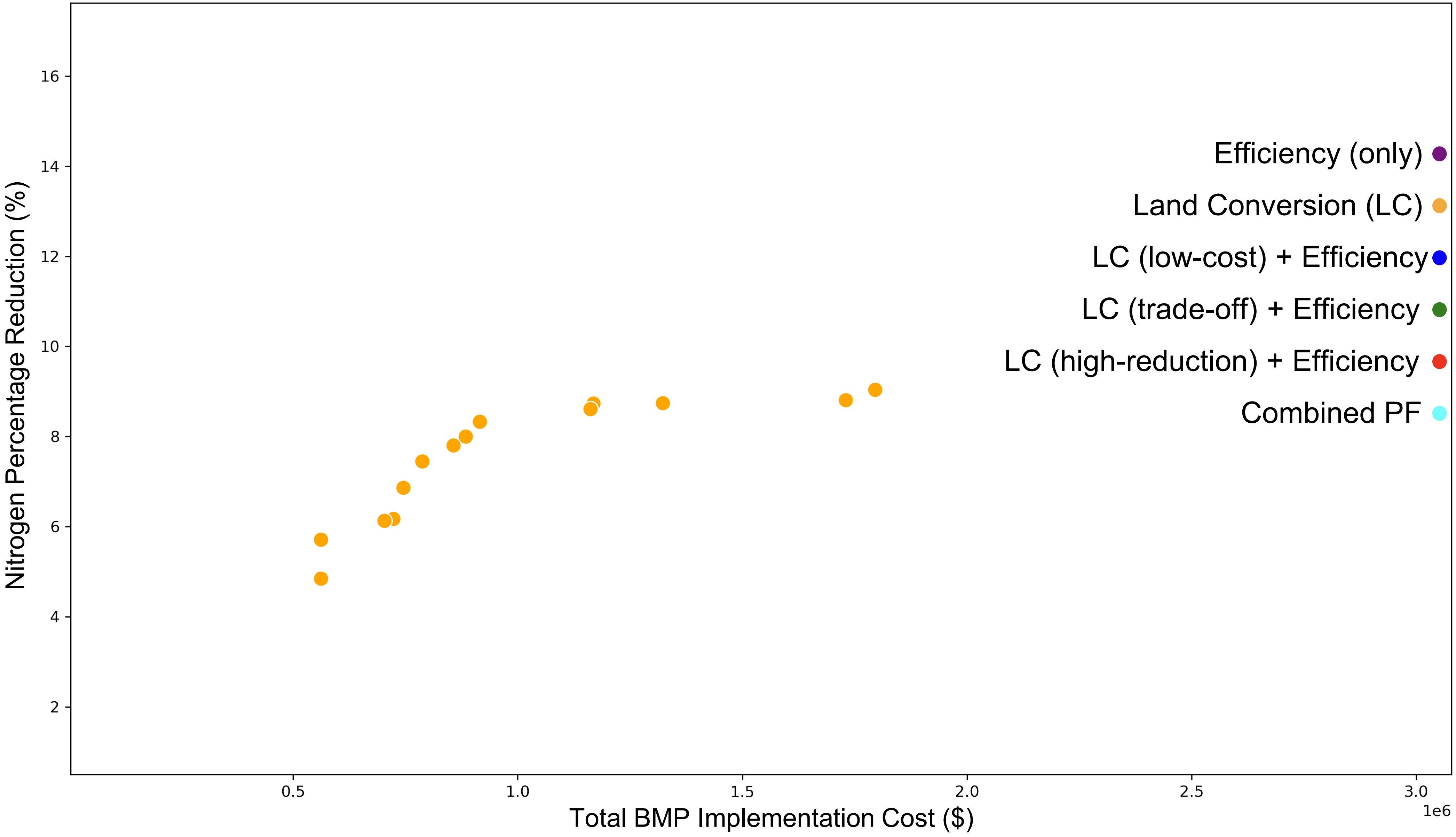
2 Land Conversion and then Efficiency BMPs (Nelson)

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E)	
Experiment 2	Only Land Conversion BMPs (LS)	(LS) first, then (E)

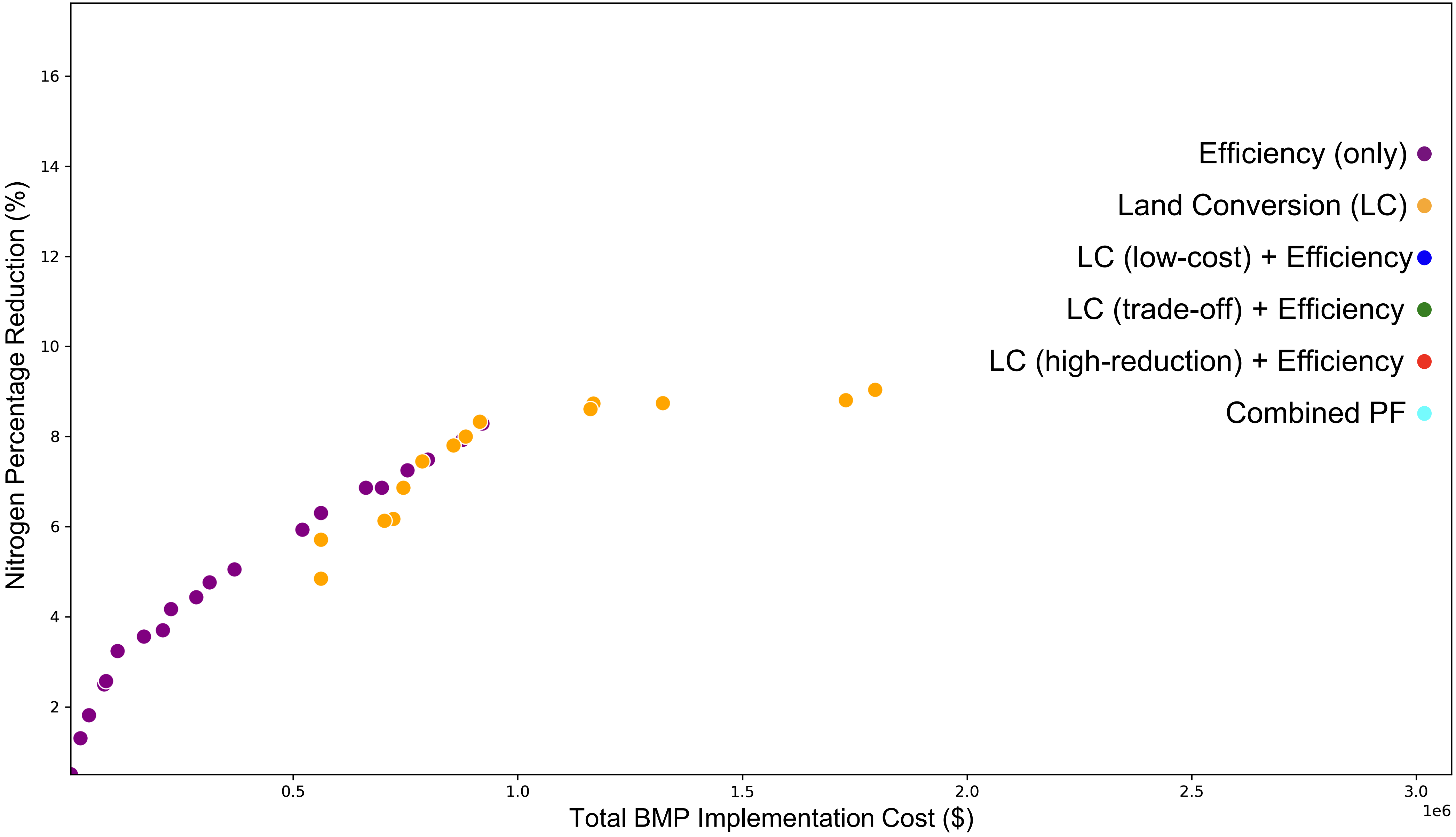
$500K < Total LC BMP Implantation Cost <$2M

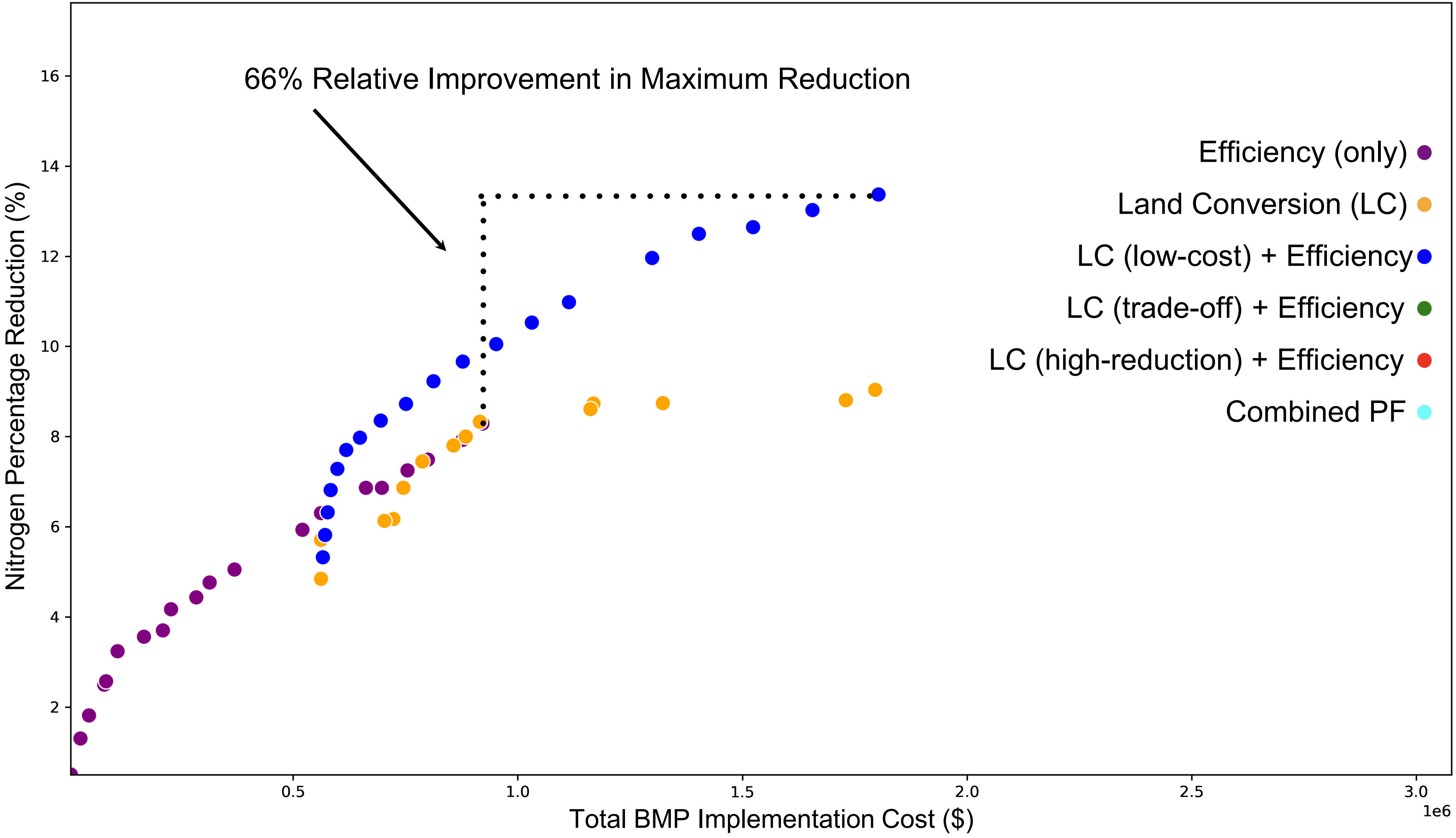


Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF
Nitrogen Percentage Reduction (%)
16
14
12
10
8
6
4
2
0.5
1.0
1.5
2.0
2.5
3.0
1e6
Total BMP Implementation Cost ($)

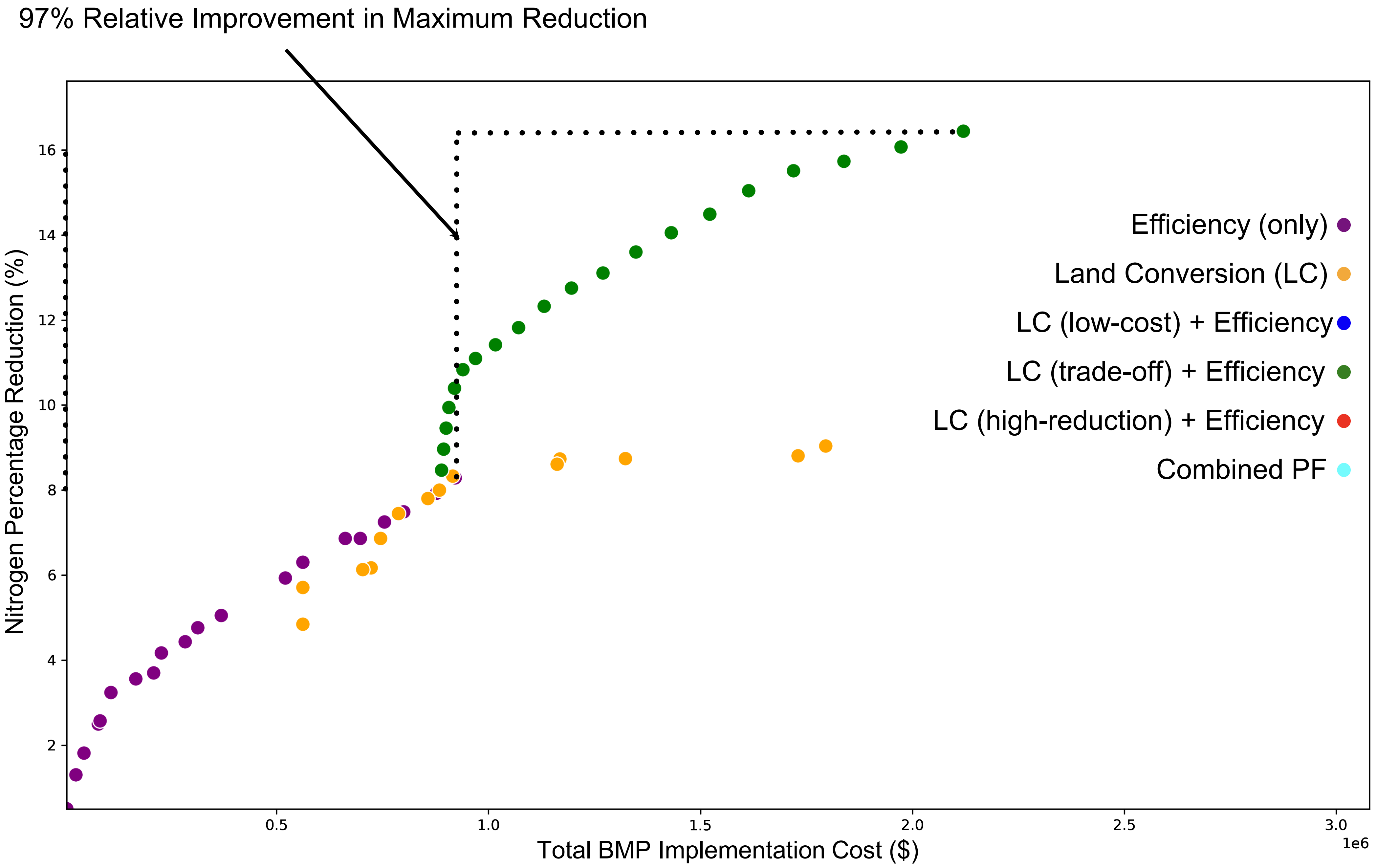


Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
0.5
1.0
1.5
2.0
2.5
3.0
2
4
6
8
10
12
14
16

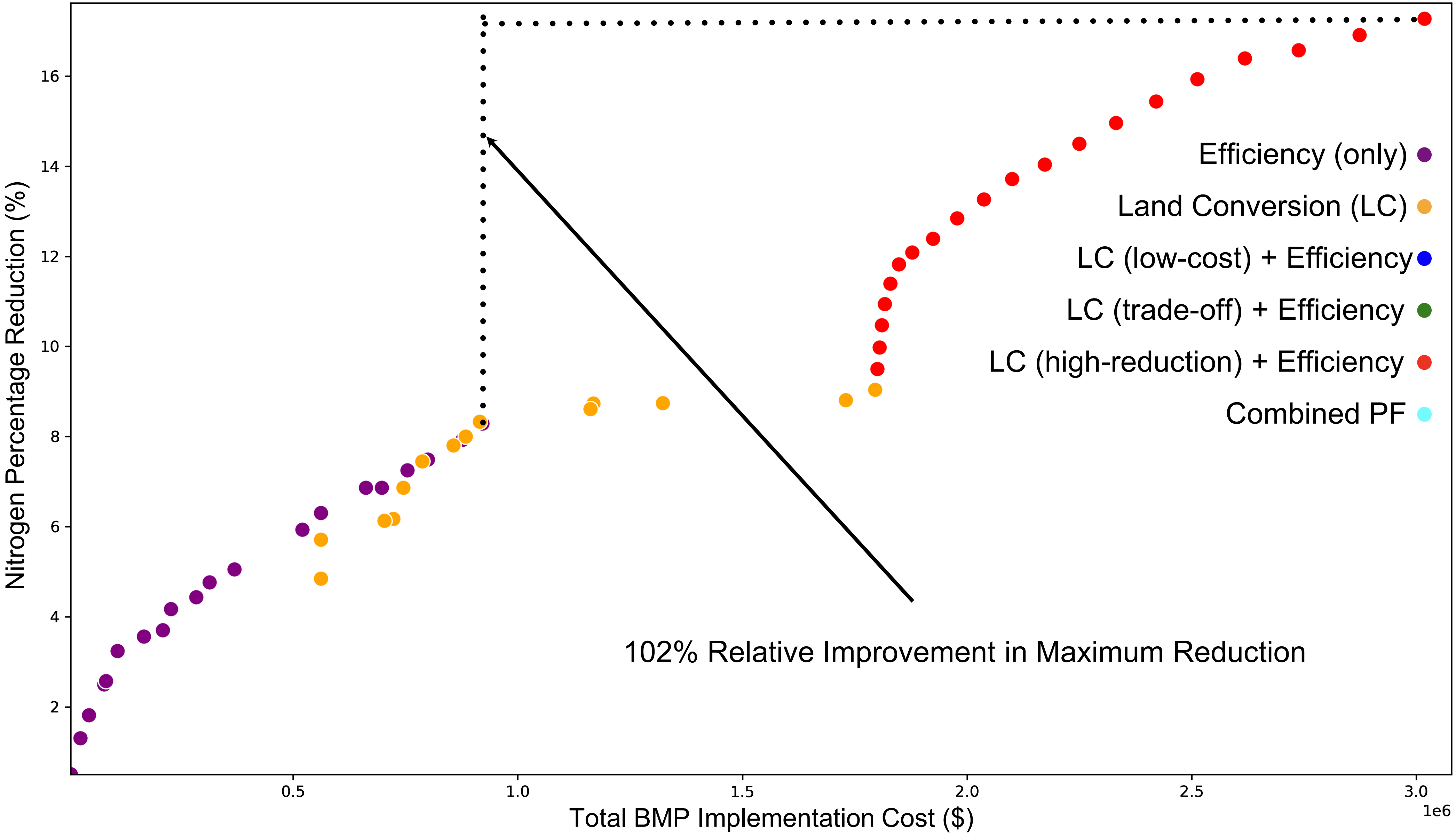

Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
2
4
6
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0



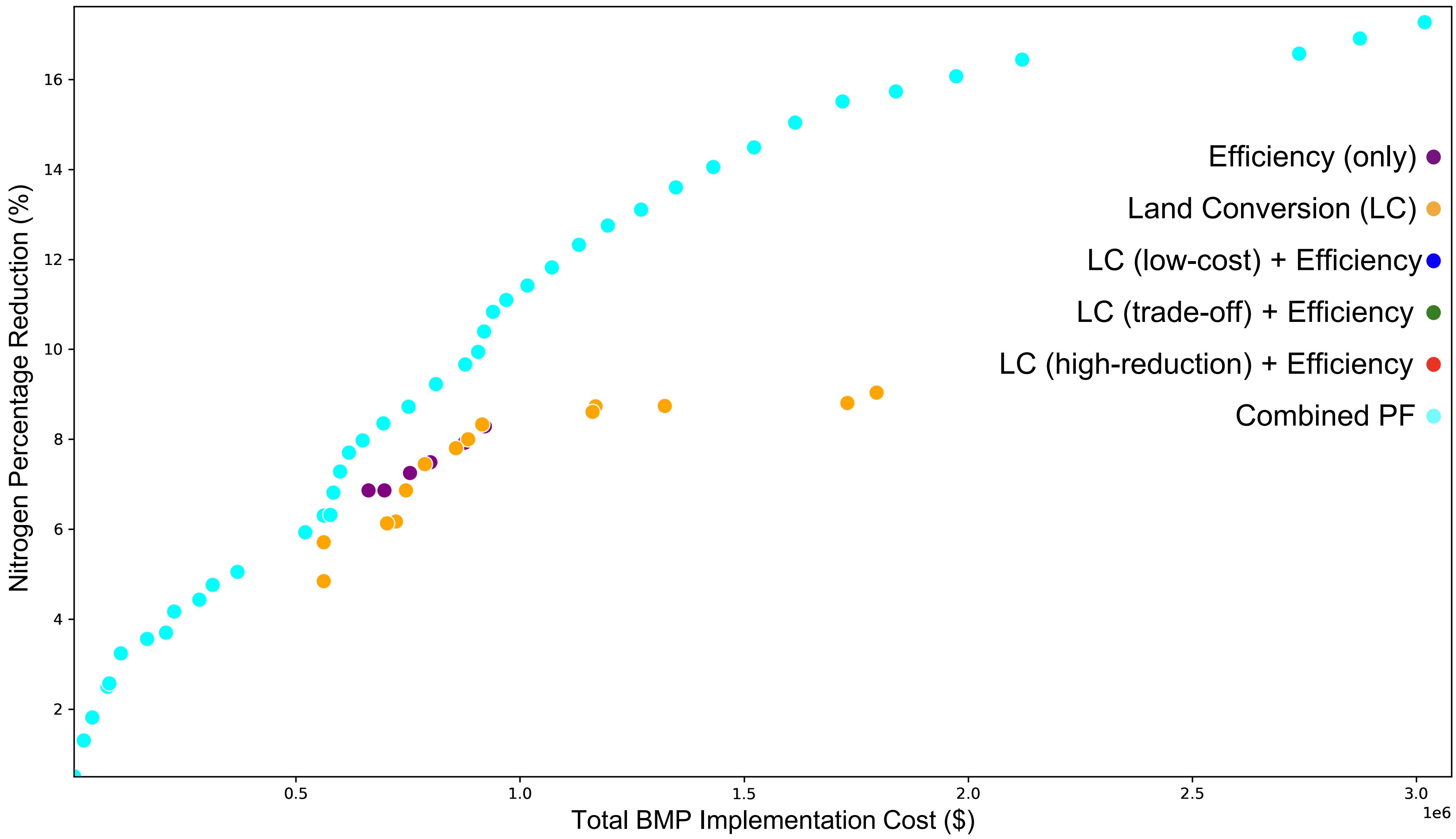
66% Relative Improvement in Maximum Reduction
Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
16
14
12
10
8
6
4
2
0.5
1.0
1.5
2.0
2.5
3.0



97% Relative Improvement in Maximum Reduction
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
0.5
1.0
1.5
2.0
2.5
3.0
2
4
6
8
10
12
14
16
Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF



Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
2
4
6
8
10
12
14
16
0.5
1.0
1.5
2.0
2.5
3.0
Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF
102% Relative Improvement in Maximum Reduction



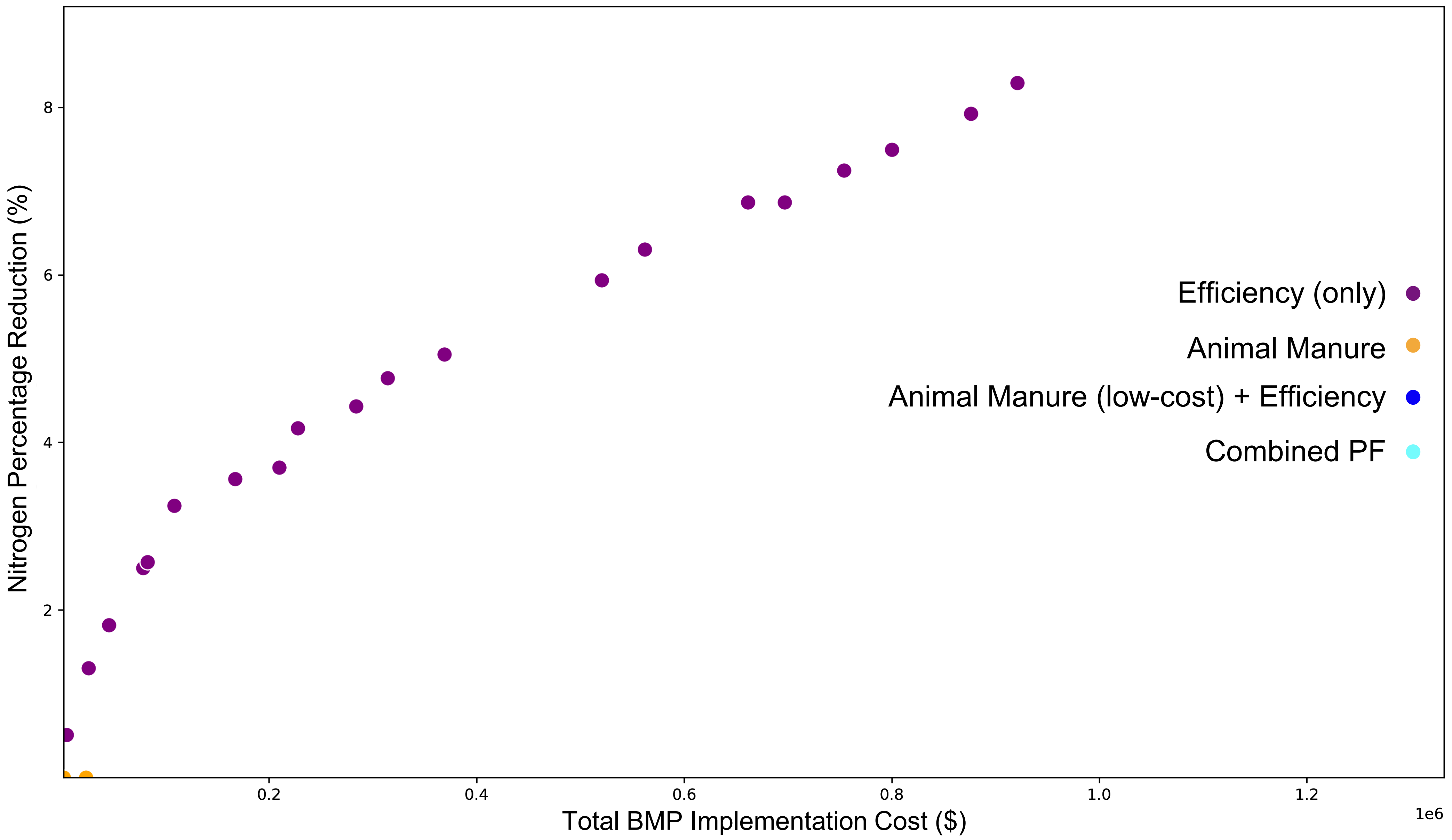
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
Efficiency (only)
Land Conversion (LC)
LC (low-cost) + Efficiency
LC (trade-off) + Efficiency
LC (high-reduction) + Efficiency
Combined PF

Animal Manure BMPs

3

Animal Manure BMPs (Nelson)

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E) →	
Experiment 2	Only Land Conversion BMPs (LS) →	(LS) first, then (E)
Experiment 3	Only Animal Manure (AM) →	(AM) first, then (E)

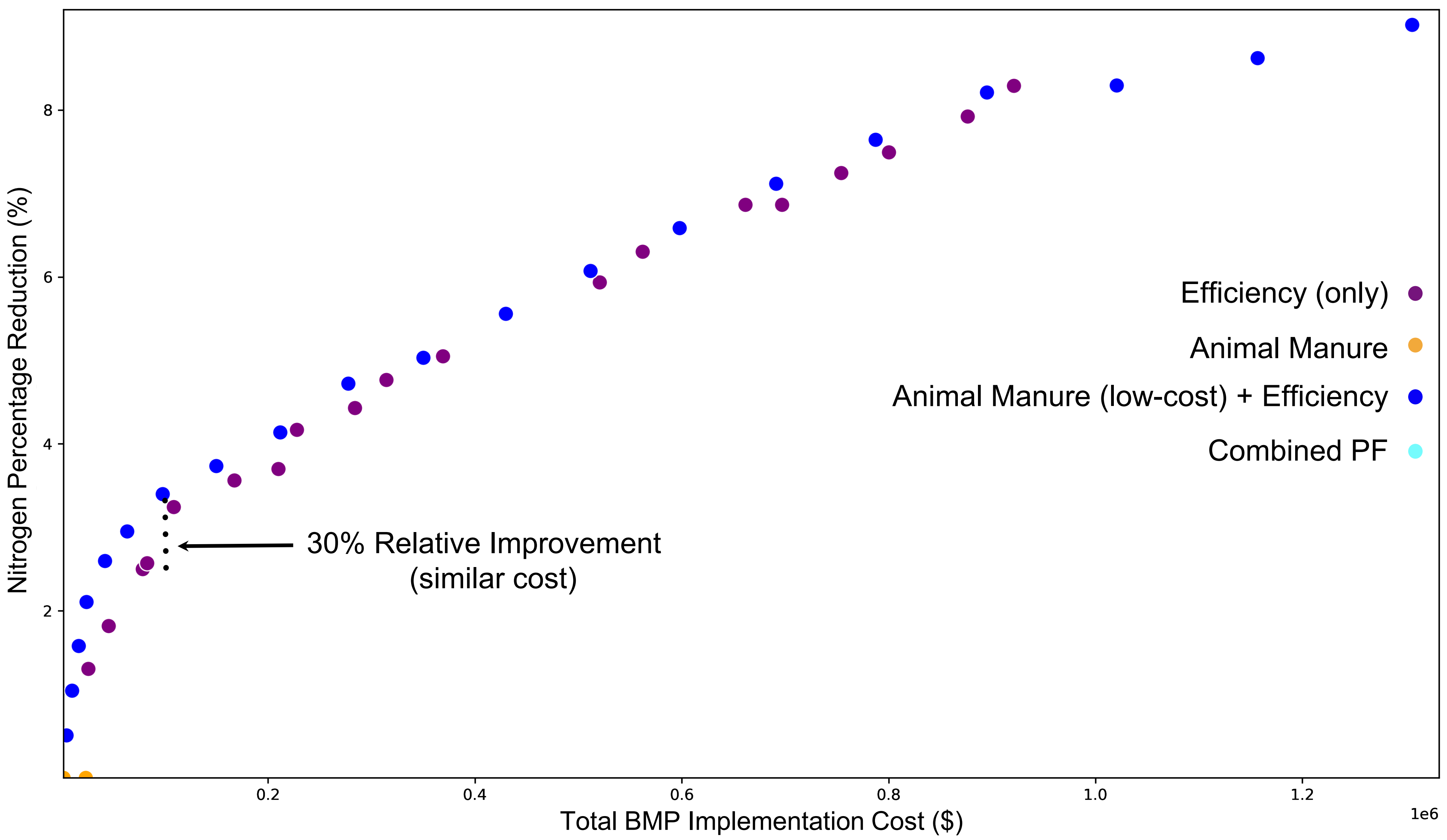


Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
0.2
0.4
0.6
0.8
1.0
1.2
2
4
6
8
Efficiency (only)
Animal Manure
Animal Manure (low-cost) + Efficiency
Combined PF

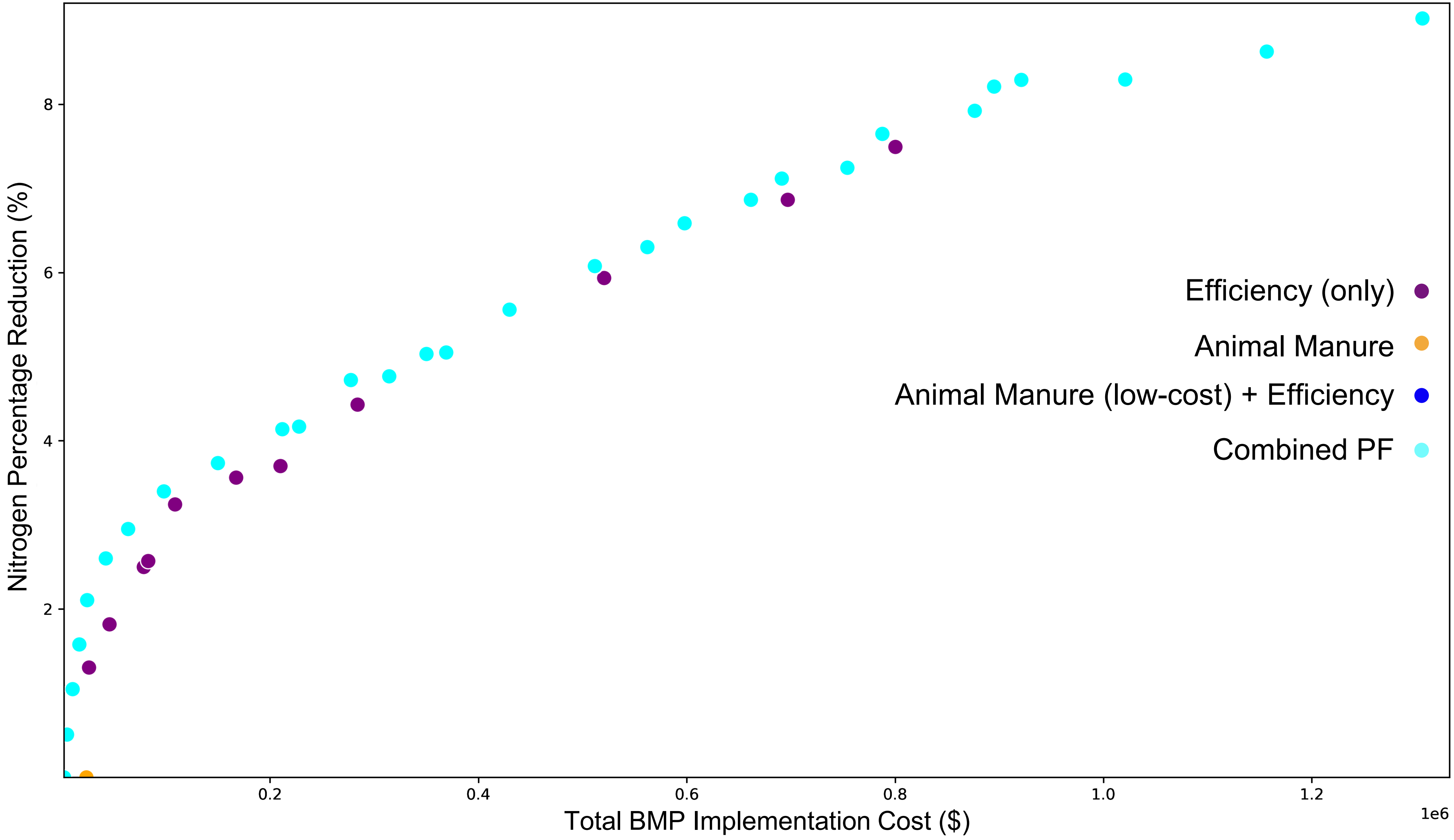
3

Animal Manure and then Efficiency BMPs (Nelson)

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E) →	
Experiment 2	Only Land Conversion BMPs (LS) →	(LS) first, then (E)
Experiment 3	Only Animal Manure (AM) →	(AM) first, then (E)



Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
2
4
6
8
0.2
0.4
0.6
0.8
1.0
1.2
Efficiency (only)
Animal Manure
Animal Manure (low-cost) + Efficiency
Combined PF
30% Relative Improvement
(similar cost)

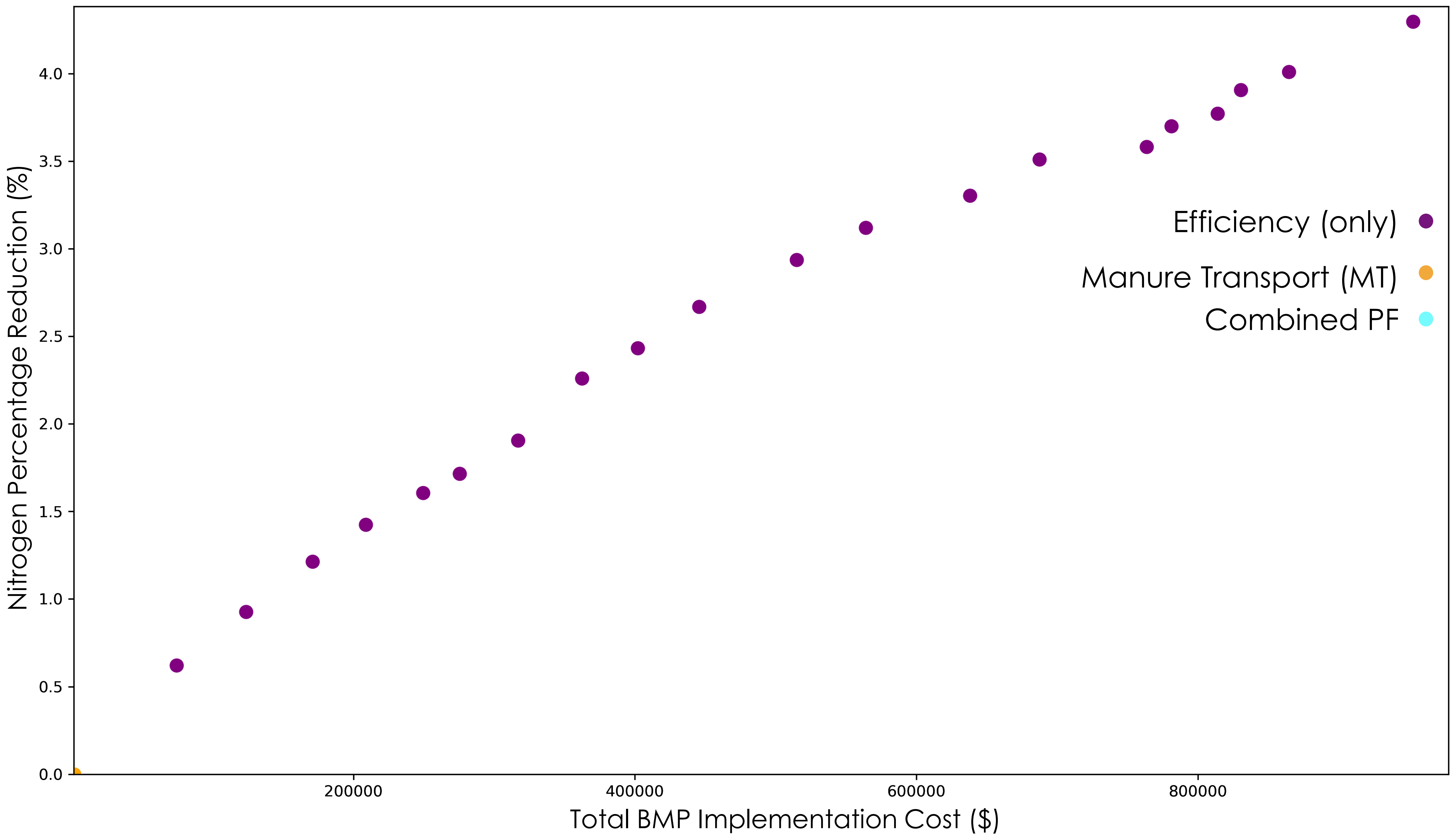

Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
1e6
0.2
0.4
0.6
0.8
1.0
1.2
2
4
6
8
Efficiency (only)
Animal Manure
Animal Manure (low-cost) + Efficiency
Combined PF

4

Manure transport BMPs

4 Manure Transport BMPs (Nelson and neighboring countries)

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E)	
Experiment 2	Only Land Conversion BMPs (LS)	(LS) first, then (E)
Experiment 3	Only Animal Manure (AM)	(AM) first, then (E)
Experiment 4	Only Manure Transport (MT)	(MT) first, then (E)

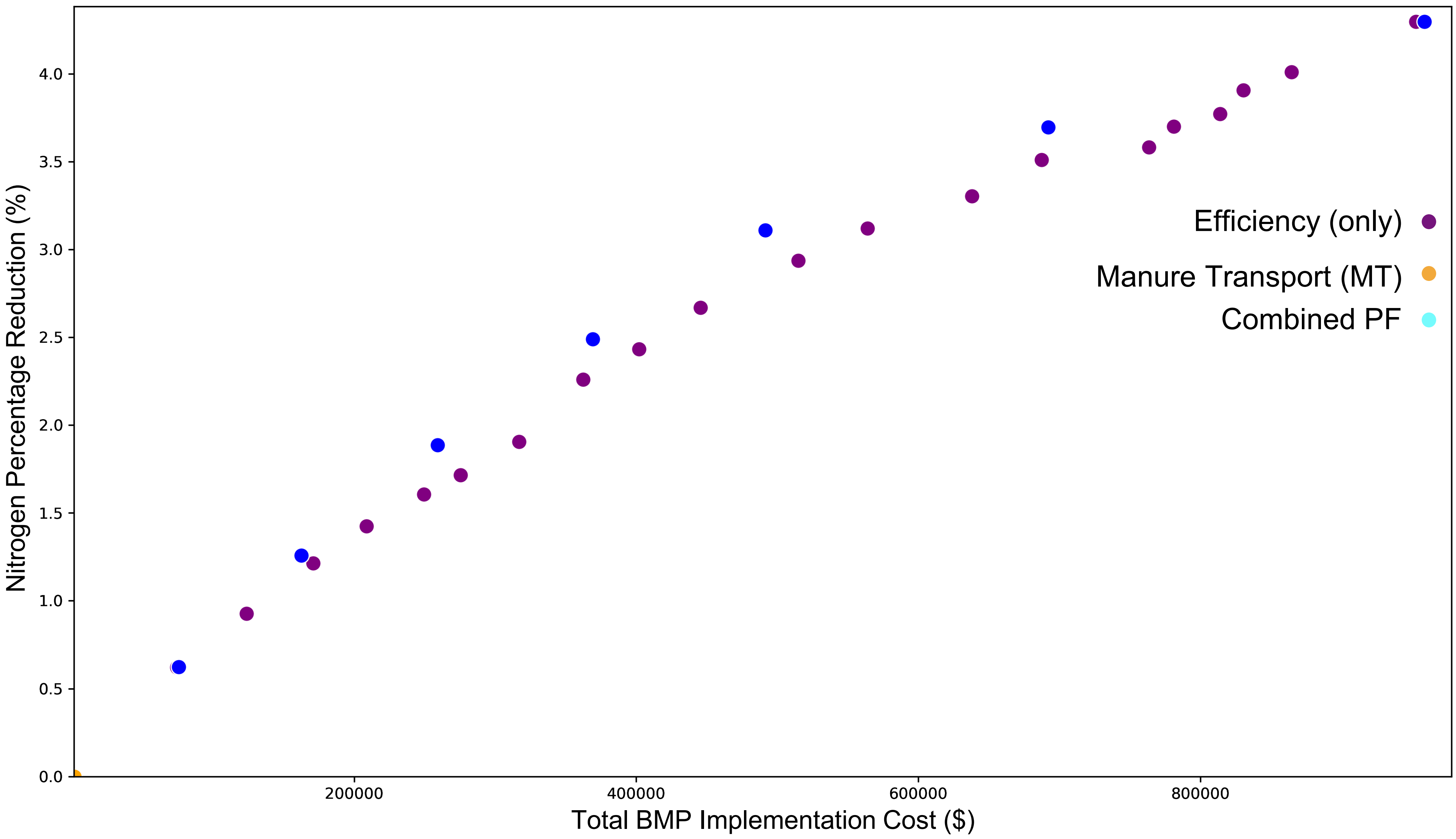


Efficiency (only)
Manure Transport (MT)
Combined PF
Nitrogen Percentage Reduction (%)
Total BMP Implementation Cost ($)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
200000
400000
600000
800000

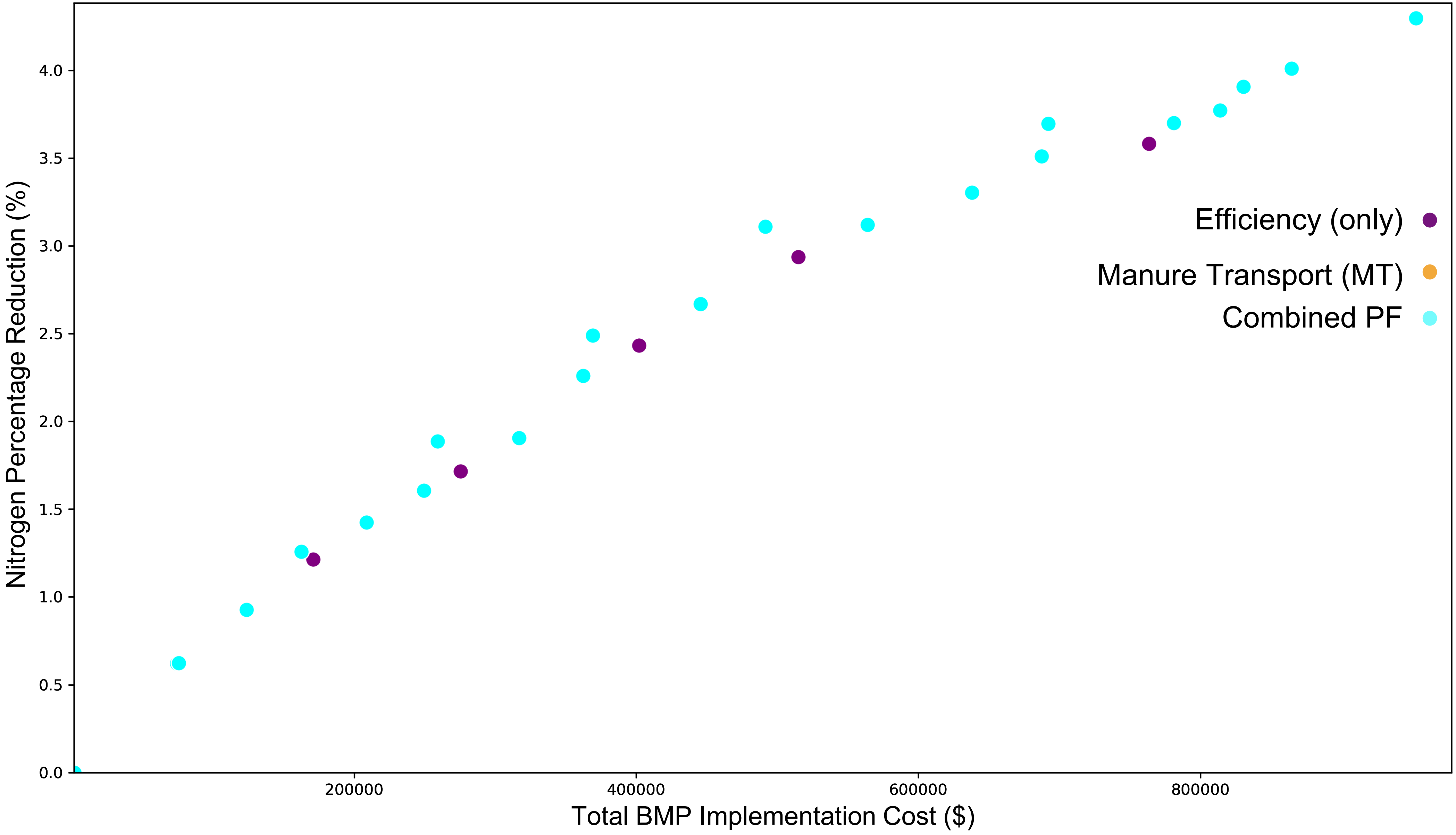
4

Manure Transport BMPs (Nelson and neighboring countries)

	Phase (I)	Phase (II)
Experiment 1	Only Efficiency BMPs (E) →	
Experiment 2	Only Land Conversion BMPs (LS) →	(LS) first, then (E)
Experiment 3	Only Animal Manure (AM) →	(AM) first, then (E)
Experiment 4	Only Manure Transport (MT) →	(MT) first, then (E)



Nitrogen Percentage Reduction (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
200000
400000
600000
800000
Total BMP Implementation Cost ($)
Efficiency (only)
Manure Transport (MT)
Combined PF



Nitrogen Percentage Reduction (%)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
200000
400000
600000
800000
Total BMP Implementation Cost ($)
Efficiency (only)
Manure Transport (MT)
Combined PF

Take home message

- LC BMPs produce a significant reduction in loads
- Animal and manure transport BMPs do not produce good trade-off results
- Mixed optimization produced the best results in our studies

Multi-Criteria Decision Making (MCDM)

Multi-Criteria Decision Making

VIKOR

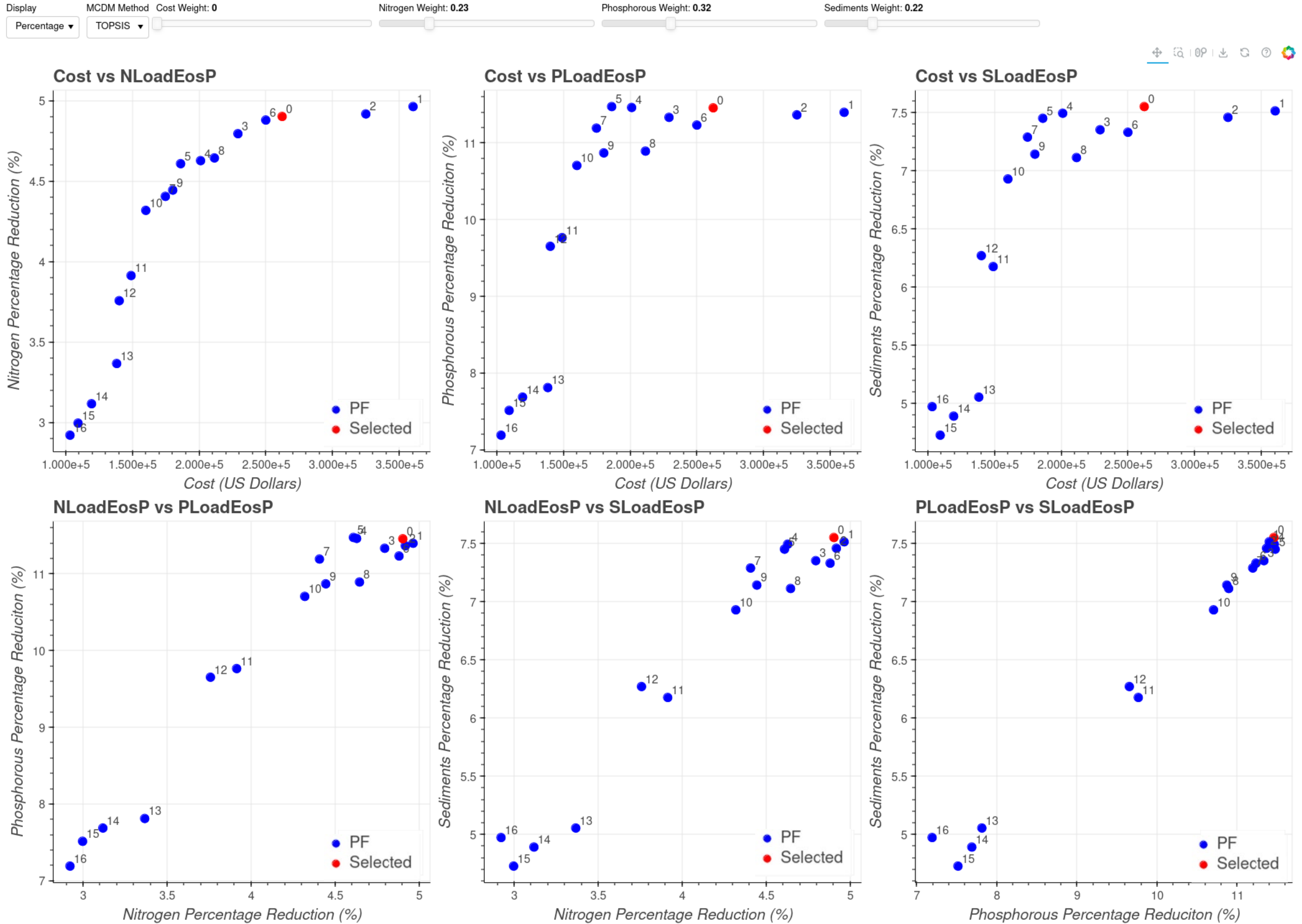
Applications: criteria are conflicting and may have different importance levels

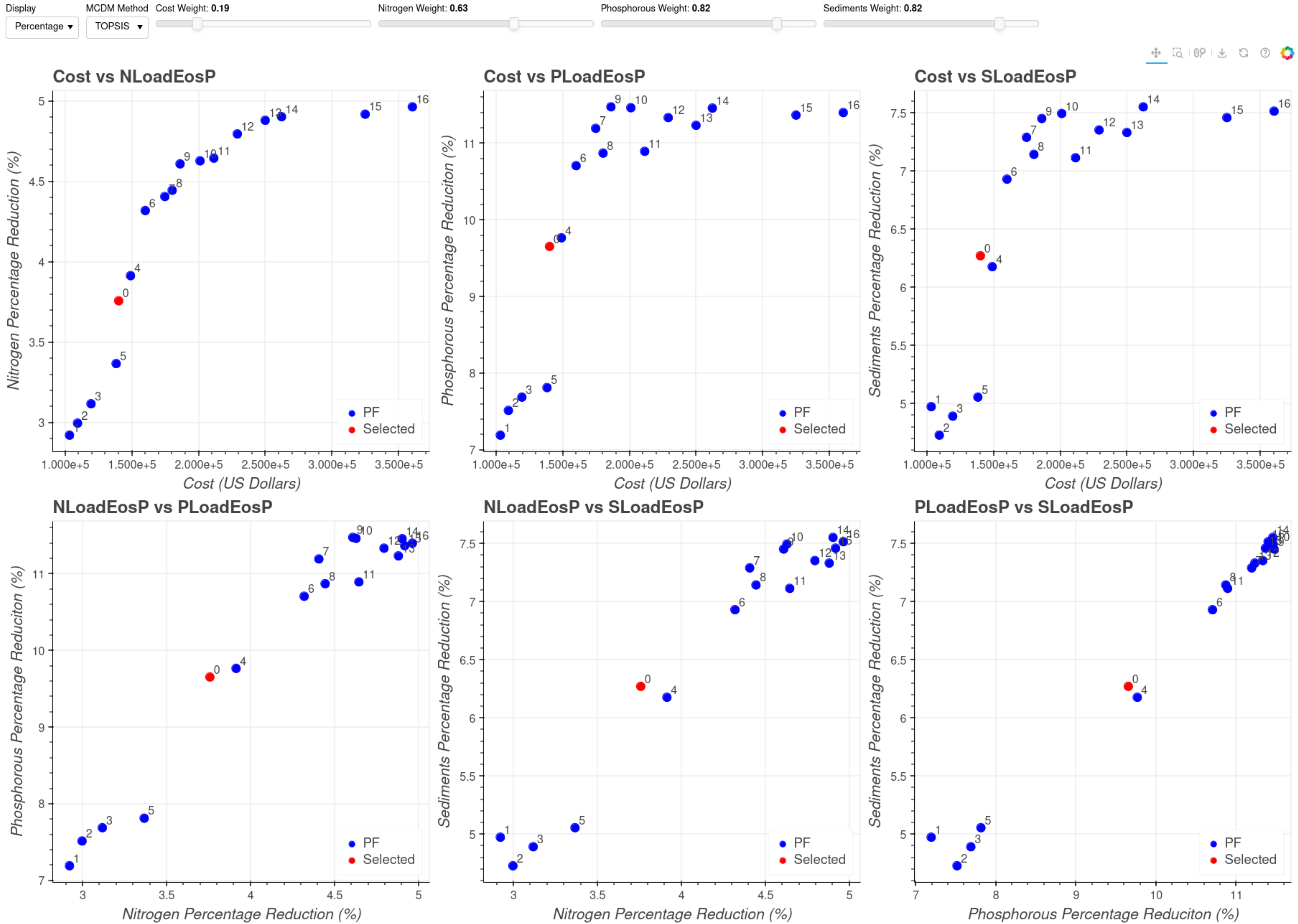
TOPSIS

Applications: rank alternatives based on their proximity to the ideal solution

Nelson County

TOPSIS Method

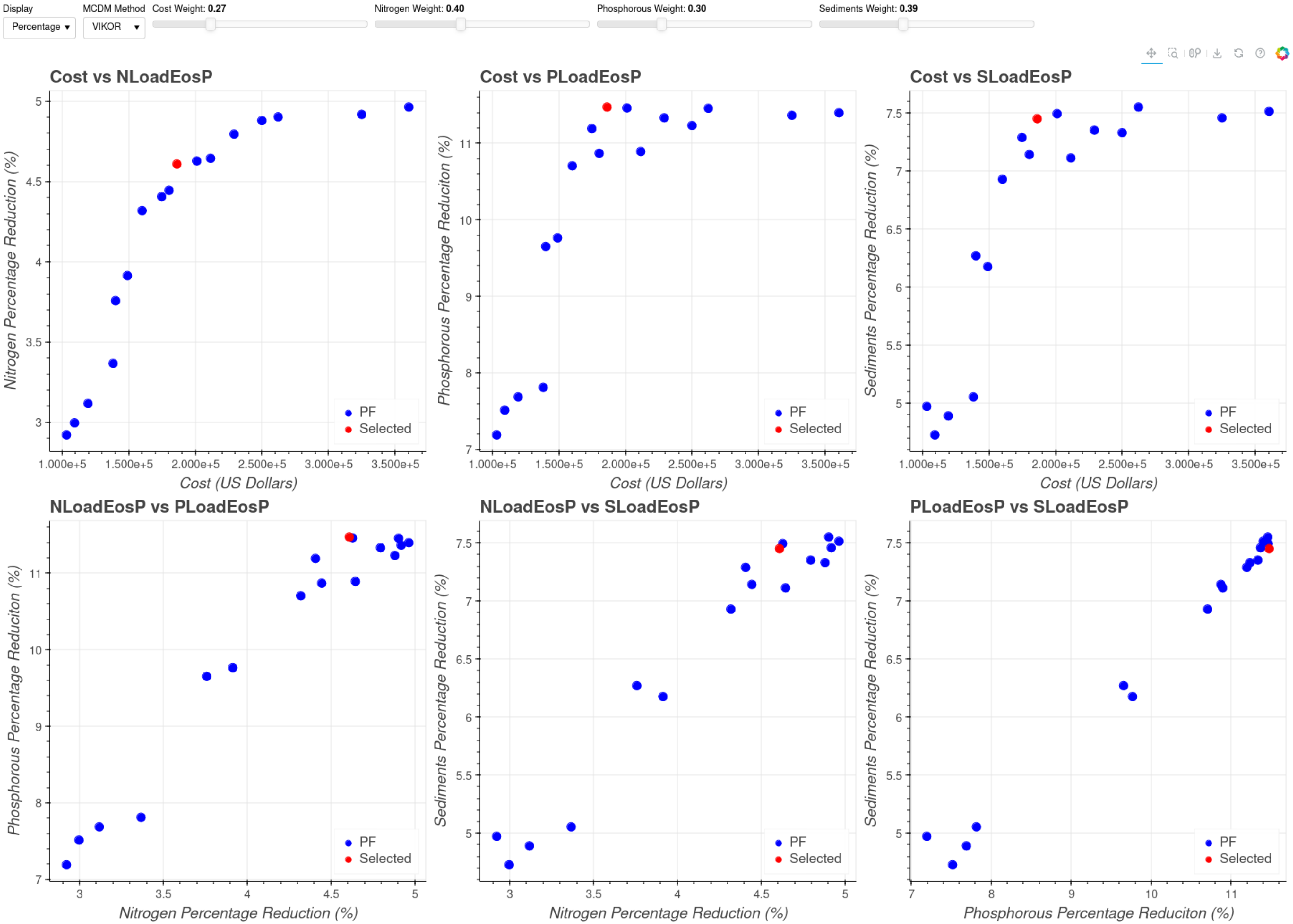

Display
Percentage
MCDM Method
TOPSIS
Cost Weight: 0
Nitrogen Weight: 0.23
Phosphorous Weight: 0.32
Sediments Weight: 0.22
Cost vs NLoadEosP
Nitrogen Percentage Reduction (%)
Cost (US Dollars)
Cost vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Cost (US Dollars)
Cost vs SLoadEosP
Sediments Percentage Reduction (%)
Cost (US Dollars)
NLoadEosP vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Nitrogen Percentage Reduction (%)
NLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Nitrogen Percentage Reduction (%)
PLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Phosphorous Percentage Reduciton (%)
PF
Selected

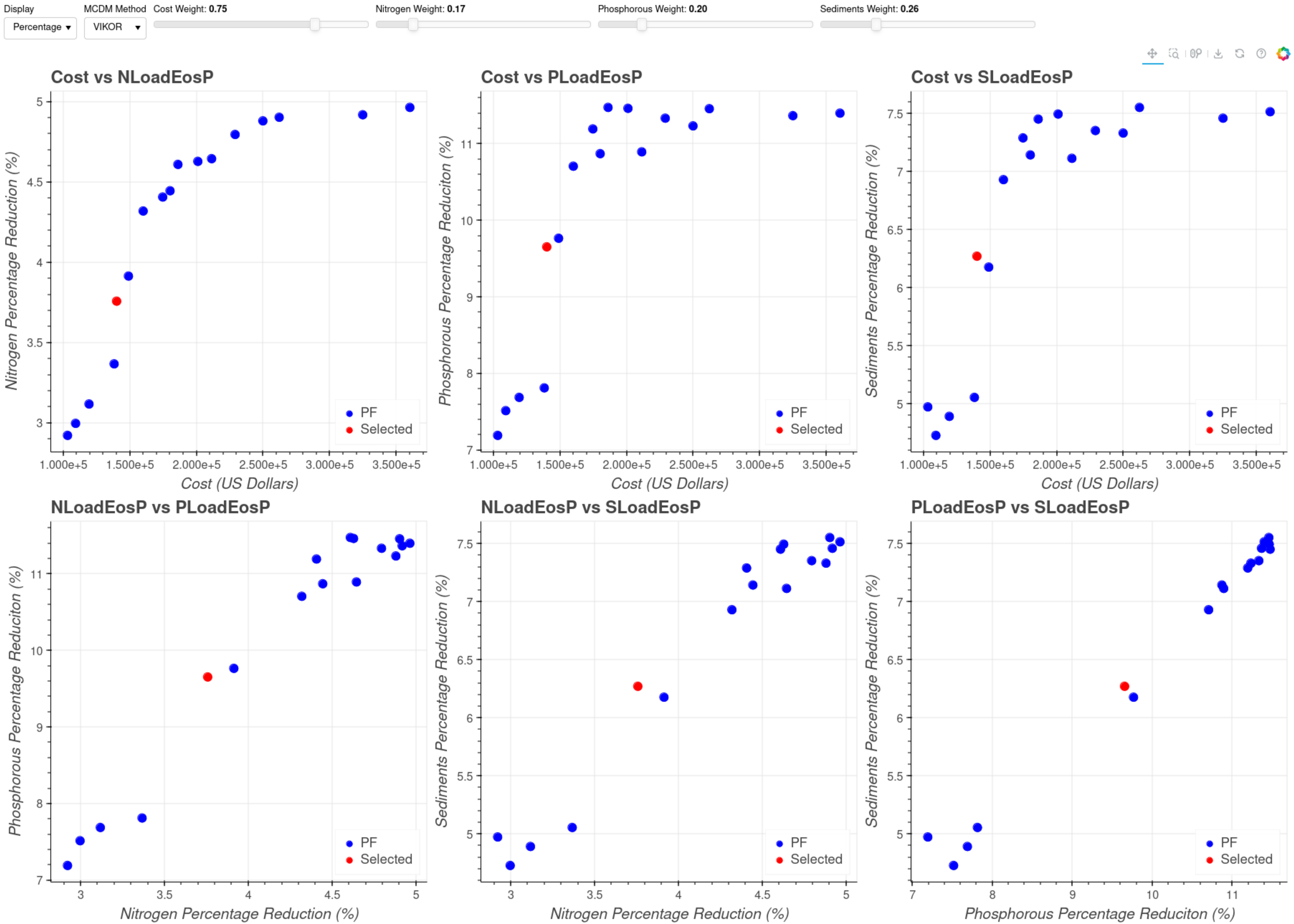


Display
Percentage
MCDM Method
TOPSIS
Cost Weight: 0.19
Nitrogen Weight: 0.63
Phosphorous Weight: 0.82
Sediments Weight: 0.82
Cost vs NLoadEosP
Nitrogen Percentage Reduction (%)
Cost (US Dollars)
Cost vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Cost (US Dollars)
Cost vs SLoadEosP
Sediments Percentage Reduction (%)
Cost (US Dollars)
NLoadEosP vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Nitrogen Percentage Reduction (%)
NLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Nitrogen Percentage Reduction (%)
PLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Phosphorous Percentage Reduciton (%)
PF
Selected

Nelson County

VIKOR Method


Display
Percentage
MCDM Method
VIKOR
Cost Weight: 0.27
Nitrogen Weight: 0.40
Phosphorous Weight: 0.30
Sediments Weight: 0.39
Cost vs NLoadEosP
Nitrogen Percentage Reduction (%)
Cost (US Dollars)
Cost vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Cost (US Dollars)
Cost vs SLoadEosP
Sediments Percentage Reduction (%)
Cost (US Dollars)
NLoadEosP vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Nitrogen Percentage Reduction (%)
NLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Nitrogen Percentage Reduction (%)
PLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Phosphorous Percentage Reduciton (%)
PF
Selected



Display
Percentage
MCDM Method
VIKOR
Cost Weight: 0.75
Nitrogen Weight: 0.17
Phosphorous Weight: 0.20
Sediments Weight: 0.26
Cost vs NLoadEosP
Nitrogen Percentage Reduction (%)
Cost (US Dollars)
Cost vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Cost (US Dollars)
Cost vs SLoadEosP
Sediments Percentage Reduction (%)
Cost (US Dollars)
NLoadEosP vs PLoadEosP
Phosphorous Percentage Reduciton (%)
Nitrogen Percentage Reduction (%)
NLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Nitrogen Percentage Reduction (%)
PLoadEosP vs SLoadEosP
Sediments Percentage Reduction (%)
Phosphorous Percentage Reduciton (%)
PF
Selected

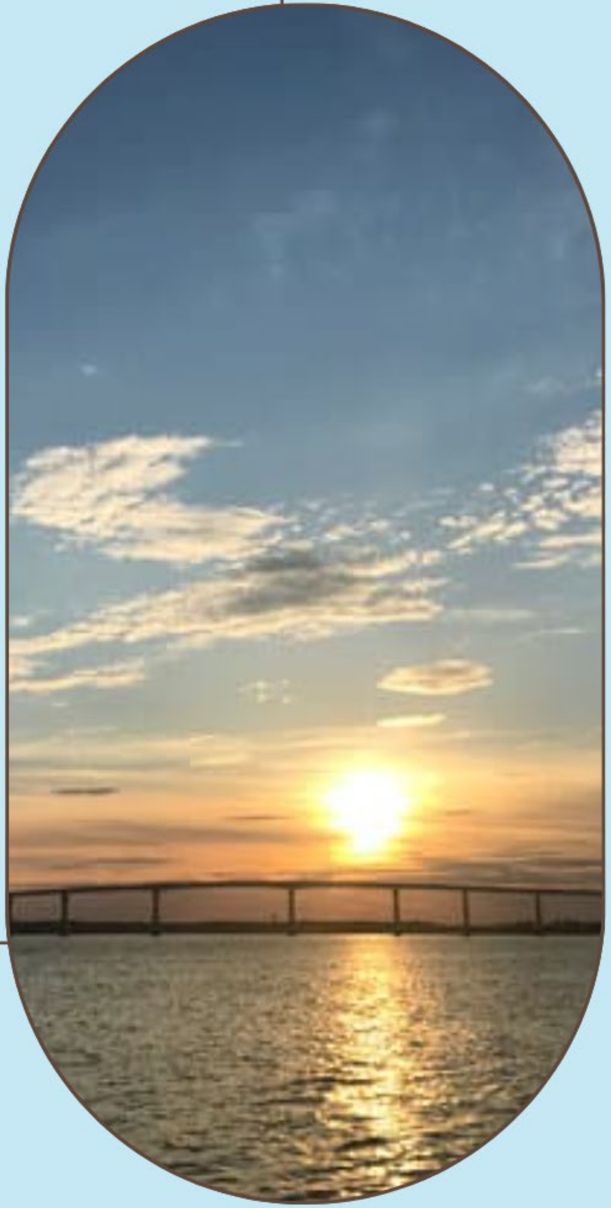
Multi-Criteria Decision Making Tool

NEXT STEP

- Interactive Optimization-Decision making
- Extensions to more counties and states
- Validation of our results on some critical county/state cases
- Parallel computing platform for faster execution
- Uncertainty and other practicality handling
- Workshops with CBP users for feedback and improvement of our approaches

Chesapeake Bay Optimization Webinars

Join experts in the discussion of bay preservation.



2024 Chesapeake Bay Optimization Webinars

Objective:

* Raise awareness about our BMP optimization framework.
* Train users and practitioners to use the framework to optimize real-world scenarios.

Features:

* Interactive show of the framework capabilities
* Interactive Q&A sessions

Benefits:

* Enhanced decision-making
* Foster community collaborations
* Efficient BMP implementations
* Feedback

MICHIGAN STATE
UNIVERSITY

Computational Optimization and Innovation

Thank you

C-ECO

Computational Ecohydrology