Modeling Workgroup Meeting Quarterly Review

Optimization update: Progress on Multi-objective methods and Land-Conversion BMPs

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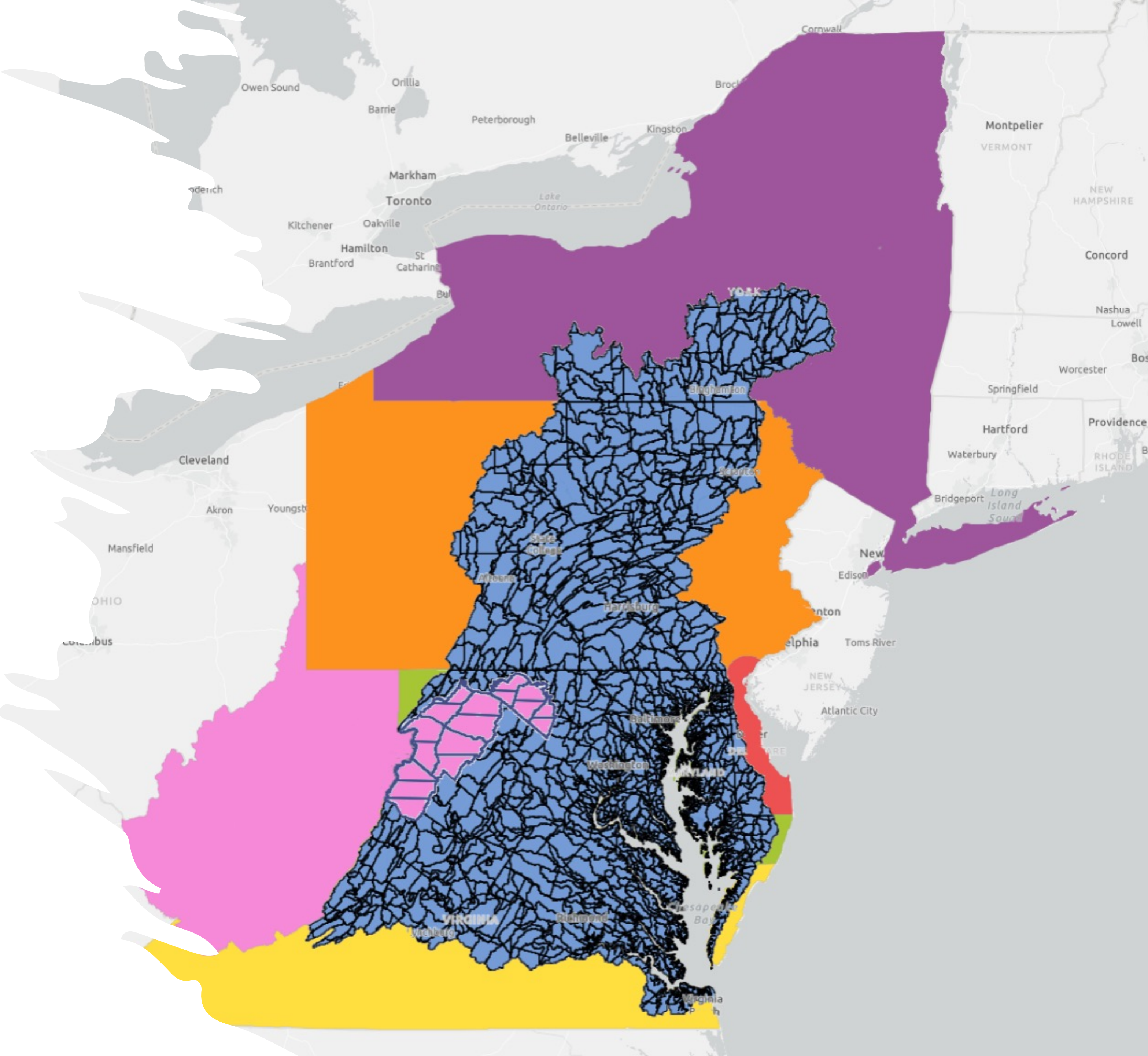
Agenda

- Objective 2: Development of Efficient Multi-objective Optimization Procedures e
  - Oct 1, 2021 to December 31, 2023 (18 months)
- Current Accomplishments:
  1) Multiobjective-based approach (**Opt6**)
     1) Presentation of article at WCCI’2022
     2) Visualization plots
  2) New added BMPs (Land Conversion)
- Next Steps:
  1) Remaining BMPs
  2) Decision Making

Algorithm Developed

- **Mathematical Optimization Algorithm** (IPOpt)
- Generic **Population-Based Optimization** (Genetic Algorithm)
- IPOpt + C++ (rewritten in C++, compute of derivatives and Jacobians).
- IPOpt + Smart Initialization
- **Scalarization-based optimization** (Epsilon Constraint).
- Epsilon Constraint + **Multi-objective Optimization** (NSGA-III)
- Epsilon Constraint + NSGA-III + new BMPs

Study area: West Virginia



Variables and Constraints of West Virginia counties

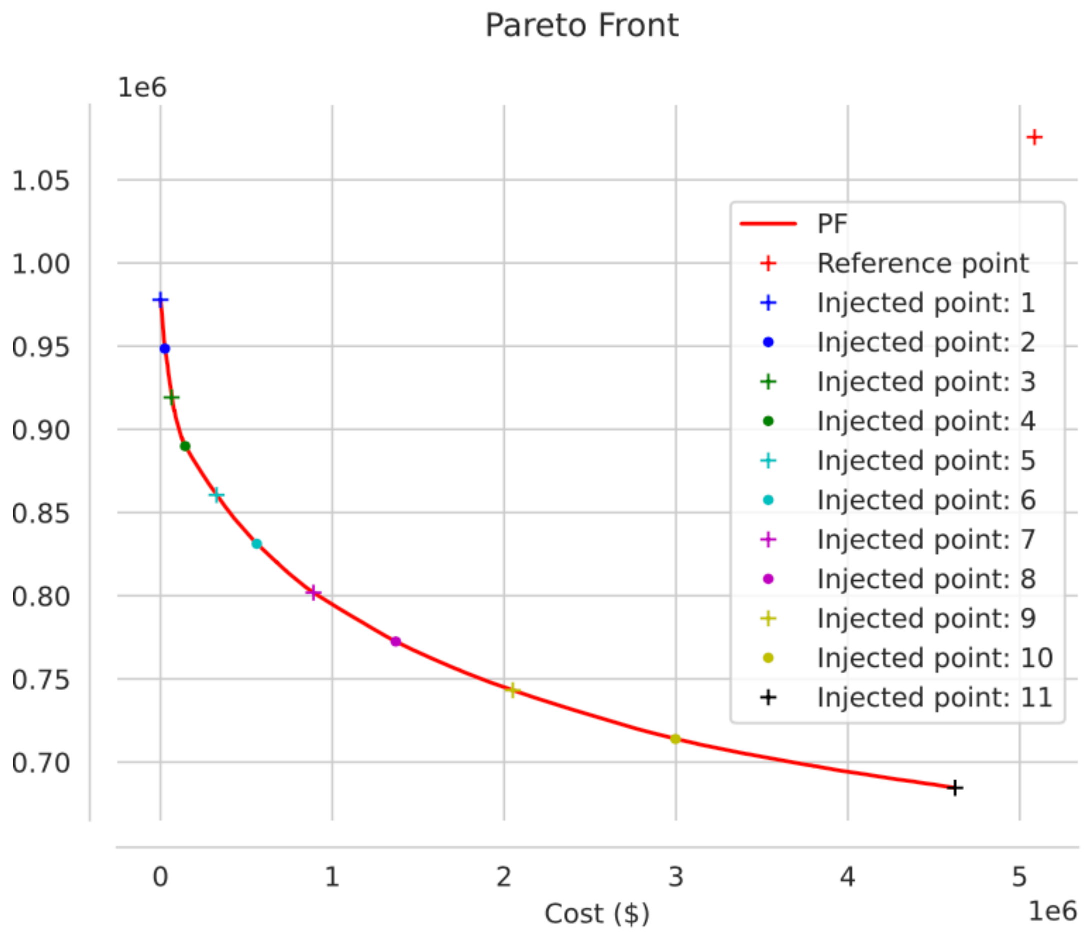
County	#Variables	#Constraints	Base N_2 (f_2^{base})
Berkeley	14,090	1,813	977,896
Grant	25,228	3,448	1,049,450
Hampshire	12,783	1,700	1,012,797
Hardy	18,607	2,491	1,344,295
Jefferson	12,303	1,606	1,018,012
Mineral	20,260	2,698	763,864
Monroe	3,102	399	48,655
Morgan	11,880	1,665	271,134
Pendleton	33,083	4,352	1,133,327
Preston	1,470	193	4,683
Tucker	1,012	144	1,702
Total	153,818	20,509	7,625,818

Experiments performed using the NSGA-III

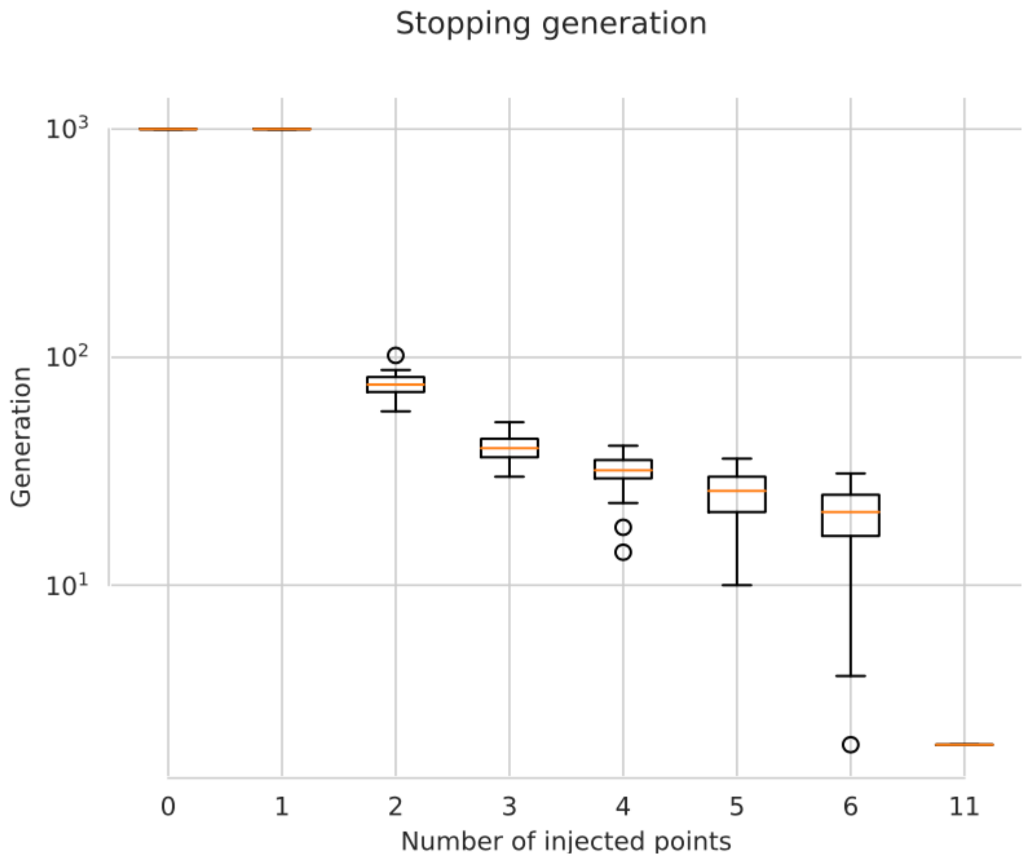
- Experiment 1: Knowledge incorporation through solution injection in the initial population.
- Experiment 2: Reduction of constraints with a repair approach.
- Experiment 3: Scale-up study.
- Experiment 4: Deciphering common patterns of BMP allocation in final trade-off solutions.

Experiment I: Knowledge Incorporation

- EAs can take advantage of knowledge incorporation
- 11 independent executions of the ε-constraint approach.
- ε from 0% to 30% nitrogen reduction (inclusive), using 3% of step size.
- The search method uses the IPOPT, an interior-point-based optimization method widely used on many real-world applications.



Example of injection points on Berkeley county

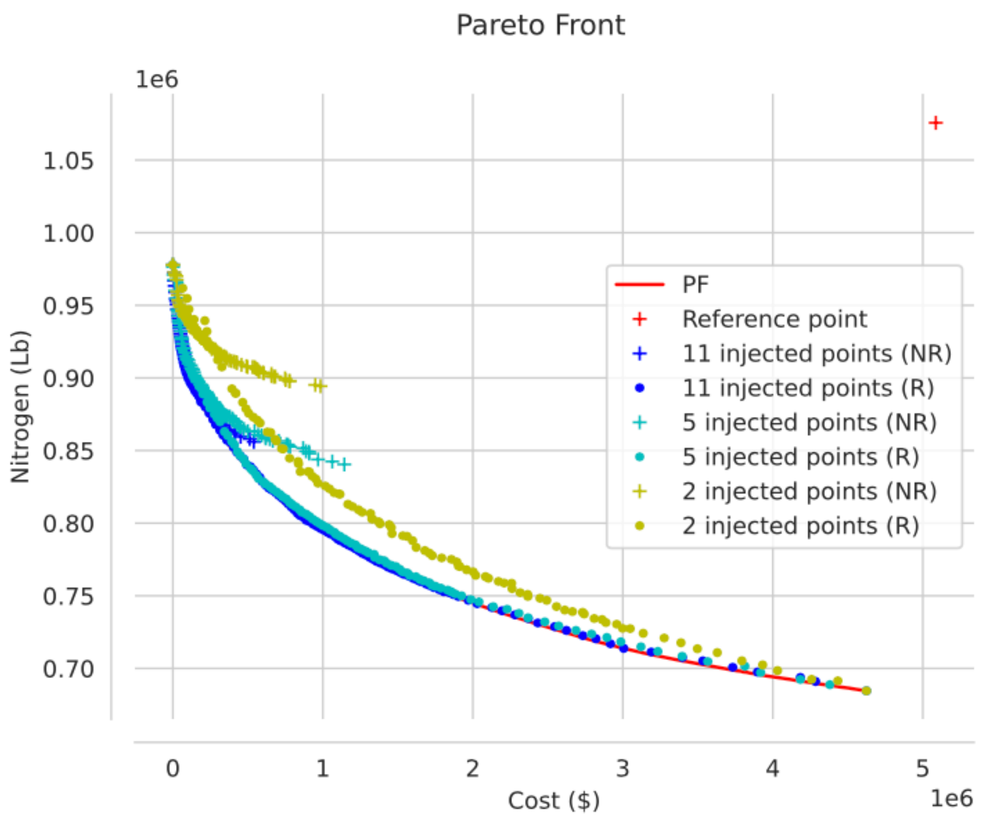


Experiment I: Results of Point Injection

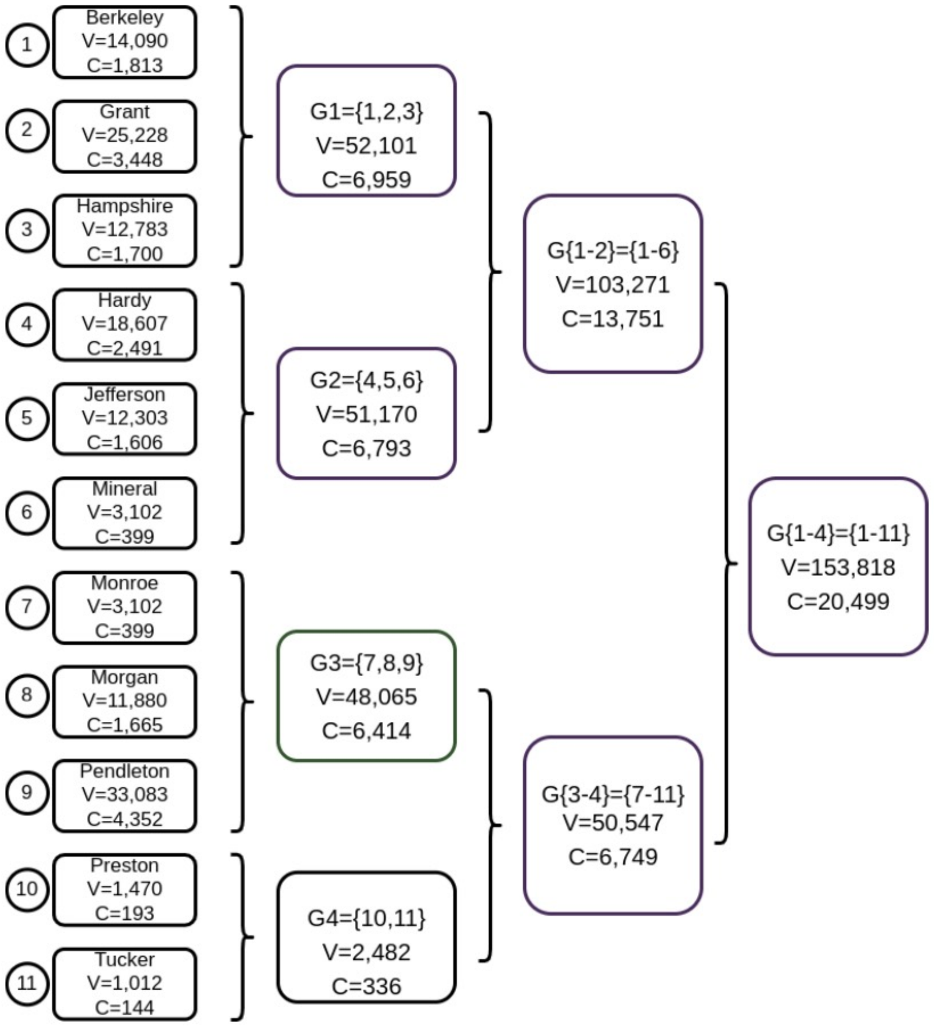
- Results indicate that some counties required as low as two injected points into the NSGA-III to improve the results
- Although results gets better with more injected solutions, the improvement is almost imperceptible on few occasions.
- 11 points (it reached 90% of the PF's HV using a low number of generations).

Experiment 2: Repair Operator

- Constraints add an extra burden to the optimization process.
- When we eliminate the constraints and let the NSGA-III work on a feasible search space, it can produce significantly better results.
- Repair operator improves the NSGA-III performance.



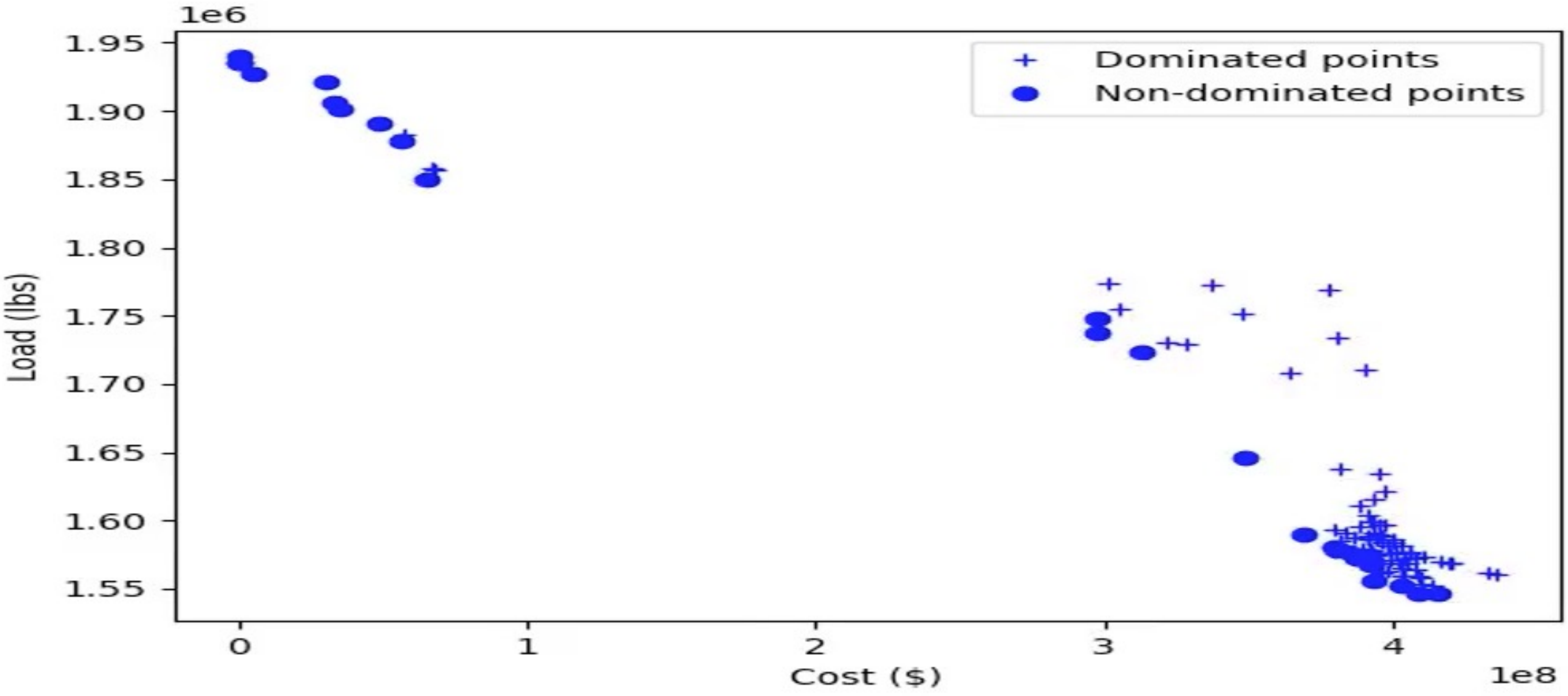
Berkeley County: Not repair (NR) vs. repair operator (R). operator helps in reaching a more diverse set of points.



Experiment 3: Scale-up Study

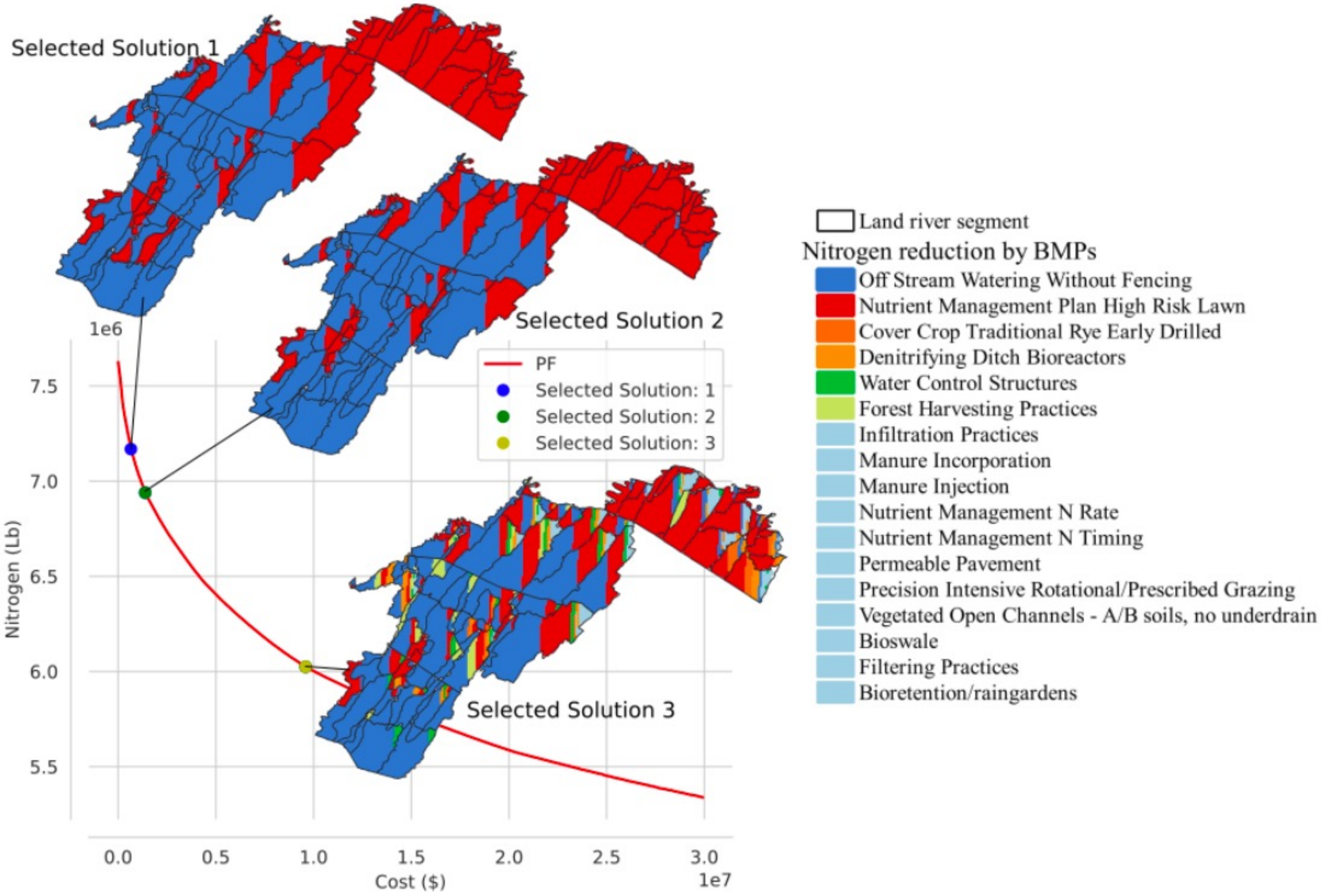
1. Use the agglomerating approach for the scaling.
2. Four groups of scaling are considered.
3. Finally, we solve one problem with all the counties together. The number of variables varies from 1,012 to a staggering 153,818.

Convergence plot



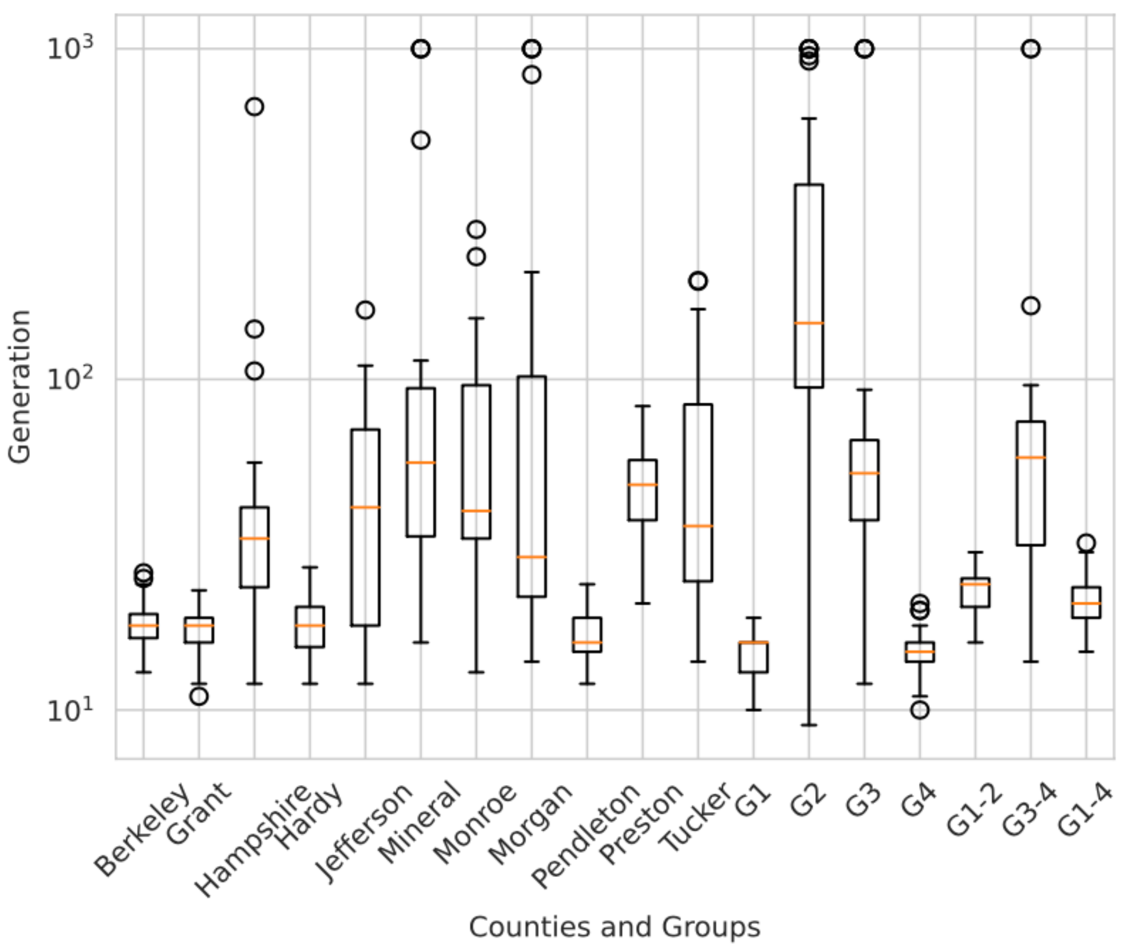
Obtained solutions

- Initial solution utilizes almost every BMP in every LRS by every agency and every load source. Such a solution is usually not cost-effective and challenging from the implementation point of view.
- The injected points show a bias, where 90% of the variables have a negligible value across the population.
- Such a bias helped NSGA-III to start its search in a better way.

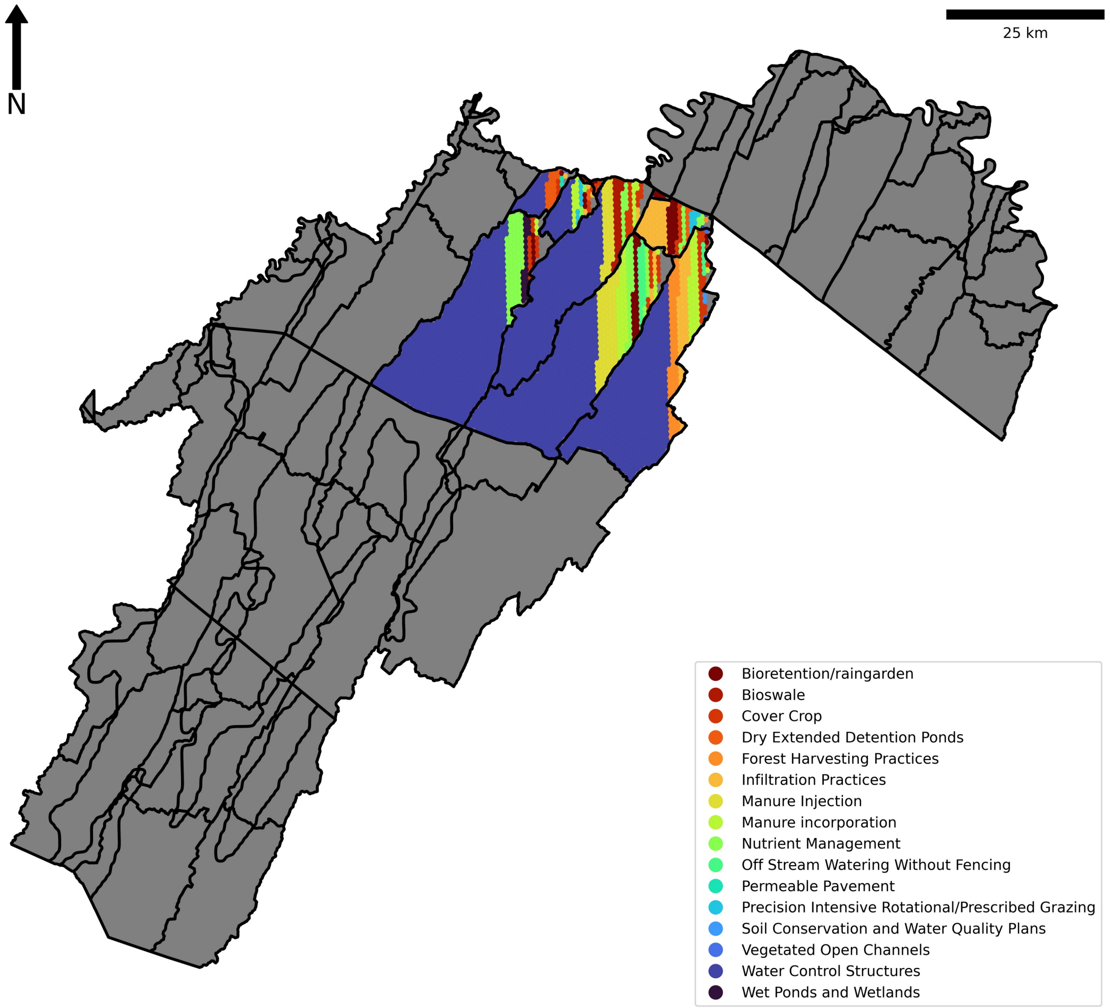


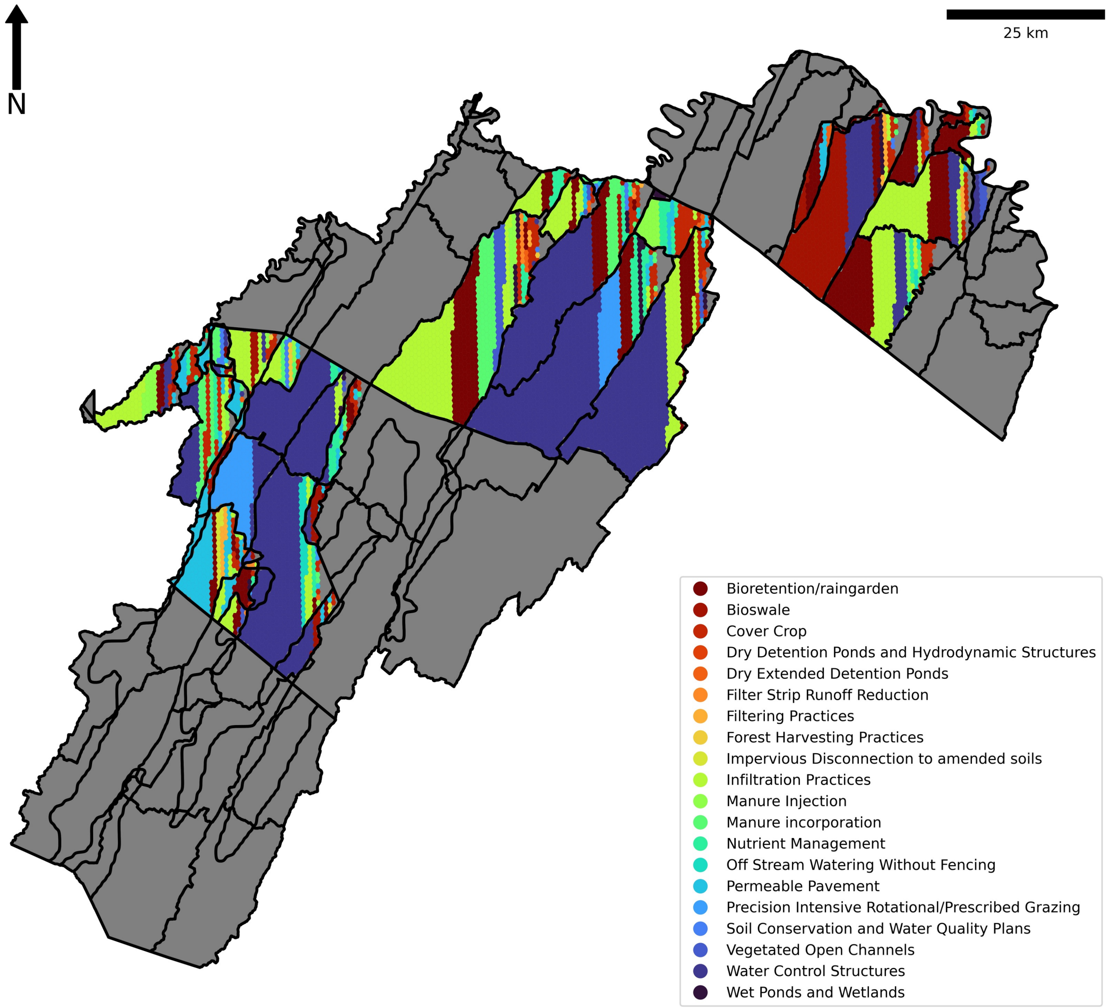
Results of our Scale-up Study

- The problem becomes more challenging as the targeting areas are scarce.
- The problem starts relaxing with enough target areas to apply BMPs (i.e., when we grouped different counties).
- Hampshire is difficult to solve, but when Berkeley and Grant are added, the problem becomes more accessible as NSGA-III.
- Hampshire country demography makes challenging the nitrogen reduction, the addition of neighboring counties takes the load and helps solve the combined problem faster.
- Our proposed NSGA-III approach behaved remarkable and shows promise to be applied to multiple counties to the watershed level.



Independent vs Group Optimization





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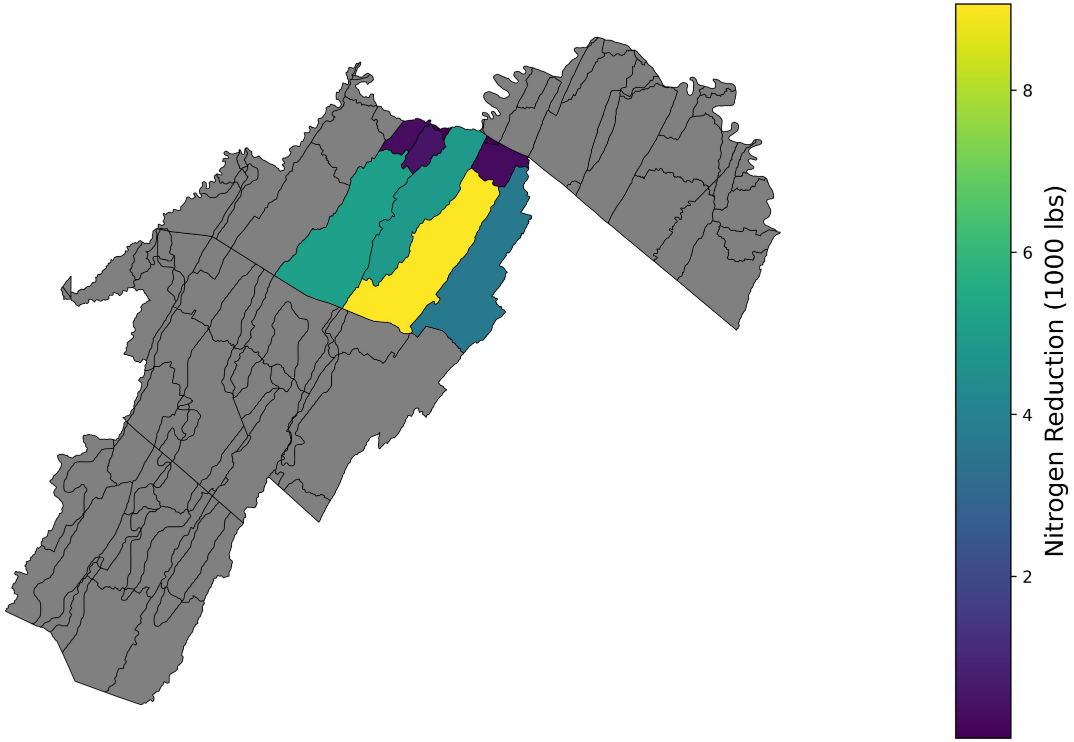
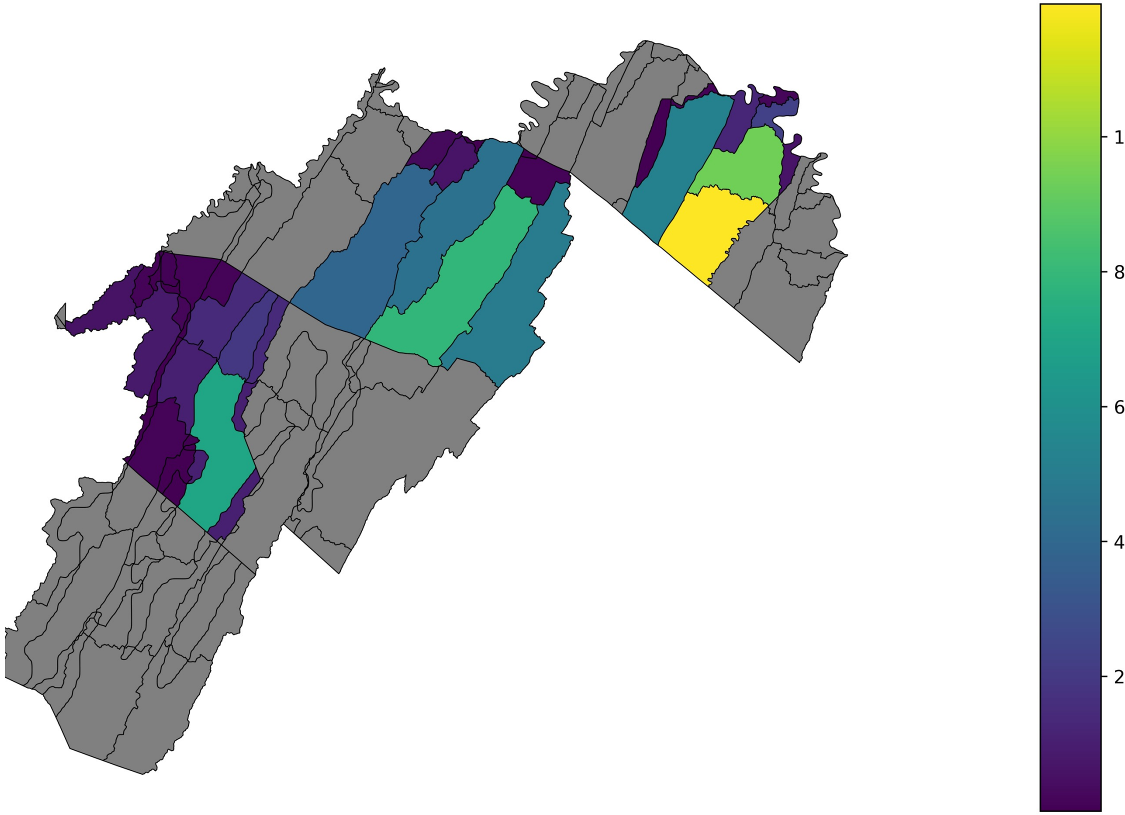
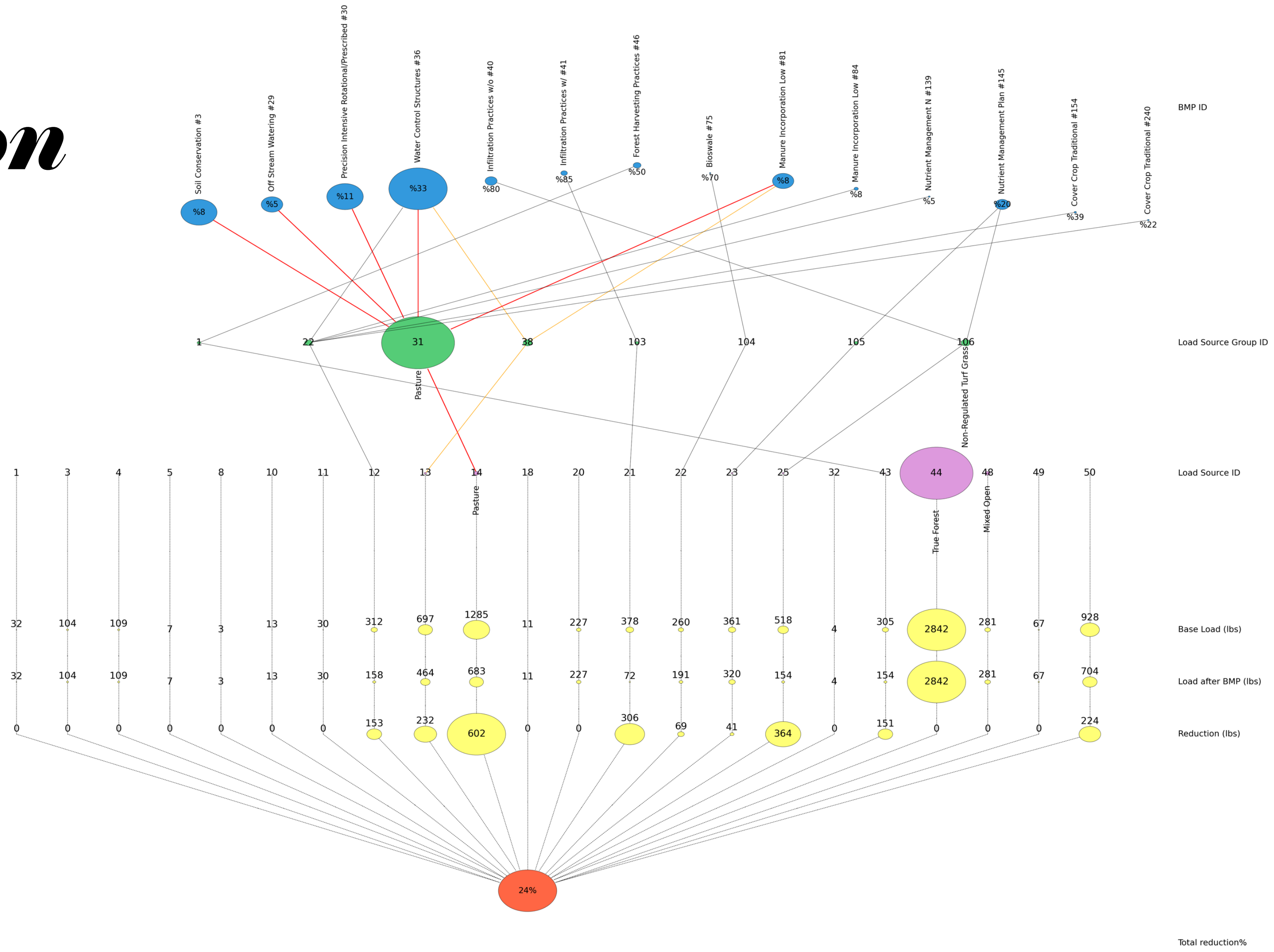


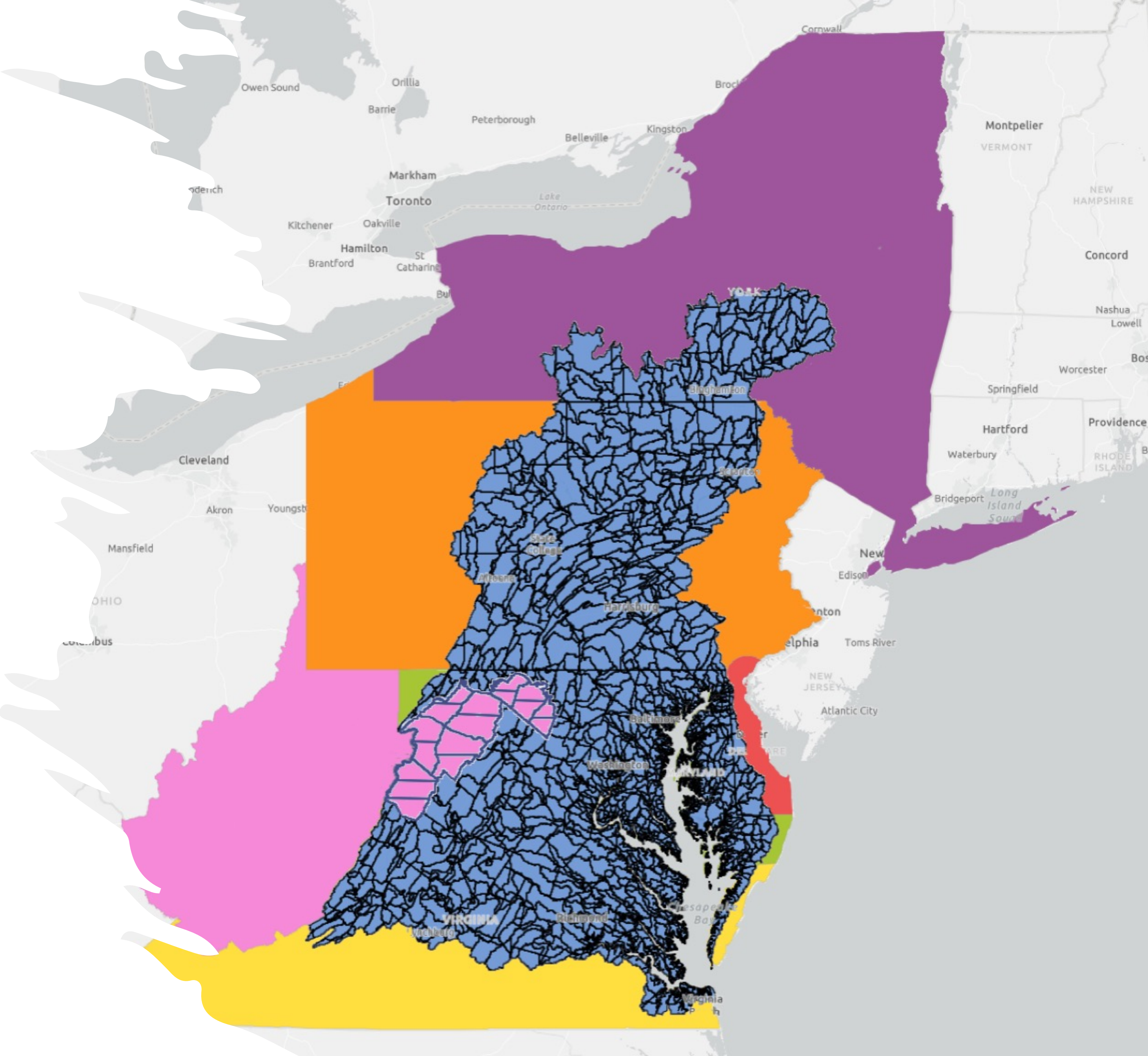


New Visualization Tool



Study recognition

- Presentation of article: **Large-scale Multi-objective Optimization for Water Quality in Chesapeake Bay Watershed**
- IEEE World Congress on Computational Intelligence
- **Best Paper Award** Nomination



PART 2

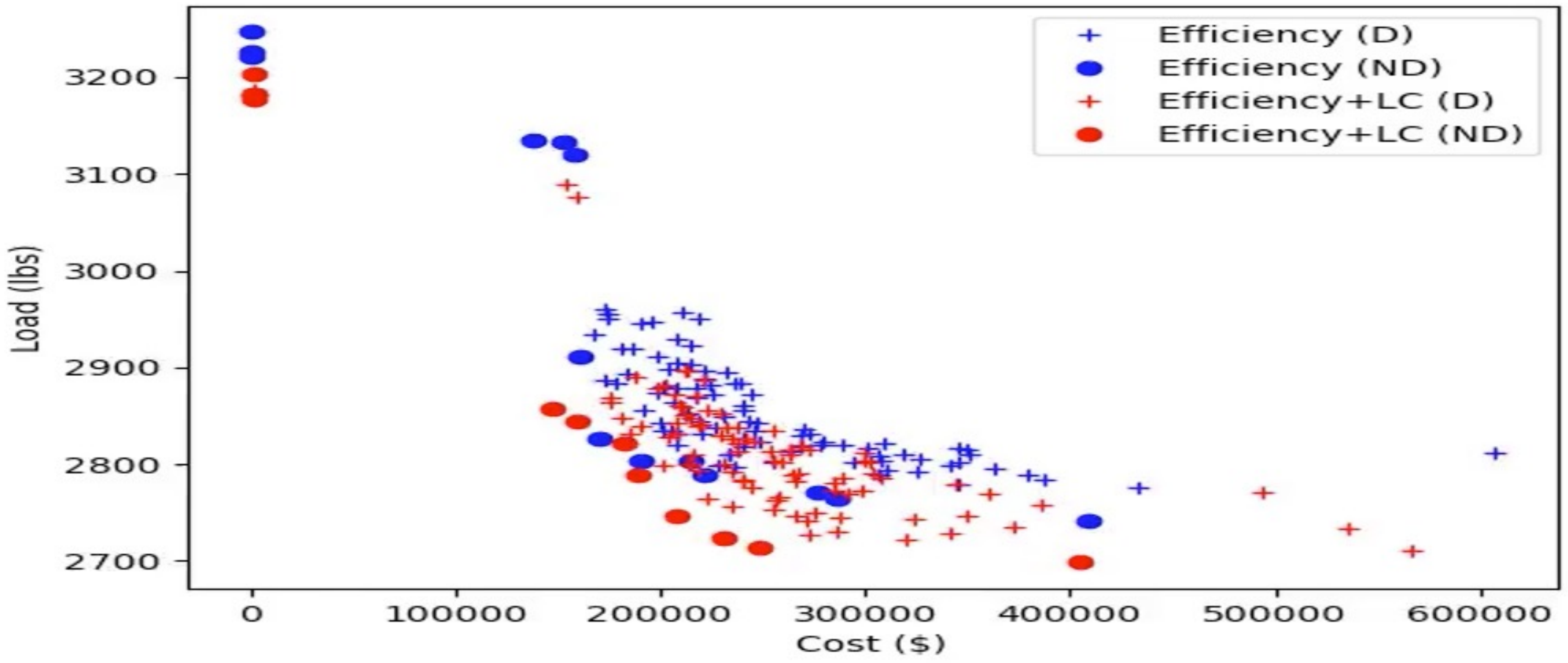
- Incorporation of new BMP type into Optimization platform
- Running Optimization using CoreCAST

Efficiency and Land Conversion BMPs

- **Efficiency*: 205 BMPs**
- **Land Conversion*: 40 BMPs (24 in use)**
- Pond reduction: 31 BMPs
- Animal manure: 5 BMPs
- Manure transport: 21 BMPs

*** Efficiency + Landuse change represent 80% of BMPs**

Comparison run: Efficiency vs Efficiency + Land Conversion



Conclusions and Future Work

- Grouping of certain counties together for optimization help find efficient solutions faster than optimizing for a single county alone.
- Despite the large number of initial BMP combinations, only 10% were used in the optimized solution.
- Land conversion BMPs help to improve cost and load.

- Add this work to the web interface (future work).
- Incorporation of remaining BMPs (future work).
- Improve the decision making process (future work).

Thank you