Development of Efficient Multi-Objective Optimization Procedures

Kalyanmoy Deb, Pouyan Nejadhashemi, Ritam Guha, Auden Garrard and Parimal Kodumuru

Agenda

- New Member Onboarding: Parimal Kodumuru

- Revised Work Plan (Approved)

- Conflict Resolution between Optimization WebApp and CAST –
  - Wastewater
  - Base Scenario
  - Efficiency and Land Conversion BMP Implementation

- Webinar Planning

- Future Plan

About the New Member

Project Experience

- 3D Point Cloud Analysis and Defect Detection

    Technologies:
    Python, OpenCV, NumPy, Machine Learning, PCL (Point Cloud Library)

- Predictive Maintenance System

    Technologies: Python, AWS, SQL

Parimal Kodumuru

Education

Masters in Business Statistics Michigan State University

Contact Information

Kodumuru@msu.edu

Revised Timeline of the Project

Original End Date: March 31, 2026

Proposed Extended End Date: March 31, 2027

Calendar Year			2020			2021				2022				2023				2024				2025				2026				2027
Calendar Quarter			Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1
Project Year			Year 1						Year 2					Year 3				Year 4				Year 5				Year 6				Year 7 (extended)

Task 1: Development of an efficient single-objective optimization procedure for cost-effective BMP allocation
- 1.1: Understanding CAST modules and effect of BMPs on objectives and constraints
- 1.2: Development of a simplified point-based structured single-objective optimization procedure
- 1.3: Development of a hybrid customized single-objective optimization procedure
- 1.4: Verification and validation with CBP users and decision-makers and update of optimization procedure

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 procedre 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

Task 3: Multi-state implementation using machine learning and parallel computing platforms
- 3.1: Comparative study to choose a few best performing methods
- 3.2: Scalability to State and Watershed level Scenarios
- 3.3: "Innovization" approach for improving scalability
- 3.4: Distributed computing approach for improving scalability

Task 4: Interactive optimization and decision-making using user-friendly dashboard
- 4.0: Completion of remaining studies of Task 3
- 4.1: User-friendly optimization through a dashboard
- 4.2: Surrogate-assisted optimization procedure
- 4.3: Robust optimization method for handling uncertainties in variables and parameters
- 4.4: Sustainable watershed management practices

We are here

Task 4: Interactive optimization and decision-making using user-friendly dashboard

4.0 Completion of remaining studies of Task 3

4.1 User-friendly optimization through a dashboard

4.2. Surrogate-assisted optimization procedure

4.3 Robust optimization methods for handling uncertainty in variables and parameters

4.4 Sustainable watershed management practices

Current Sprint of the Project

Ongoing Sprint of the Project

Task 4: Interactive optimization and decision-making using user-friendly dashboard

4.0 Completion of remaining tasks of Task 3

4.0.1 Implement the Base BMPs for each year

Users can now select the base year and the backend would automatically include the necessary BMP files
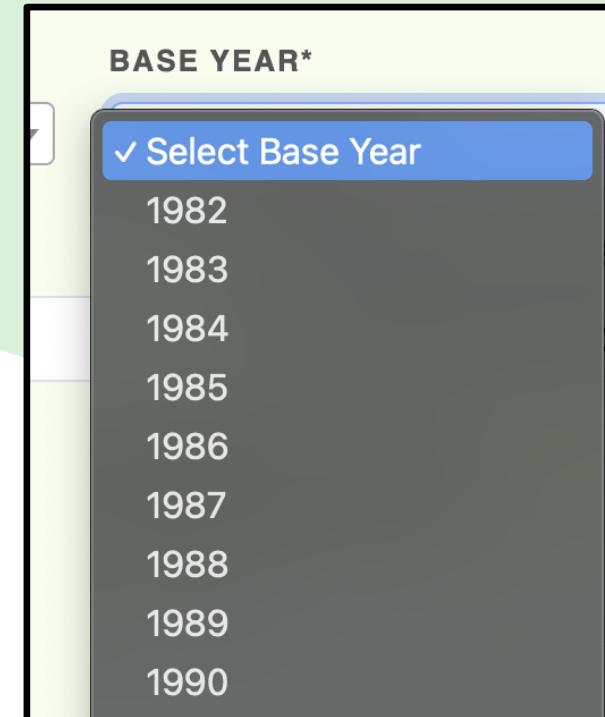
Ongoing Sprint of the Project

Task 4: Interactive optimization and decision-making using user-friendly dashboard

4.0 Completion of remaining tasks of Task 3

4.0.2 Add the Land Conversion and Efficiency BMPs for Optimization
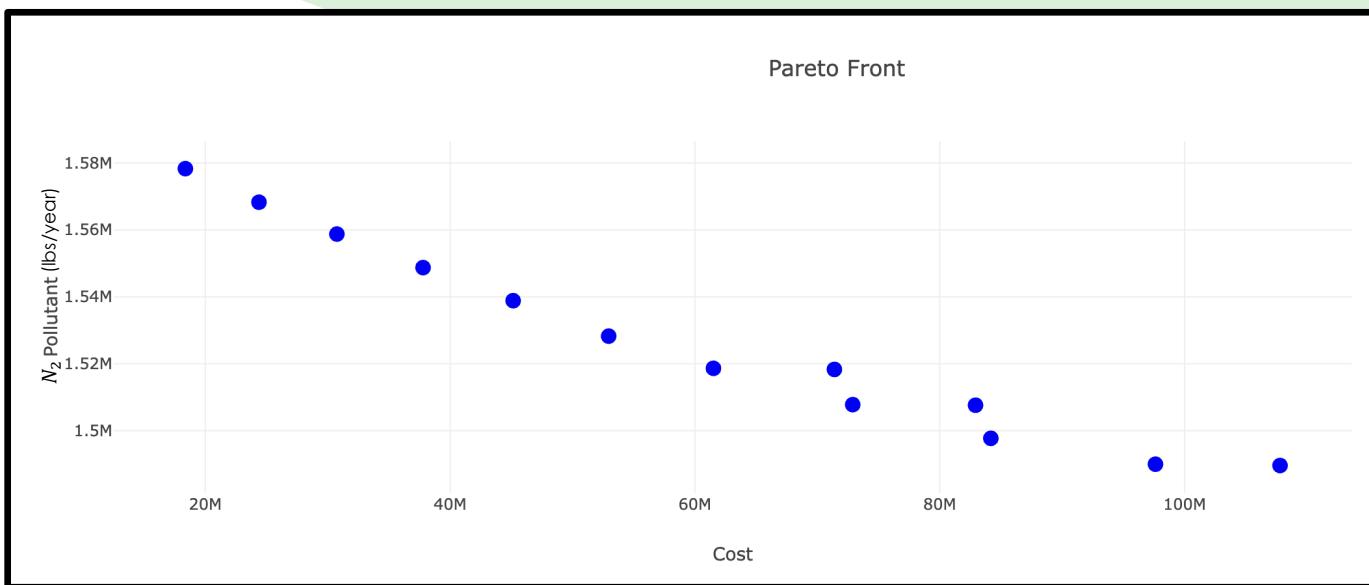
Ongoing Sprint of the Project

Task 4: Interactive optimization and decision-making using user-friendly dashboard

4.1 User-friendly optimization through a dashboard

Ongoing Sprint of the Project

Task 4: Interactive optimization and decision-making using user-friendly dashboard

4.2 Surrogate-assisted optimization procedure

- CoreCAST evaluation is still time consuming at scale
- Can we develop an approximate surrogate for CoreCAST for running the optimization process?
- Idea:
  - Evaluate a few BMP allocation schedules and evaluate for pollutants using CoreCAST
  - Build surrogates with fewer derived/hidden variables
    - Artificial neural network or response surface
    - Variable reduction techniques
  - Use the surrogates to continue the optimization run
  - May need to re-build the surrogates during optimization progressively
  - Evaluation of final solutions using CoreCAST
- Note, the built surrogates alone are not a replacement of CoreCAST

High fidelity
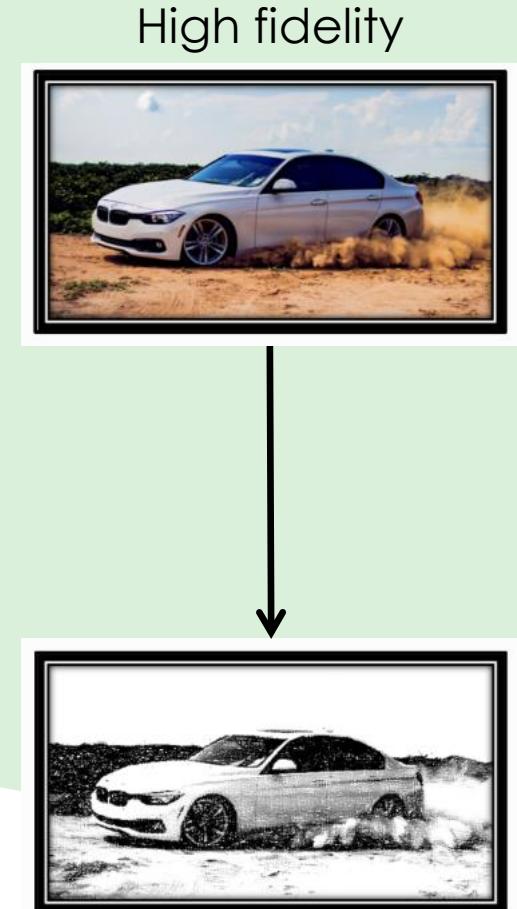
Low fidelity

Optimization Process Overview (Recap)

Optimization Algorithm

BMP Solution

Cost Calculation

Solution Evaluation

Pollution Load

CoreCAST

MSU Optimization System

Optimization Run with Washington DC

Pareto Front

Base Load

Optimization Run 1

N_2 Pollutant (lbs/year)

Sector	Nitrogen (lbs/yr)	Phosphorus (lbs/yr)	Sediments (lbs/yr)	
Agriculture	0	0	0	
Developed	152,480	9,506	25,947,779	
Natural	22,633	2,472	17,926,838	
Septic	235	0	0	
Total	206,523	18,611	44,736,900	
Wastewater	31,175	6,633	862,283	

Optimization Run with Washington DC

Sector	Nitrogen (lbs/yr)	Phosphorus (lbs/yr)	Sediments (lbs/yr)
Agriculture	0	0	0
Developed	152,480	9,506	25,947,779
Natural	22,633	2,472	17,926,838
Septic	235	0	0
Total	206,523	18,611	44,736,900
Wastewater	31,175	6,633	862,283

Everything is matching except Wastewater in two sub-segments: **Industrial** and **Municipal** loads; And a small portion for developed

CAST Result Verification

Sector		
▶ Sector: Agriculture		0.00
▶ Sector: Developed		152,450.14
▶ Sector: Natural		22,632.79
▶ Sector: Septic		235.42
◢ Sector: Wastewater		
◢ AgencyType: Non Federal		
◢ Agency: Non-Federal		
Combined Sewer Overflow		31,174.86
Industrial Wastewater Treatment Plant		33,000.65
Municipal Wastewater Treatment Plant		1,316,067.67
		1,380,243.18
		1,380,243.18

Sector		
▶ Sector: Agriculture		0.00
▶ Sector: Developed		9,504.43
▶ Sector: Natural		2,472.05
▶ Sector: Septic		0.00
◢ Sector: Wastewater		
◢ AgencyType: Non Federal		
◢ Agency: Non-Federal		
Combined Sewer Overflow		6,632.95
Industrial Wastewater Treatment Plant		3,575.89
Municipal Wastewater Treatment Plant		44,359.74
		54,568.58

Sector		
▶ Sector: Agriculture		0.00
▶ Sector: Developed		25,937,147.16
▶ Sector: Natural		17,926,837.68
▶ Sector: Septic		0.00
◢ Sector: Wastewater		
◢ AgencyType: Non Federal		
◢ Agency: Non-Federal		
Combined Sewer Overflow		862,283.32
Industrial Wastewater Treatment Plant		272,925.09
Municipal Wastewater Treatment Plant		556,828.46
		1,692,036.87

Wastewater Mismatch Correction

- We have identified that the two sub-segments of wastewater namely Industrial and Municipal Treatment Plant loads can be retrieved from Wastewater Reports:
    1. **Nitrogen Loads EOS**: No3LbsPerYearEos, Nh3LbsPerYearEos, OrgnLbsPerYearEos
    2. **Phosphorus Loads EOS**: Po4LbsPerYearEos, OrgpLbsPerYearEos
    3. **Sediments Loads EOS**: TssLbsPerYearEos

- We are in the process of obtaining the reports and integrating it to our web interface.

Wastewater is polluting more than what our system thinks!

Wastewater Mismatch Correction

CAST Reports Section

Create Reports ⓘ

* Required field

Report Type *
Wastewater Report

Report Name *
Wastewater Report 2023

Check to view geographies located only in the Chesapeake Bay Watershed Area ☑

Geographic Scale *
Chesapeake Bay Watershed

Geographic Area *
Search...

Chesapeake Bay Watershed

Wastewater *
2023

Submit Report
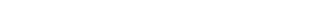
Match!

EOS Nitrogen	EOS Phosphorus	EOS Sediments	EOT Nitrogen	EOT Phosphorus	EOT Sediments
119071.8860	4747.7632	76731.9283	74980.9756	2992.3246	27398.6016
22543.8977	171.8241	42983.9054	263.7143	55.0644	23710.3483
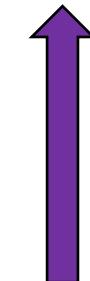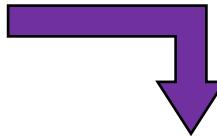
Aggregations

WasteWater	Npdes	Facility	Outf	LandRiverSegment	Geography	Agency	LoadSource	Sign	FloAvgMillion	BodLbsPerY	DoLbsPerYe	No3LbsPerY	Nh3LbsPerY	OrgnLbsPerY	Po4LbsP	OrgpLbs	TssLbsPerYe	NO3LbsPe	NH3LbsPer	ORGNLbsPe	PO4LbsPerY	ORGPLbs	TSSLbsPerYearE
2023	MD0022578	MANCHESTER WWTP	002	MD-N24013WU0_3021_3020(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Municipal Wastewater Treatment Plant	N	0.3222	11674.7340	0.0000	13851.2592	0.0000	0.0000	0.0000	0.0000	15001.7976	1738.8931	0.0000	0.0000	0.0000	0.0000	48.6034
2023	MDG766057	CARROLL COUNTY FAMILY YM	001	MD-N24013WM0_3881_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0002	18.1820	3.0303	1.0303	0.0848	0.0970	0.0861	0.0352	9.0910	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MD0065927	RUNNYMEADE WWTP	001	MD-N24013PM1_3120_3400(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Municipal Wastewater Treatment Plant	N	0.0019	35.2993	47.8545	0.0000	27.2440	0.0000	0.0000	0.0000	27.1505	0.0000	19.7136	0.0000	0.0000	0.0000	17.9857
2023	MDG766144	SOUTH CARROLL SWIM CLUB	001	MD-N24013WM0_3881_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0002	18.1820	3.0303	1.0303	0.0848	0.0970	0.0861	0.0352	9.0910	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MDP121831	WATER DEPOT	001	MD-N24013PM1_3450_3400(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MD0001881	BTR HAMPSTEAD, INC.-BLACK	001	MD-N24013WM0_3881_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.2170	19826.5950	3304.4325	17820.2490	1467.5499	1677.2000	19.1700	7.8300	4503.9999	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MD0024546	PHEASANT RIDGE WWTP	001	MD-N24013WM1_3882_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0354	487.8486	812.0506	2711.9621	153.2796	83.0781	470.2674	113.4804	599.8585	1427.5690	80.6860	43.7321	214.2935	51.7112	165.1853
2023	MDG492472	S & G CONCRETE - FINKSBUR	001	MD-N24013WM0_3881_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0010	0.0000	24.3401	4.4421	0.7302	0.9128	0.0204	0.0100	91.2754	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MDG490433	THOMAS, BENNETT & HUNTER	001	MD-N24013PM1_3450_3400(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0010	0.0000	24.3401	4.4421	0.7302	0.9128	0.0204	0.0100	91.2754	3.5275	0.5799	0.7248	0.0144	0.0071	62.2918
2023	MD0021512	FREEDOM DISTRICT WWTP	001	MD-N24013WM1_3882_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Municipal Wastewater Treatment Plant	Y	2.0243	7091.6907	47097.9902	9388.4351	518.0356	6516.9934	0.0000	608.1958	24514.8642	5128.9491	283.0054	3560.2661	0.0000	277.1453	6750.7497
2023	MDG344224	WALSH FUEL & SUPPLY CO,IN	001	MD-N24013PM2_2860_3040(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MD0024589	SOUTH CARROLL HIGH SCHO	001	MD-N24013WM1_3882_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Municipal Wastewater Treatment Plant	N	0.0054	25.9532	135.4949	325.6338	300.0502	9.2326	0.0000	2.6092	148.6450	90.3270	83.2304	2.5610	0.0000	0.2028	3.0747
2023	MDG912397	SHEETZ STORE # 132	001	MD-N24013PM3_3040_3340(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0025	228.2607	38.0434	32.3369	2.6630	3.0435	1.0804	0.4413	114.1303	21.8978	1.8033	2.0610	0.8055	0.3290	64.4877
2023	MD0000779	LEHIGH CEMENT COMPANY L	001	MD-N24013PM1_3450_3400(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.1400	12791.3519	2131.8919	28.9798	2.3866	2.7275	0.0000	0.0000	33727.7961	23.0135	1.8952	2.1660	0.0000	0.0000	23017.8547
2023	MDG499852	C. J. MILLER, LLC	001	MD-N24013WM0_3881_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0010	0.0000	24.3401	4.4421	0.7302	0.9128	0.0204	0.0100	91.2754	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MD0022527	MOUNT AIRY WWTP	001	MD-N24013WM1_3882_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Municipal Wastewater Treatment Plant	Y	0.6536	5382.5892	14577.4628	1058.7626	550.9026	1069.8109	29.9366	169.0661	1990.0273	578.4073	300.9608	584.4431	13.6416	77.0408	548.0012
2023	MD0001384	CONGOLEUM CORPORATION	001	MD-N24013WM0_3881_3880(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	Y	0.1195	807.0417	2279.7744	413.8601	76.8661	654.8738	29.6006	20.5699	3281.3356	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	MDG498000	MEDFORD QUARRY (REICHLI	001	MD-N24013PM1_3450_3400(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Industrial Wastewater Treatment Plant	N	0.0010	0.0000	24.3401	4.4421	0.7302	0.9128	0.0204	0.0100	91.2754	3.3169	0.5453	0.6816	0.0144	0.0071	62.2918
2023	MD0022454	UNION BRIDGE WWTP	001	MD-N24013PM1_3450_3400(CBWS)	Carroll, MD (CBWS Portion Only)	Non-Federal	Municipal Wastewater Treatment Plant	N	0.1293	1554.1708	3156.0736	6618.7784	342.5110	258.9353	648.5850	66.0771	1151.6430	5256.1107	271.9952	205.6259	456.7233	46.5305	785.9497

Wastewater Mismatch Resolution

Sector	Nitrogen (lbs/yr)	Phosphorus (lbs/yr)	Sediments (lbs/yr)	
Agriculture	0	0	0	
Developed	88,485	5,602	11,109,186	
Natural	20,678	1,048	4,678,935	
Septic	235	0	0	
Total	1,489,642	61,218	17,480,158	
Wastewater	1,380,243	54,569	1,692,037	

Nitrogen Loads (lbs/yr) ⦰

	Load Source	DC Land Test 2023 (Edge of Stream)
▶ Sector: Agriculture		
		0.00
▶ Sector: Developed		
		84,809.08
▶ Sector: Natural		
		18,206.05
▶ Sector: Septic		
		235.42
▶ Sector: Wastewater		
		1,380,243.18
		1,483,493.73

Phosphorus Loads (lbs/yr) ⦰

	Load Source	DC Land Test 2023 (Edge of Stream)
▶ Sector: Agriculture		
		0.00
▶ Sector: Developed		
		4,970.99
▶ Sector: Natural		
		18.03
▶ Sector: Septic		
		0.00
▶ Sector: Wastewater		
		54,568.58
		59,557.60

Sediment Loads (lbs/yr) ⦰

	Load Source	DC Land Test 2023 (Edge of Stream)
▶ Sector: Agriculture		
		0.00
▶ Sector: Developed		
		10,775,310.93
▶ Sector: Natural		
		2,712,979.71
▶ Sector: Septic		
		0.00
▶ Sector: Wastewater		
		1,692,036.87
		15,180,327.51

Base Progress Scenario Addition

- We also have identified a way to add the base scenario BMP implementations to the process by using the Reports.

- We are also in the process of obtaining the Progress reports and integrating it to our web interface.
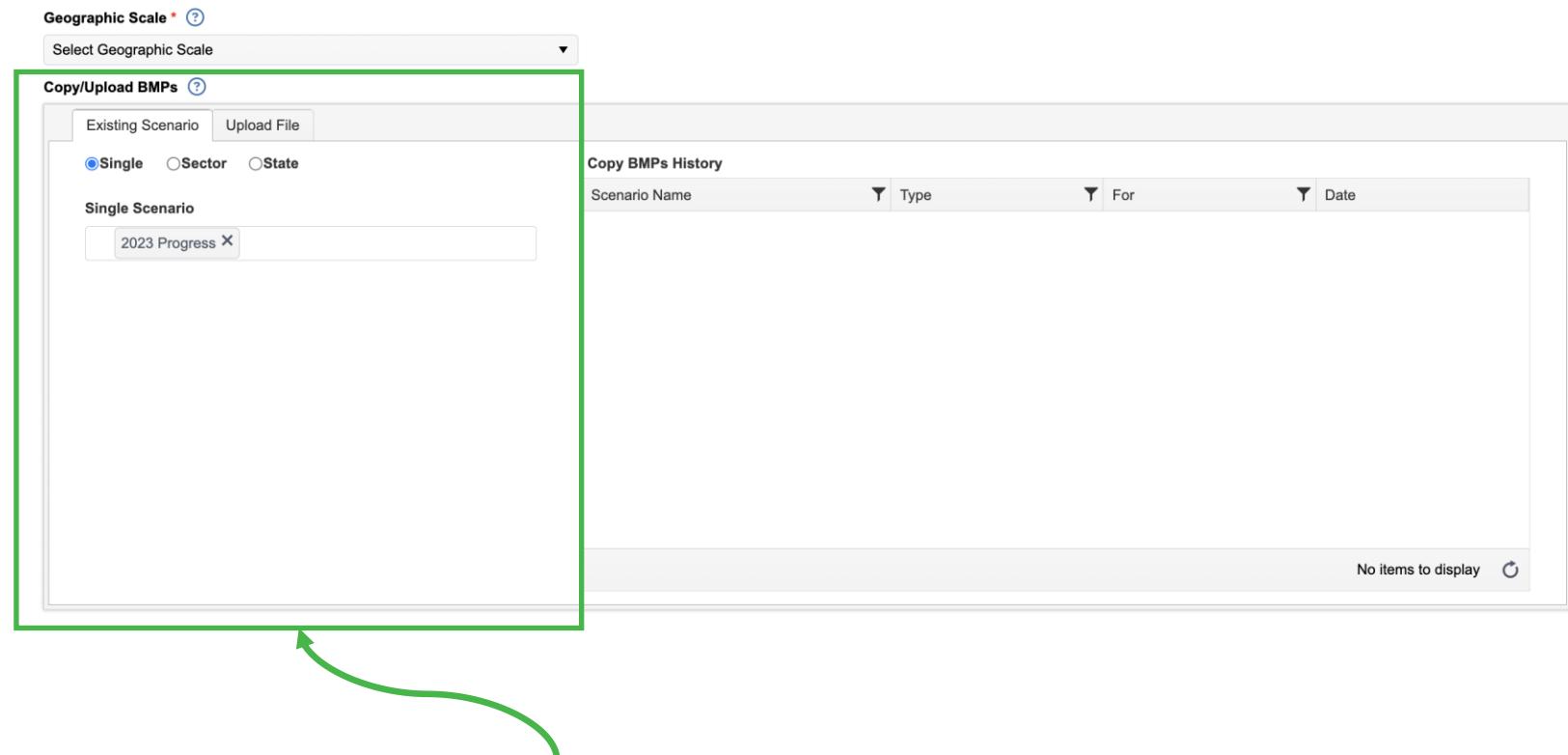
Adding this functionality;
Need to optimize on top of this

Base Progress Scenario Addition

Optimization Run with Base Progress

Washington DC
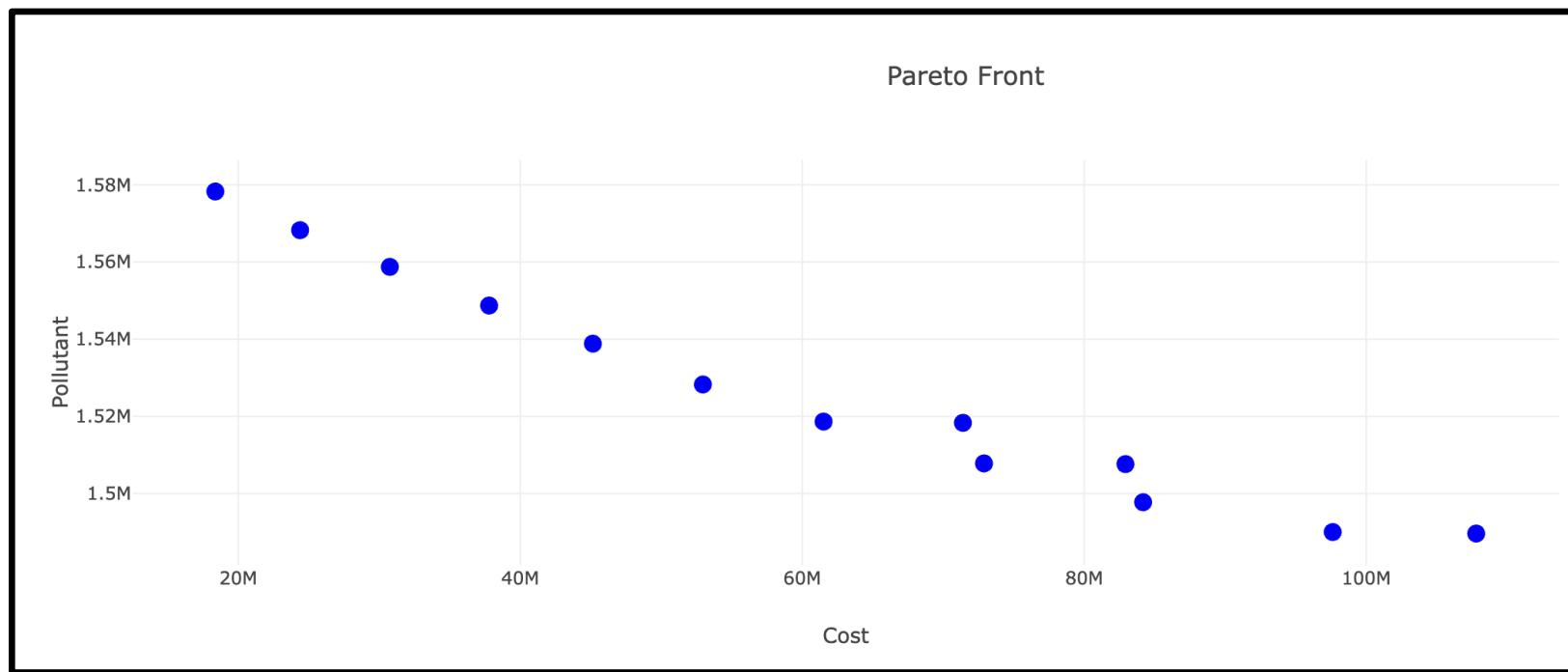
Budget Constrained Optimization

- Some cost values after the optimization might not be feasible.

- If there is a constraint (upper limit) on the budget, that can be now added to the system.
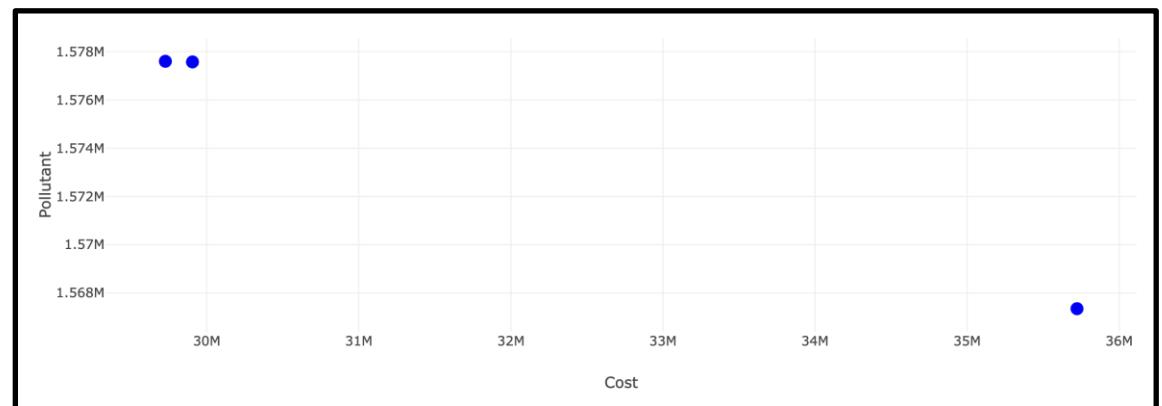
DO YOU HAVE A LIMIT ON THE ALLOCATED BUDGET FOR BMP IMPLEMENTATION?: ● YES ○ NO

$ 40000000   Next

Future Dashboard Improvements: Status Updates (In Progress)

Insert a status column

ID	Optimization Scenario Name	Wastewater Data Set	Counties	Date modified (EST)	Actions	Status
3	Carroll	2023 Progress	MD: [Carroll]	12/02/2024 6:22 p.m.		Completed
4	Kent	2023 Progress	DE: [Kent]	12/02/2024 7:08 p.m.		Initializing
5	Richmond	2023 Progress	VA: [Richmond]	12/02/2024 9:03 p.m.		Optimizing
6	Lancaster	2023 Progress	VA: [Lancaster]	12/02/2024 9:03 p.m.		Completed
7	Washington DC	2023 Progress	DC: [Washington]	12/02/2024 9:05 p.m.		Completed
16	Richmond 20 Iter	2023 Progress	VA: [Richmond]	12/11/2024 4 p.m.		Optimizing

ID	Optimization Scenario Name	Base Scenario	Counties	Date modified (EST)	Status	Actions
112	DC Test 2023	2023 Progress	DC: [Washington]	07/07/2025 7:57 a.m.	Optimization Complete	

Future Dashboard Improvements: Email Updates

- Will notify the users with two emails:
  - o   When Optimization starts
  - o   When Optimization completes

- When the optimization completes, the email might have a link to access the optimization results.

Future Dashboard Improvements: Cost Updates (Advanced Settings)

Update Costs

BMP*

STATE*

COST

0.0

UNIT

N/A

NEW COST*

[Submit]

- Some of the cost information in the system might be old.

- If the user has updated cost information, the costs can be updated based on latest information

Future Improvements: Enable result sharing

Id	# Optimization Run	# Solutions	Actions	
3	1	12		

Should help the user
Share the results of the
Optimization with other users
in the system

Future Improvements: Deleting Scenarios/Results

- Right now, only the admins can delete scenarios

ID	Optimization Scenario Name	Wastewater Data Set	Counties	Date modified (EST)	Actions
3	Carroll	2023 Progress	MD: [Carroll]	12/02/2024 6:22 p.m.	
4	Kent	2023 Progress	DE: [Kent]	12/02/2024 7:08 p.m.	
5	Richmond	2023 Progress	VA: [Richmond]	12/02/2024 9:03 p.m.	
6	Lancaster	2023 Progress	VA: [Lancaster]	12/02/2024 9:03 p.m.	
7	Washington DC	2023 Progress	DC: [Washington]	12/02/2024 9:05 p.m.	
16	Richmond 20 Iter	2023 Progress	VA: [Richmond]	12/11/2024 4 p.m.	
17	Washington DC 20 Iter	2023 Progress	DC: [Washington]	12/11/2024 4:01 p.m.	
18	Lancaster 20 Iter	2023 Progress	VA: [Lancaster]	12/11/2024 4:01 p.m.	
19	Kent Iter 20	2023 Progress	DE: [Kent]	12/12/2024 10:35 a.m.	

Not needed anymore. The user should have the ability to delete it.

Delete optimization results at will

Id	# Optimization Run	# Solutions	Actions
3	1	12	

Webinar Planning

- We want to make the animal and manure transport BMPs part of the process by October

- In October or November, we would like to have a meeting with the advisory group – Comprised of Lew, Olivia, Raj, and other volunteers from modeling working group

- We are planning the first webinar in January next year

MICHIGAN STATE UNIVERSITY

COiX
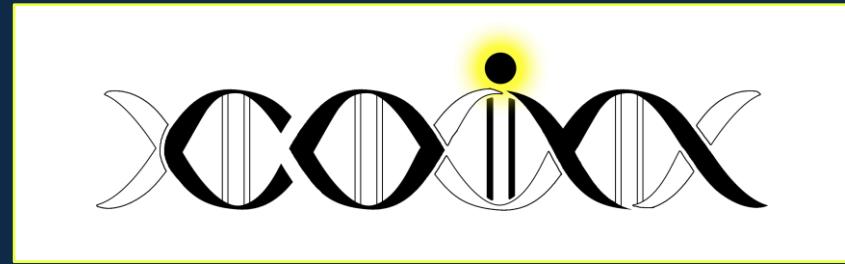
Computational Optimization and Innovation

Thank you

C-ECO
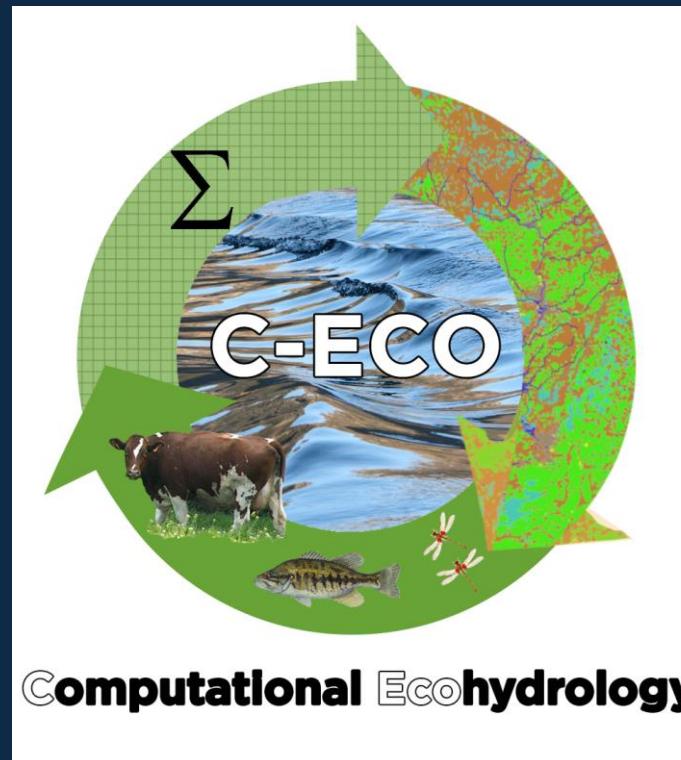
Computational Ecohydrology