Modeling Workgroup Meeting
Quarterly Review

Optimization update: Integration with CAST.

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MICHIGAN STATE UNIVERSITY

Agenda

- Objective 1: Understanding the CAST system and Development of an Efficient Single-objective Hybrid Optimization Procedure
  - April 1, 2020 to September 30, 2021 (18 months)
- Current Accomplishments:
  1) A sample-based selection approach (**Opt1**)
  2) A simplistic model-based optimization algorithm using point-based method (**Opt2**)
  3) Interface our optimization method with CAST system (**Opt3**)
  4) Population-based genetic algorithm (**Opt4**).
- Next Steps:
  1) Hybrid population-point based optimization method will be developed (**Opt5**).
  2) Development of a user interface to interact with our developed algorithms (**Opt6**).

Adopted models

Analytical Model

$$\text{Minimize} \quad f(\mathbf{x}) = \sum_{s\in S}\sum_{h\in H_s}\sum_{u\in U}\sum_{b\in B_u} \tau_b x_{s,h,u,b},$$

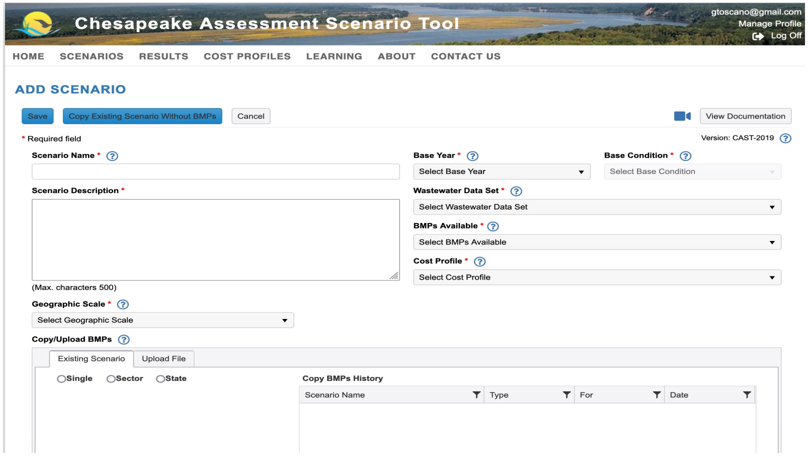
$$\text{Subject to} \quad \sum_{s\in S}\sum_{h\in H_s}\sum_{u\in U}\left[\alpha_{s,h,u}\phi_{s,h,u}\Pi_{G^B\in\mathcal{G}^B}\left(1-\sum_{b\in G^B}\eta_{s,h,b}\frac{x_{s,h,u,b}}{\alpha_{s,h,u}}\right)\right] \le \Theta,$$

$$\sum_{b\in G^B} x_{s,h,u,b} \le \alpha_{s,h,u}, \quad \forall s\in S,\ h\in H_s,\ u\in U_s,\ G^B\in\mathcal{G}^B,$$

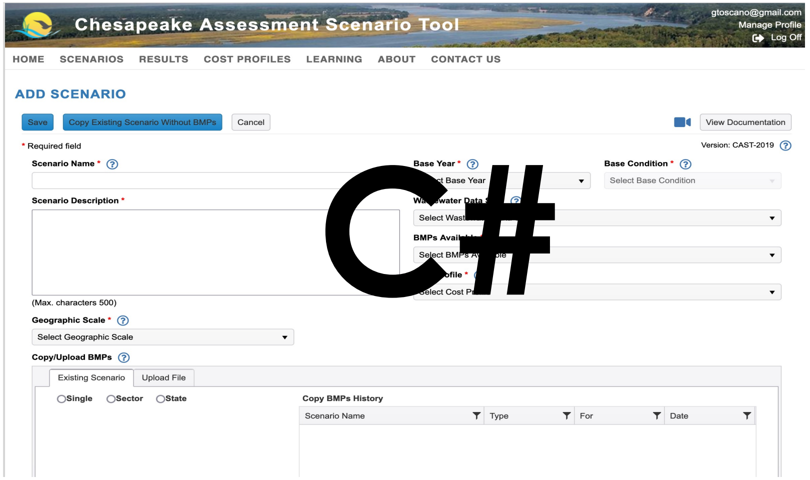
$$x_{s,h,u,b} \ge 0, \quad \forall s\in S,\ h\in H_s,\ u\in U_s,\ b\in B_u. \tag{1}$$

The variable $x_{s,h,u,b}$ indicates the acres used for implementing a BMP b to reduce a load resource u.

WebCast



CoreCast



Highlights

- Gradients
- Jacobians
- Hessian matrix
- Fast calculation
- Fast convergence
- Abstraction
- Accuracy

Highlights

- Well-stablished
- Validated
- Web interface
- Manual execution
- Black box

Highlights

- C# (fast implementation)
- Callable
- Slower than analytical model
- Black box

Previous presentation

- Understanding of the CBWS problem
  - Spatial Hierarchy
  - Group of BMPs
  - Decision Variables
  - Justification
- Complexity reduction
  - Dimensionality reduction
  - Screening solutions based on non-dominance
- Obtained results were encouraging

*A sample-based selection approach (**Opt1**)*

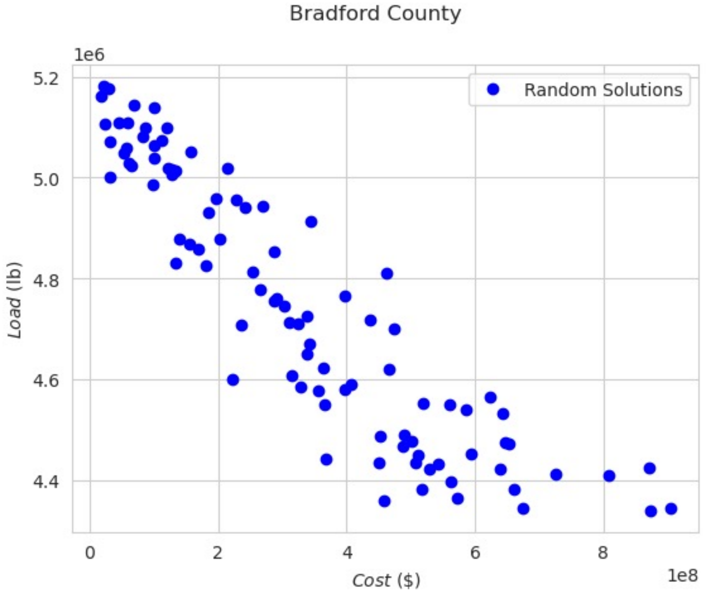
- BMP selection at random
- Evaluate in CoreCast
- 100 random solutions per county
- Presentation of results in four counties
  - Bradford, PA
  - Howard, MD
  - Lancaster, PA
  - Tioga, PA

*Base scenario**

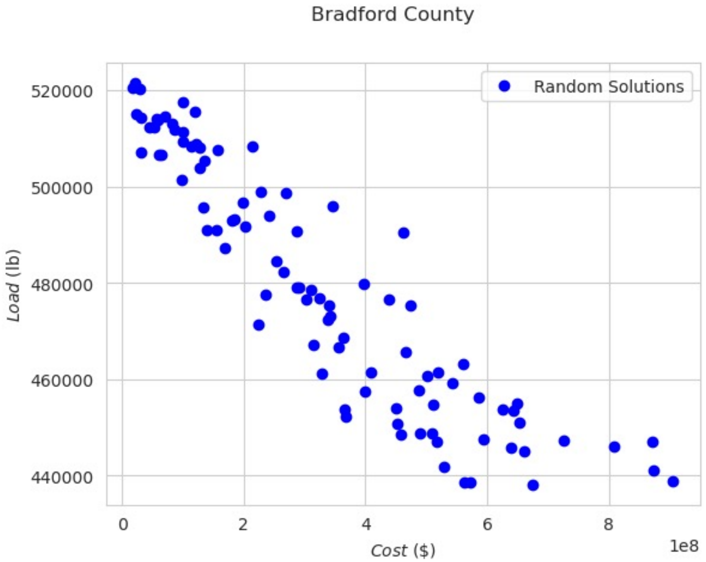
	# Variables	# Constraints	N (lb)	P (lb)	S (lb)
Bradford	28,356	2,029	5,190,951	522,346	629,678,546
Howard	16,721	1,227	1,861,150	120,745	306,170,714
Lancaster	21,256	1,532	30,466,675	1,563,829	1,175,580,233
Tioga	27,948	2,002	3,671,126	371,933	648,732,529

- **Base Scenario***: refers to the N,P,S loads when no BMP is implemented.
- **Parameters used for Base Scenario**: Base Condition: 2019 14, Backout Scenario: 2017 CAST-2019, Scenario Type: Official BMPs, Cost Profile: Watershed, Soil P Data Sets: 2014, Historical Crop Need Scenario: 6608, Point Source Data Set: No Action. ATM Dep Data Sets: Allocation Air, Climate Change: Base30Y20180615_FLOWSEDM, Base Load: Baseline Average Loads June 2018 Calibration, Data revision: 8.

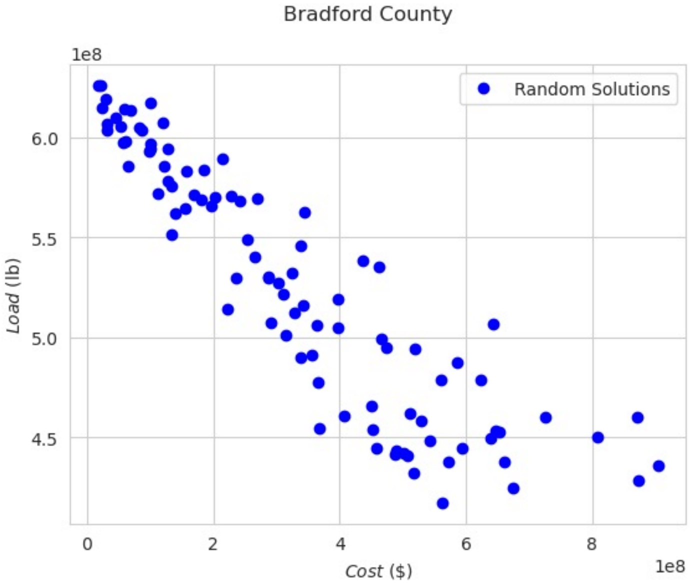
Bradford county (100 Random Solutions)



Nitrogen



Phosphorus



Sediments

Trade-off between cost and loadings is clear. More Cost, less Loadings.

*A simplistic model-based optimization algorithms using point-based method (**Opt2**)*

- Analytical model (efficiency BMPs)
- Interior point-based method
  - Exact derivatives
  - Exact Jacobian
  - Hessian Matrix
  - Smart initial point
  - Variable reduction
  - BMP screening based on Non-dominance

Summary of results of the Analytical Model compared to CoreCast

Bradford (|AM - CoreCast|%)	NLoadEos % (diff)	PLoadEos % (diff)	SLoadEos % (diff)
Min	0.02	0.05	0.39
Max	2.39	4.35	32.52
Average	1.22	2.11	13.75
Median	1.27	2.12	12.15
ST. Dev.	0.73	1.34	9.46

Howard (|AM - CoreCast|%)	NLoadEos % (diff)	PLoadEos % (diff)	SLoadEos % (diff)
Min	0.00	0.02	0.10
Max	2.44	17.79	50.76
Average	1.03	6.60	19.73
Median	1.10	6.76	18.27
ST. Dev.	0.68	4.60	14.44

Lancaster (|AM - CoreCast|%)	NLoadEos % (diff)	PLoadEos % (diff)	SLoadEos % (diff)
Min	0.01	0.02	0.11
Max	0.76	3.58	23.35
Average	0.50	1.49	9.47
Median	0.57	1.31	8.55
ST. Dev.	0.18	0.94	6.11

Tioga (|AM - CoreCast|%)	NLoadEos % (diff)	PLoadEos % (diff)	SLoadEos % (diff)
Min	0.00	0.00	0.00
Max	2.87	5.61	23.31
Average	1.32	2.52	9.55
Median	1.24	2.45	8.95
ST. Dev.	0.84	1.63	6.30

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Howard (| AM - CoreCast | %)	NLoadEos % (diff)	PLoadEos % (diff)	SLoadEos % (diff)
			10
			76
			73
			27
			44

- In average, the analytical model differs in less than **2**% regarding Nitrogen, **4** % regarding Phosphorus, and **14**% in for Sediments in average.
- The cost did not differ.

CoreCast | %)	(diff)	(diff)	(diff)
Min	0.01	0.02	0.11
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*Interface our optimization method with CoreCAST system (**Opt3**)*

- We interfaced our Opt2 approach with CoreCAST.
- Based conditions are managed by CoreCast.
- We evaluate the final solution provided by Opt2 in CoreCast.
- We can fine-tune the threshold for the Nitrogen, Phosphorous, or Sediment.
- Results are encouraging.

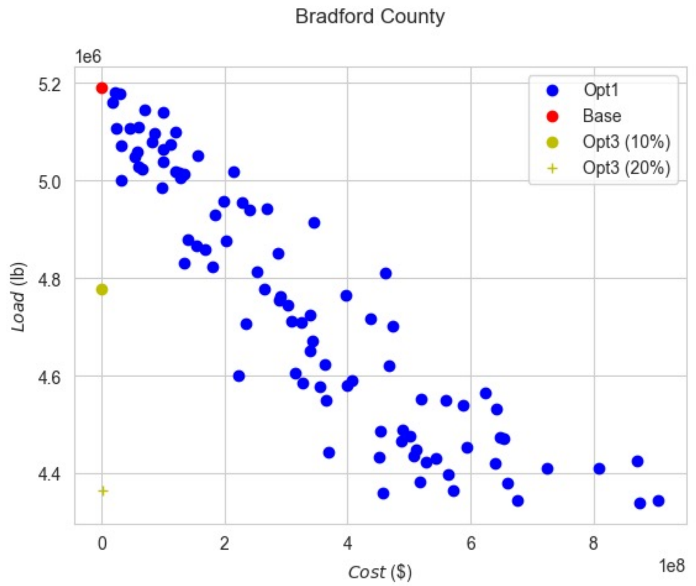
Encouraging results

- We are working with a single pollutant at a time.
- Our goal was to minimize the cost while reduce the nitrogen base load by10%.
- We re-executed the algorithm, but reducing 20% of the base load nitrogen

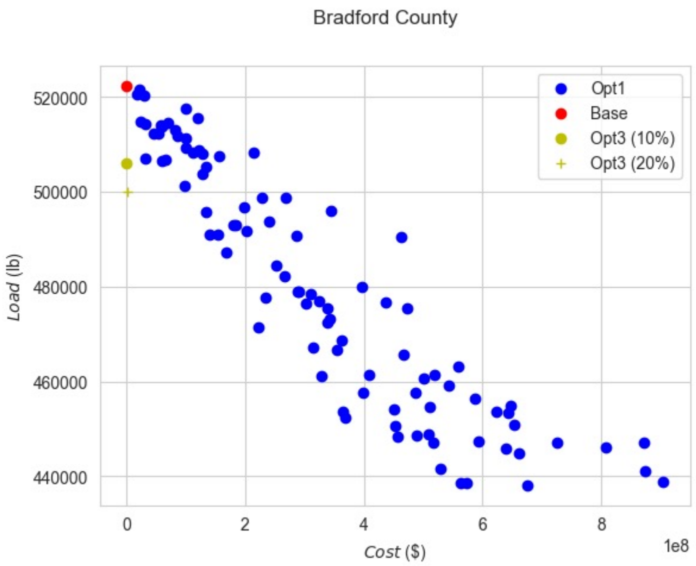
Opt3 (10% reduction)	Cost ($)	N (lb)	P (lb)	S (lb)
Bradford	570,169	4,778,962	506,153	629,279,278
Howard	196,423	1,717,602	115,387	306,158,106
Lancaster	1,676,396	27,624,574	1,525,938	1,171,957,024
Tioga	348,650	3,408,676	360,610	648,162,337

Opt3 (20% reduction)	Cost (I$)	N (lb)	P (lb)	S (lb)
Bradford	2,550,280	4,365,486	500,083	618,959,830
Howard	832,168	1,575,854	115,289	305,567,531
Lancaster	5,415,424	24,816,408	1,434,194	1,162,320,506
Tioga	1,682,485	3,147,071	355,955	640,571,659

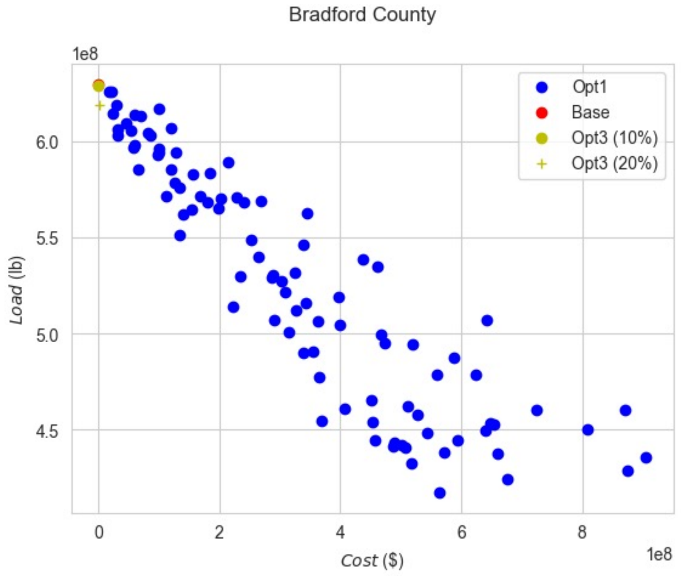
Example of results of OP3 compared to Opt1



Nitrogen



Phosphorus



Sediments

Optimized results require lower Cost.

Population-based genetic algorithm developed to solve the Analytical Model (Opt4).

- Optimization methods:
  - Point-based: Fast but local approach, sensitive to initial point
  - Population-based: Global approach to near-optimality
  - No one method is provably best for all problems (NFL theorem)
- Evolutionary optimization is flexible to be aided for handling practicalities

Population-based genetic algorithm will be applied to solve the Opt2 (Opt4).

- **Base Genetic Algorithm** (without any customization) **implemented** from scratch in C++
- Binary representation (naïve representation: 1 for a BMP means it is used in the whole parcel), 38,170 Boolean variables
- One-point crossover operator
- Flip-bit mutation operator
- Binary Tournament selection
- 0.8 crossover probability
- 1/L mutation probability (L: #variables)
- 30 executions

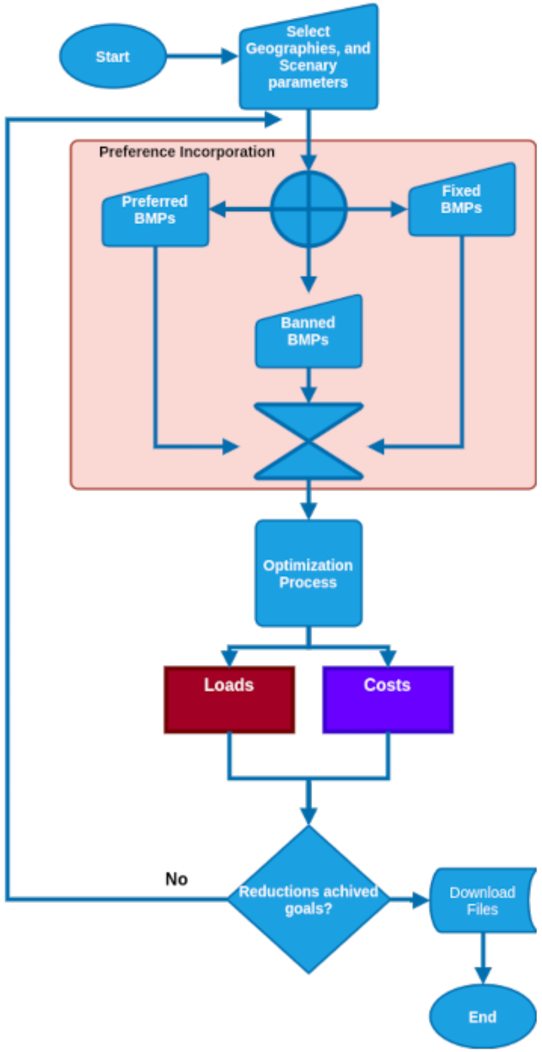
*Hybrid population-point based optimization method will be developed (**Opt5**)*

- Develop a Customized GA for a single-objective opt.:
  - Developing customized genetic operators and customized initialization should improve our BGA results
  - Hybridizing GA with an interior-point-based approach
- On going process.

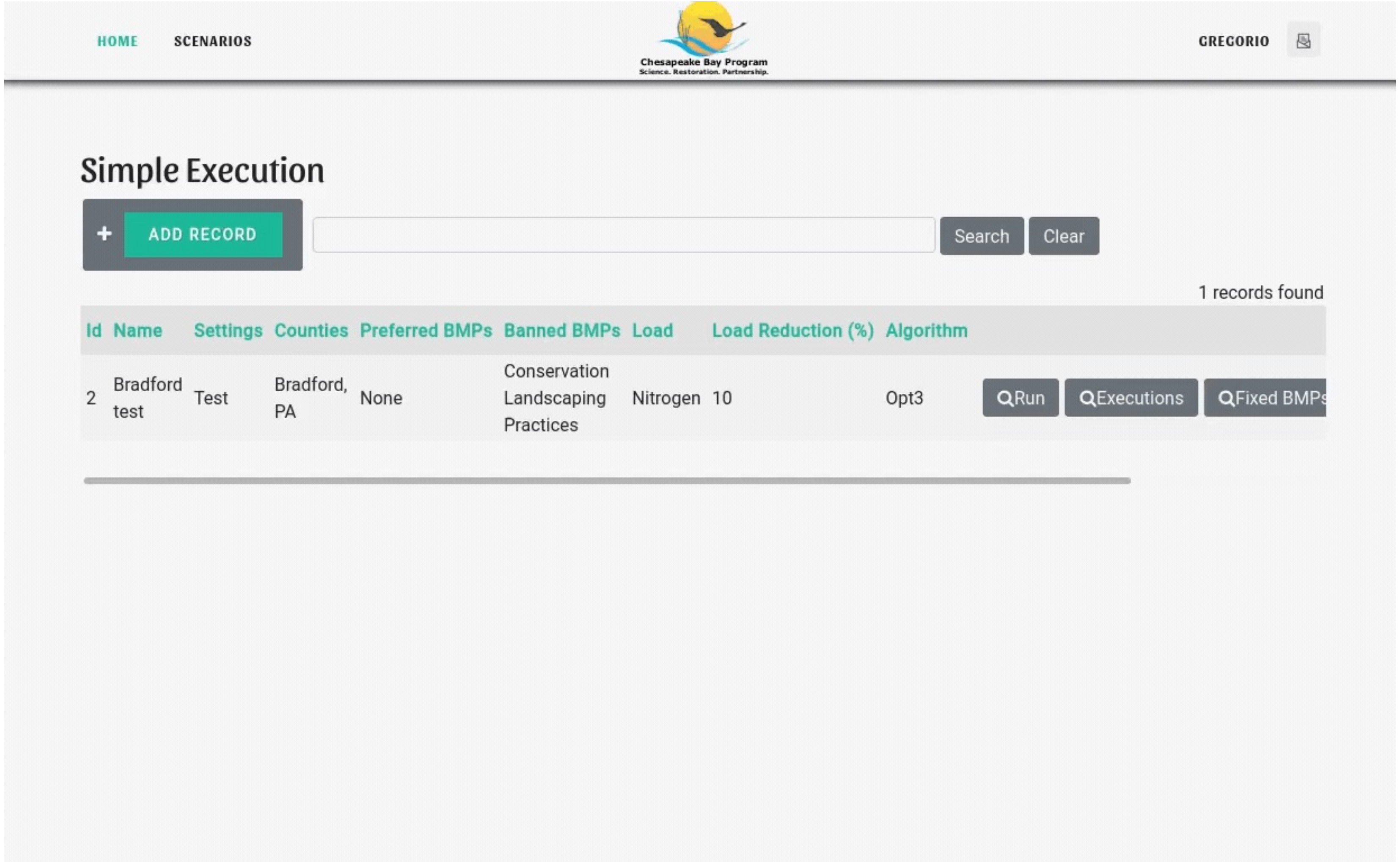
*Development of a user interface to interact with our developed algorithm (**Opt6**)*

- The approach should be useful for users.
- Developing of a user interface.
- Easy to use.
- Preference incorporation (preferred BMPs, banned BMPs, fixed BMPs).
- Sharing and re-execution.
- On going process.
- The results will be reported in our Objective 1 report.

Decision Making Tool for the Chesapeake Watershed



Banned BMPs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+ ADD RECORD
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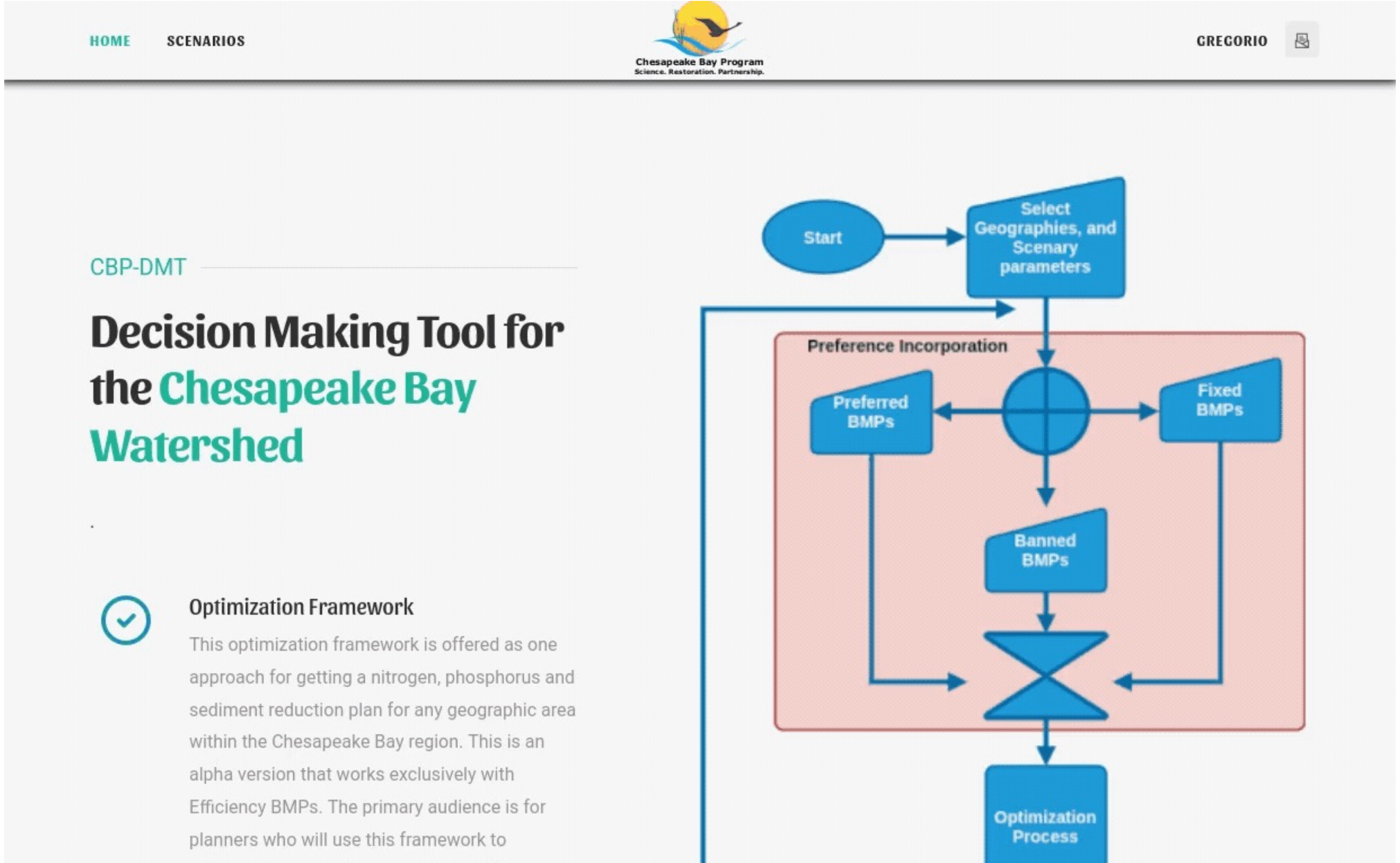
1 records found
Id Name Settings Counties Preferred BMPs Banned BMPs Load Load Reduction (%) Algorithm
2 Bradford test Test Bradford, PA None Conservation Landscaping Practices Nitrogen 10 Opt3
Run
Executions

Summary

- A sample-based selection approach showed the needs for an optimization approach
- The analytical model is quite accurate regarding nitrogen and phosphorus.
- Interior-point-based method can optimize the analytical model.
- We an interface to automatically execute CoreCast
- Well-design hybrid methods can converge faster, using fewer function calls.
- Users will be able to call our optimization approach through a web interface.

Thank you

Decision Making Tool for the Chesapeake Watershed



New Scenario

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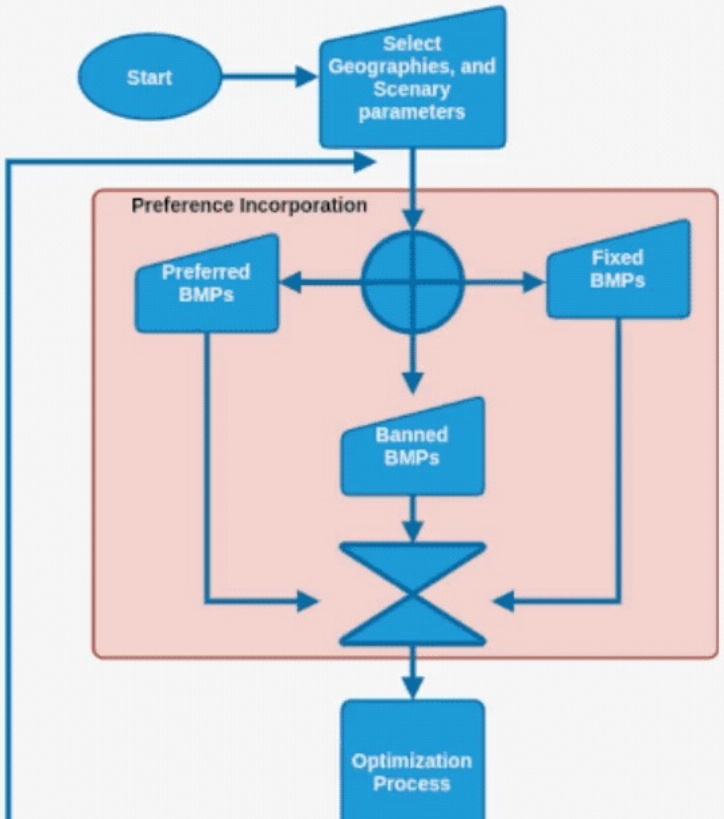
CBP-DMT

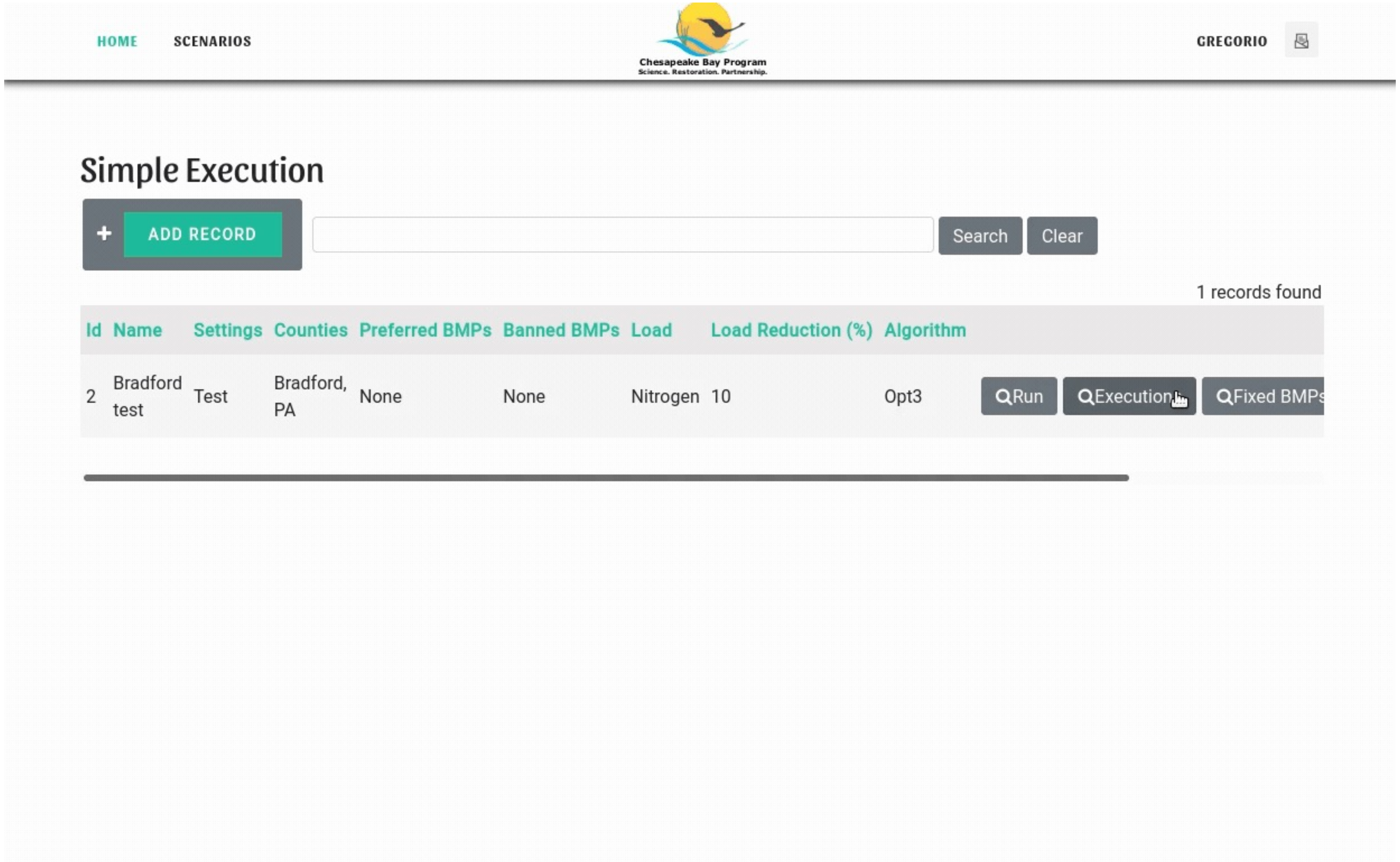
Decision Making Tool for the Chesapeake Bay Watershed

Optimization Framework

This optimization framework is offered as one approach for getting a nitrogen, phosphorus and sediment reduction plan for any geographic area within the Chesapeake Bay region. This is an alpha version that works exclusively with Efficiency BMPs. The primary audience is for planners who will use this framework to



Details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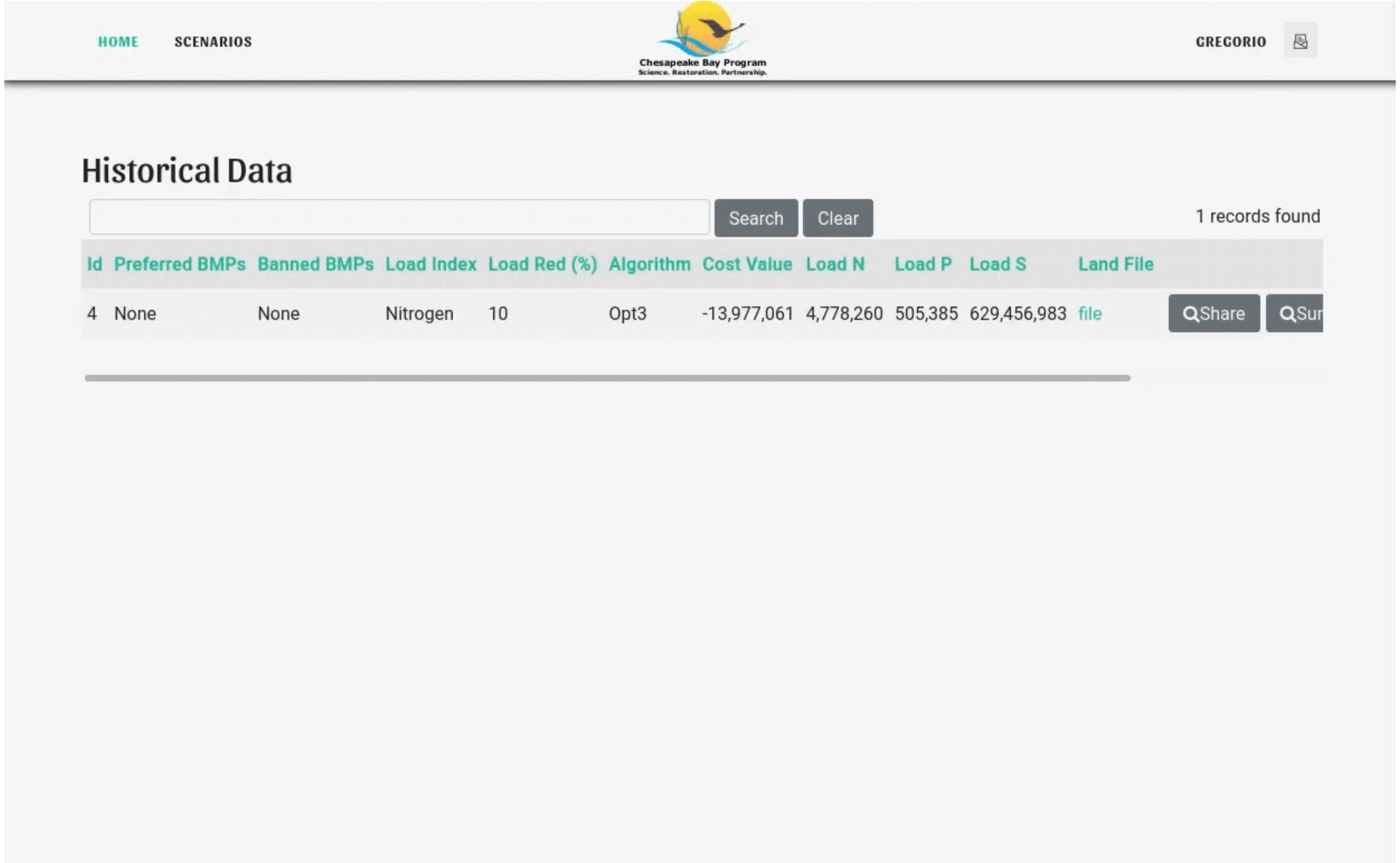
2 Bradford test Test Bradford, PA None None Nitrogen 10 Opt3
Run
Execution
Fixed BMPs

Banned BMPs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1 records found
Id Preferred BMPs Banned BMPs Load Index Load Red (%) Algorithm Cost Value Load N Load P Load S Land File
4 None None Nitrogen 10 Opt3 -13,977,061 4,778,260 505,385 629,456,983 file
Share

HOME SCENARIOS

Base Settings

BACK

ID	1
NAME	Test
BASE CONDITION	2019 14
BACKOUT SCENARIO	2017 CAST-2019
SCENARIO TYPE	Official BMPs
COST PROFILE	Watershed
SOIL P DATA SETS	2014
HISTORICAL CROP NEED SCENARIO	6608
POINT SOURCE DATA SET	No Action
ATM DEP DATA SETS	Allocation Air
CLIMATE CHANGE	BASE30Y20180615_FLOWSEDM
BASE LOAD	Baseline Average Loads
DATA REVISION	8

Submit

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Historical Data

Search Clear 4 records found

Id	Preferred BMPs	Banned BMPs	Fixed BMPs	Load Index	Load Red (%)	Algorithm	Cost Value	Load N	Load P	Load S	Land File
76	None	None	None	Nitrogen	10	Opt3	-13,977,061	4,778,260	505,385	629,456,983	file
79	None	Conservation Land...	None	Nitrogen	10	Opt3	570,169	4,778,962	506,153	629,279,278	file
80	None	Conservation Land...	None	Nitrogen	20	Opt3	2,550,280	4,365,486	500,083	618,959,830	file
81	None	Conservation Land...	None	Phosphorous	10	Opt3	424,013	5,133,044	479,546	514,554,815	file

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Bmp Summary

#	BMP	Acres	Cost
1	Agricultural Stormwater Management	10.9152209	18011.20573
1	Erosion and Sediment Control Level 1	1.405197788e-07	0.0002123562961
1	Nutrient Management Maryland Do It Yourself	3.805178353e-05	7.572304958e-05
1	Nutrient Management Maryland Commercial Applicators	3.805178353e-05	7.572304958e-05
1	Erosion and Sediment Control Level 2	3.756362004e-09	2.382427481e-05
1	Nutrient Management Plan	6.736501053e-05	0.0001340563716
1	Barnyard Runoff Control	144.5263044	83810.80746
1	Erosion and Sediment Control Level 3	2.963852585e-09	2.349733501e-05
1	Nutrient Management Plan High Risk Lawn	957.5870493	1905.598237
1	Nutrient Management N Rate	13188.19347	121858.9046
1	Nutrient Management Plan Low Risk Lawn	5.56179115e-05	0.0001106796444
1	Conservation Landscaping Practices	46803.91475	-14202648.5

Base conditions are managed by CoreCast

- Base condition (i.e., 2019)
- Backout scenario (i.e., 2017 CAST-2019)
- Scenario type (i.e., Official BMPs)
- Cost profile (i.e., Watershed)
- Soil P (i.e., 2014)
- Historical crop need scenario (i.e., 6608)
- Point source (i.e., No Action)
- ATM Dep (i.e., Allocation Air)
- Climate change (i.e., BASE30Y20180615_FLOWSEDM)
- Base load (i.e., Baseline avg loads, June 2018 calibration)
- Data revision (i.e., 8)