Introduction to Rhodium and Multiobjective Robust Decision Making

CEE 6200 Final Project

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Rhodium library in Python

Formulate simulation-optimization problem

Generate alternatives

Sample candidate solutions over possible states of world

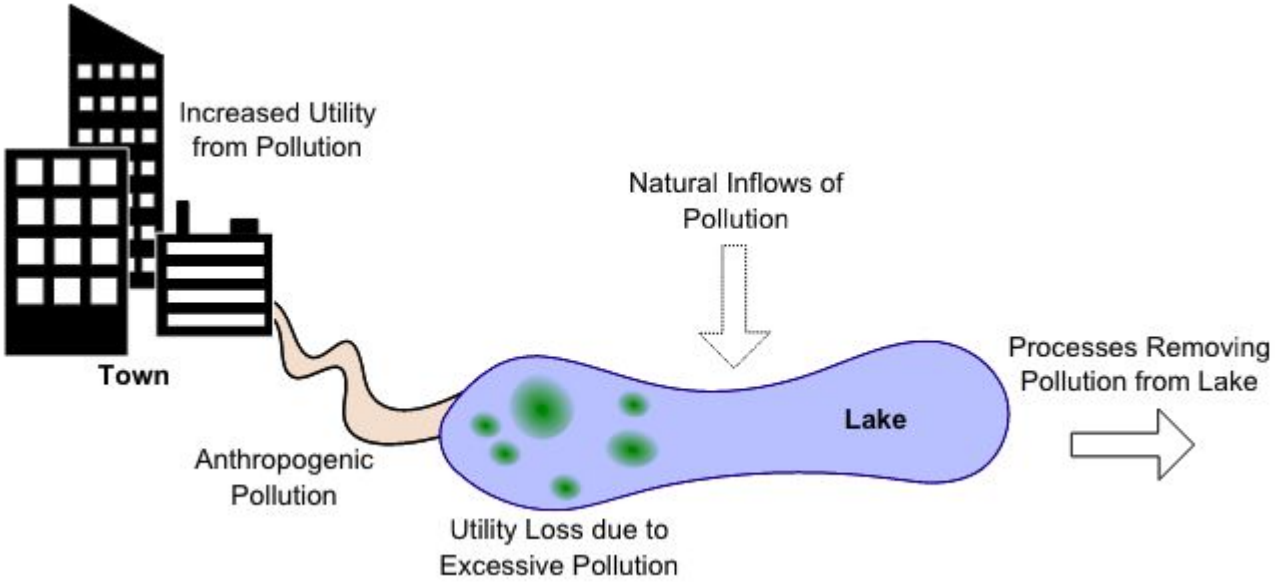
Perform sensitivity analysis

Source: JORS_Rhodium

MORDM framework has environmental relevance

- Ecosystem problems include watershed management
- Such problems often have multiple competing objectives
  - Maximum pollution limits
  - Economic utility
  - Managing wildlife

The Lake Problem



A town's inhabitants must decide how much phosphorus to release into a lake

Source: Project-Platypus, Rhodium

Lake problem equations

- Rate of eutrophication modelled as

$$\frac{dP}{dt} = I - bP + \frac{qP^a}{K^a + P^a}$$

P = mass/concentration of P

q = rate of recycling of P

I = rate of P input from watershed

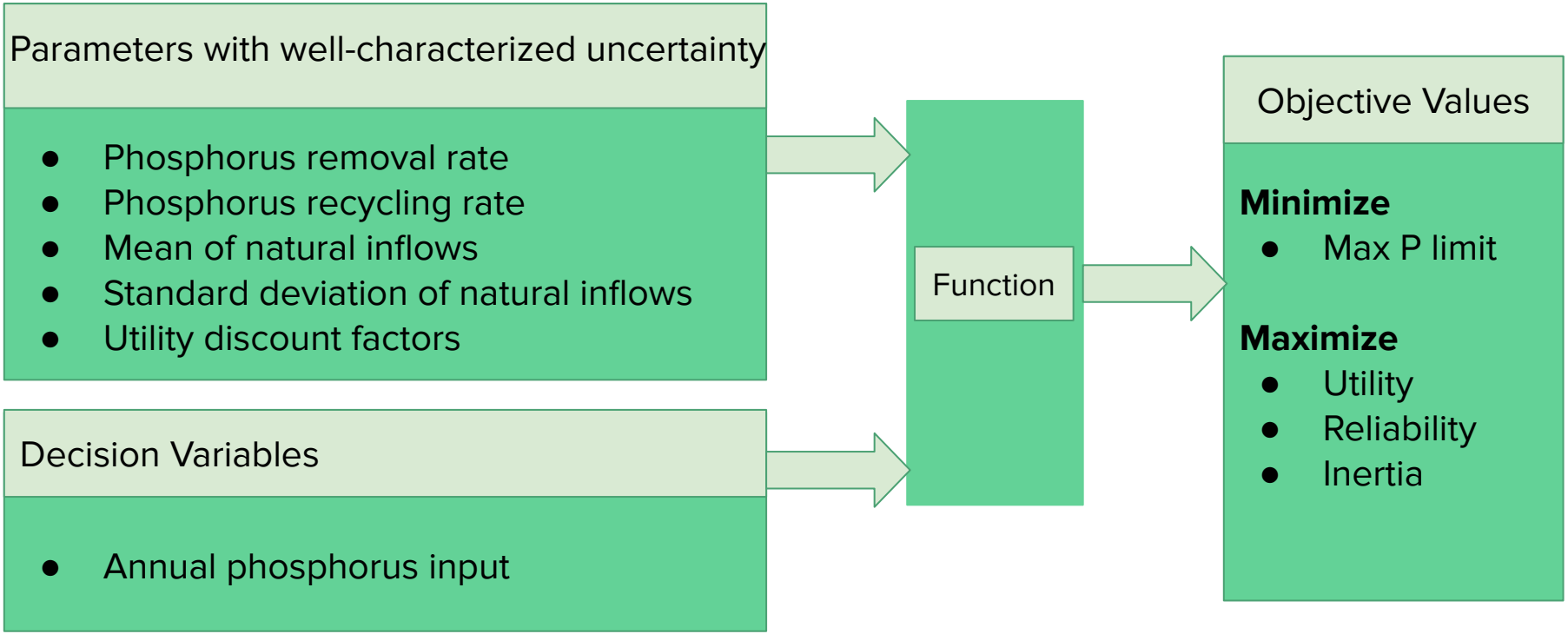
b = rate of P loss per unit time

a = dimensionless parameter describing the steepness of sigmoid curve

K = P value at which recycling reaches half the maximum rate

Source: Carpenter et al., 1999

Lake problem formulation in Rhodium



Source: https://github.com/OpenMORDM/OpenMORDM/wiki/Defining%20a%20Model

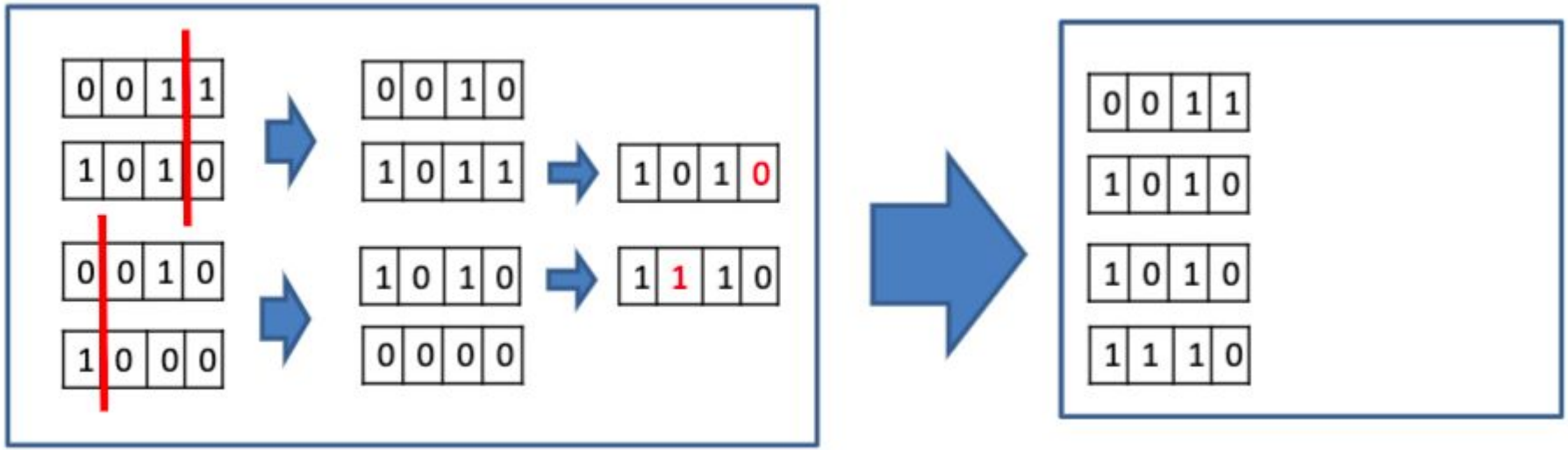
Lake problem formulation in Rhodium

- Model inputs

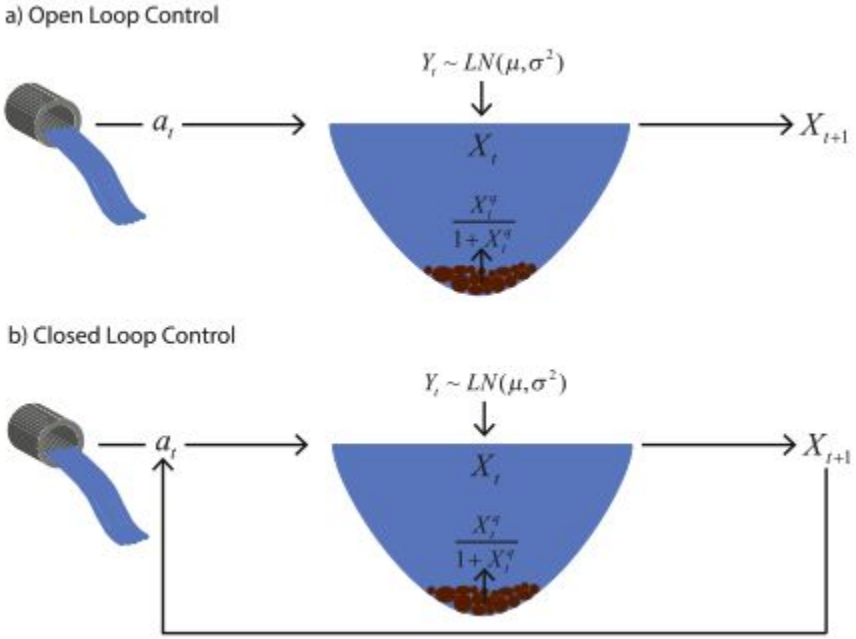
```
def lake_problem(pollution_limit,
         b = 0.42,         # decay rate for P in lake (0.42 = irreversible)
         q = 2.0,          # recycling exponent
         mean = 0.02,      # mean of natural inflows
         stdev = 0.001,    # standard deviation of natural inflows
         alpha = 0.4,      # utility from pollution
         delta = 0.98,     # future utility discount rate
         nsamples = 100): # monte carlo sampling of natural inflows)
```

Optimize the Rhodium Model

- The Rhodium model uses the NSGA-II optimization algorithm
- “Levers” or parameters in the model are iteratively tweaked by the algorithm to find optimal policies



Closed Loop Direct Policy Search vs Open Loop Intertemporal Control Strategy



Source: Quinn et al (2017)

Model Output

- Model output is a collection of optimal policies
- Each policy includes corresponding values for the 4 objective functions

	pollution_limit	max_P	utility	inertia	reliability
0	[0.02472156653486018, 0.0005092878026342444, 0...	0.230526	0.302243	0.838384	1.0000
1	[0.025479198131745425, 0.08099822347194309, 0....	0.413127	0.447774	0.727273	0.9996
2	[0.08281475714788841, 0.001261564498185647, 0....	0.217104	0.352261	0.808081	1.0000
3	[0.08111582993527067, 0.001261564498185647, 0....	0.911485	0.431152	0.757576	0.9526
4	[0.08111582993527067, 0.001261564498185647, 0....	0.329243	0.382202	0.797980	1.0000
5	[0.08270864663396345, 0.00022583728504802186, ...	0.704168	0.414815	0.808081	0.9743
6	[0.04011701826649017, 0.05257271958858992, 0.0...	0.527062	0.444348	0.747475	0.9937
7	[0.07755534965011637, 0.001261564498185647, 0....	0.826528	0.426855	0.767677	0.9622
8	[0.025479198131745425, 0.06834231918517299, 0....	0.272270	0.340484	0.818182	1.0000
9	[0.025479198131745425, 0.06834231918517299, 0....	0.311525	0.416324	0.767677	0.9994

Lake problem optimization data summarized in a data frame

Using Rhodium to Explore Optimization Data

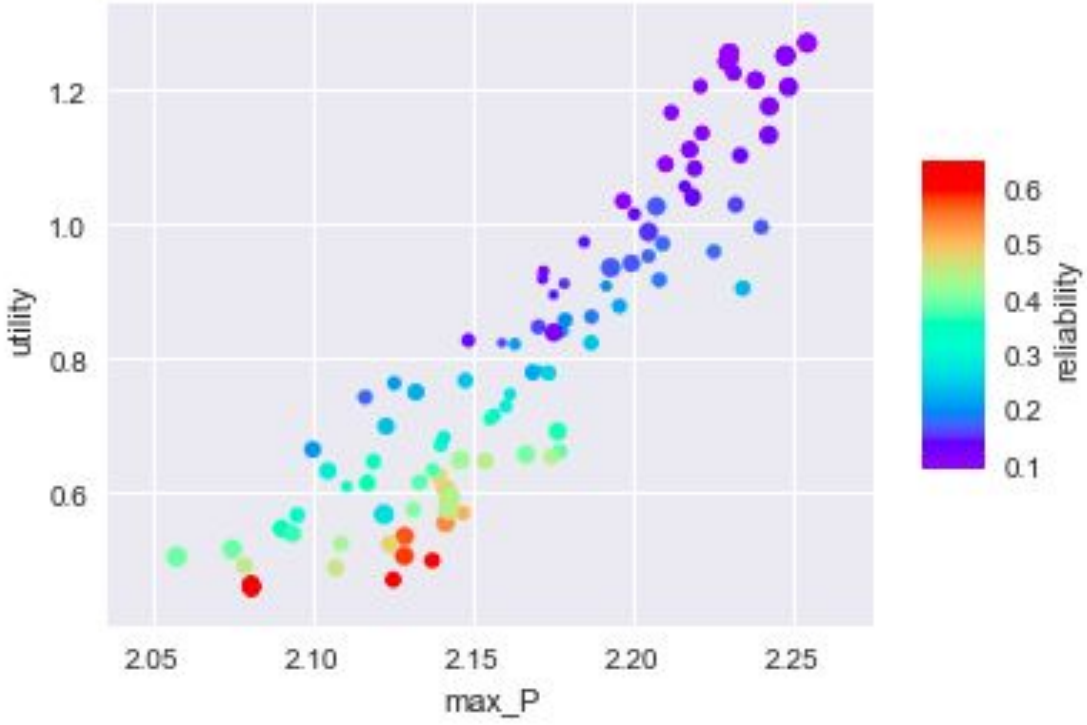
- **2D scatter plot of the Pareto front**

X-axis: Max P limit

Y-axis: Utility

Color: Reliability

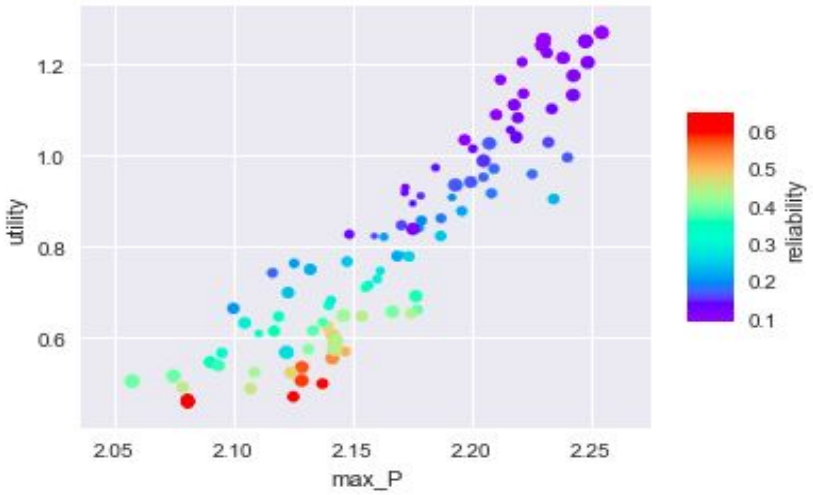
Size: Inertia



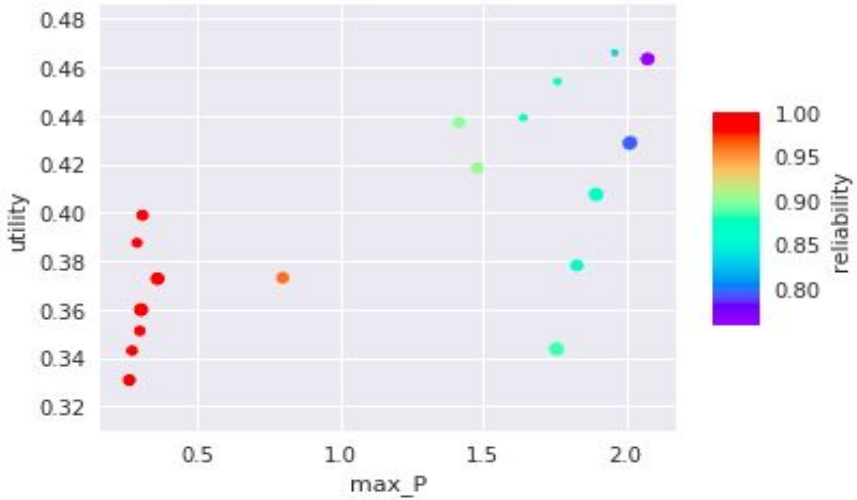
Pareto Optimal Policies

Added Optimization Constraints to Narrow Results

- Added a reliability ≥ 0.75 constraint

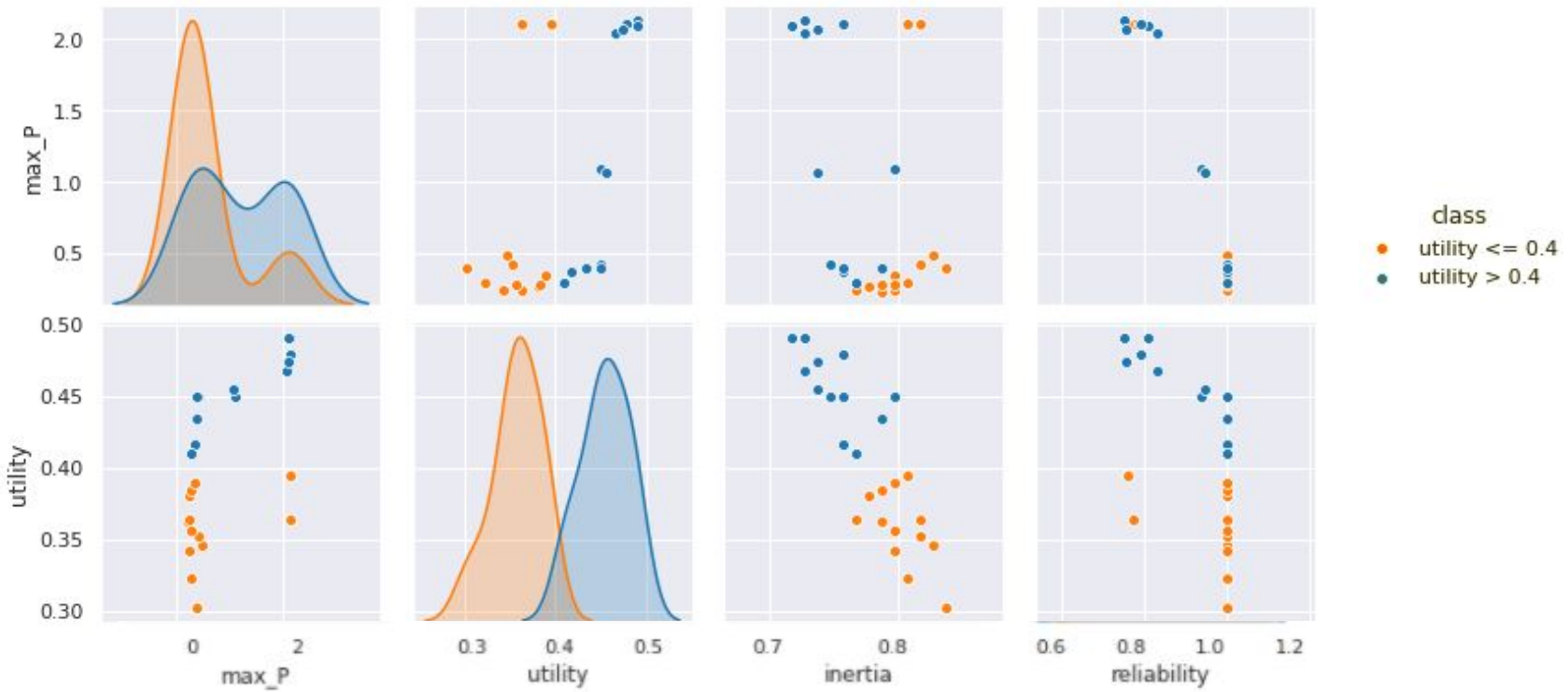


Scatter plot of pareto optimal policies



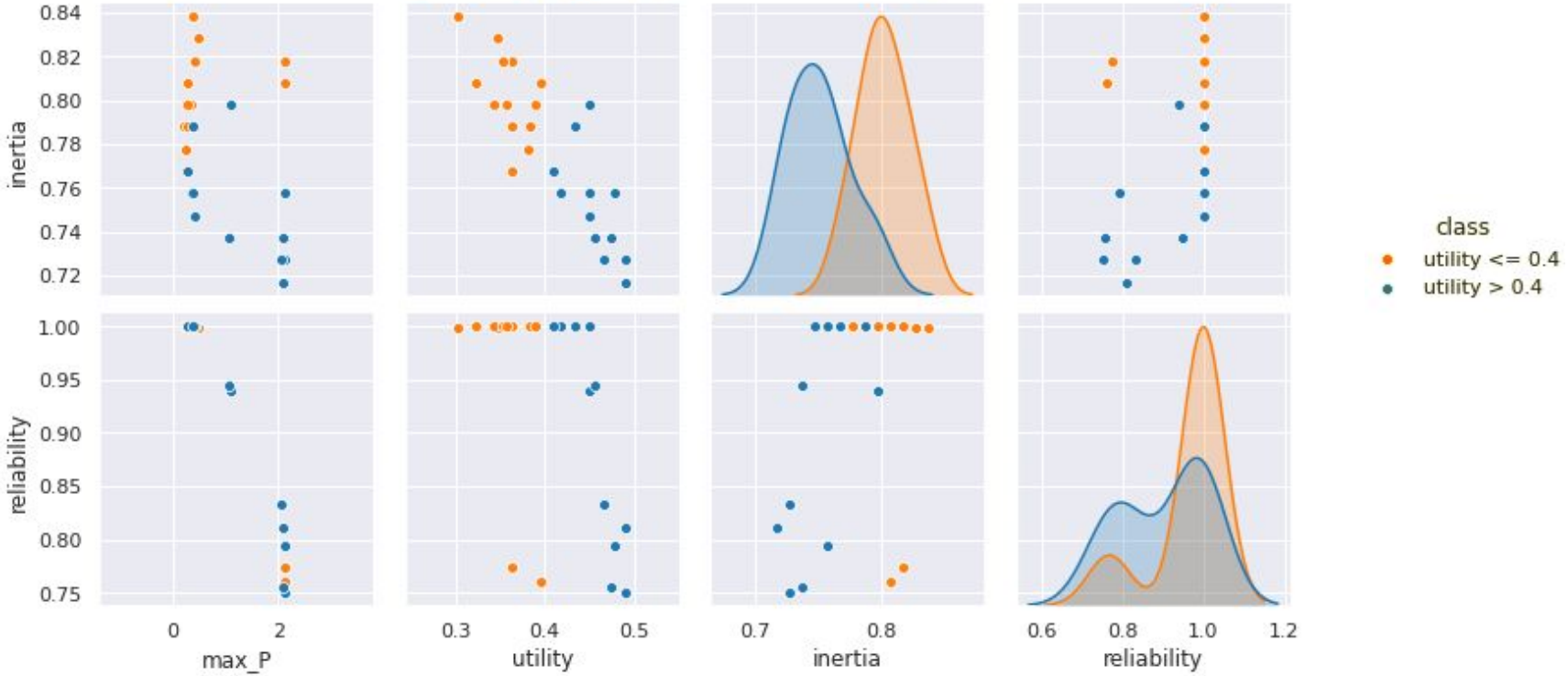
Scatter plot of pareto optimal policies from constrained problem

Pairwise Comparison of Objective Values for Pareto Optimal Policies



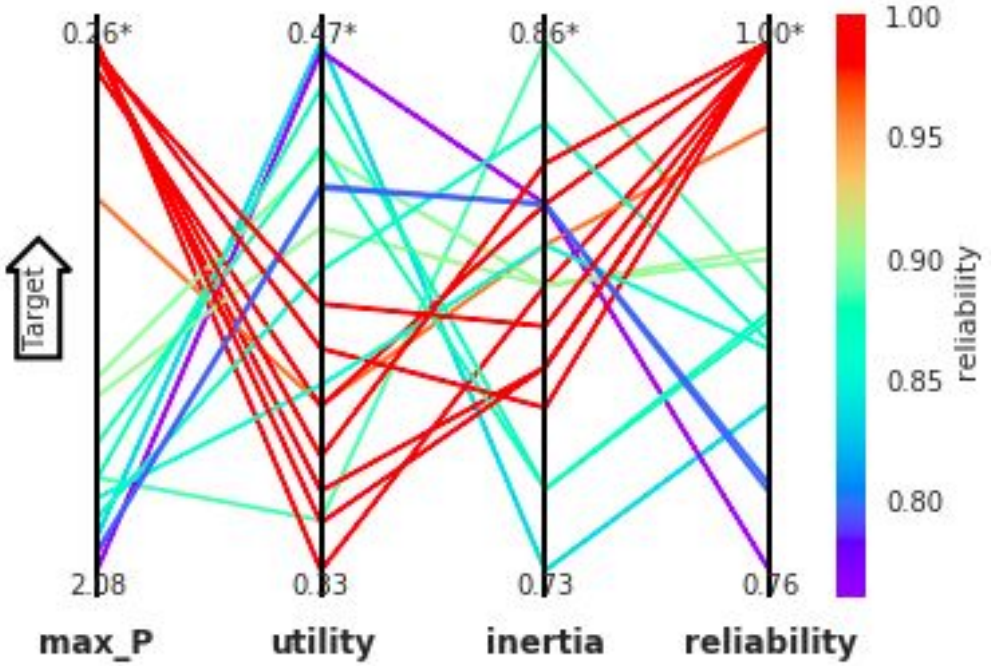
Pairwise comparisons of objectives

Pairwise Comparison of Objective Values for Pareto Optimal Policies



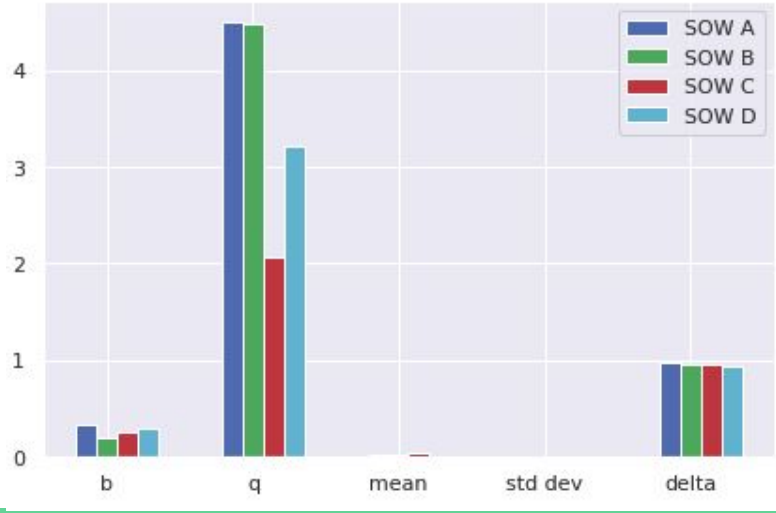
Pairwise comparisons of objectives

Parallel Axis Plot of Objective Values for Pareto Optimal Policies



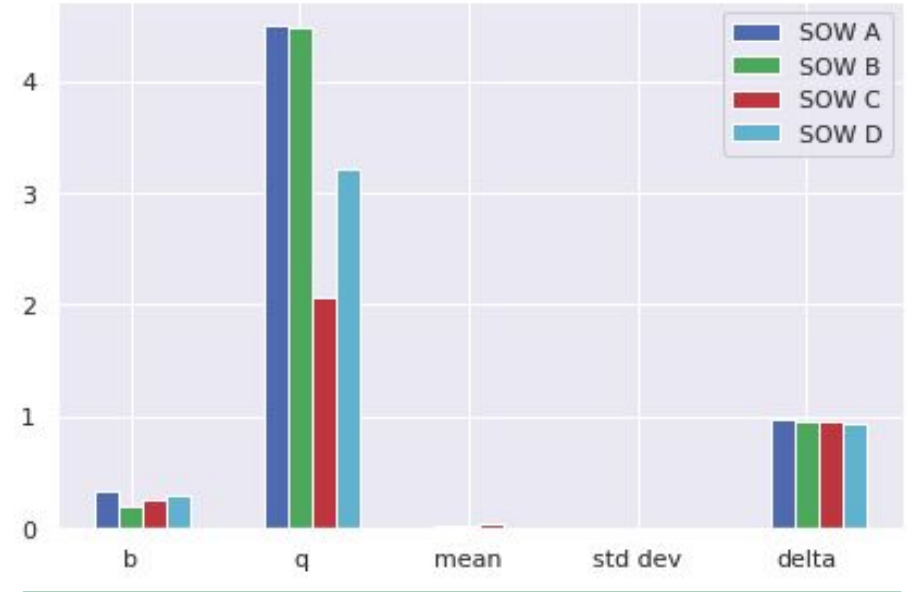
Putting the RDM in MORDM

- Generate multiple states of the world by defining the uncertain parameters in the model
- We generated 1000 states of the world by defining uniform distributions for recycling exponent, decay rate, mean of natural P inflows, standard deviation of P inflows, and future utility discount rate



Visual representation of 4 states of world that were generated using Rhodium framework

Overview of Transition from Optimization to Scenario Discovery



Policy Under Consideration

Function

Objective Values

Minimize

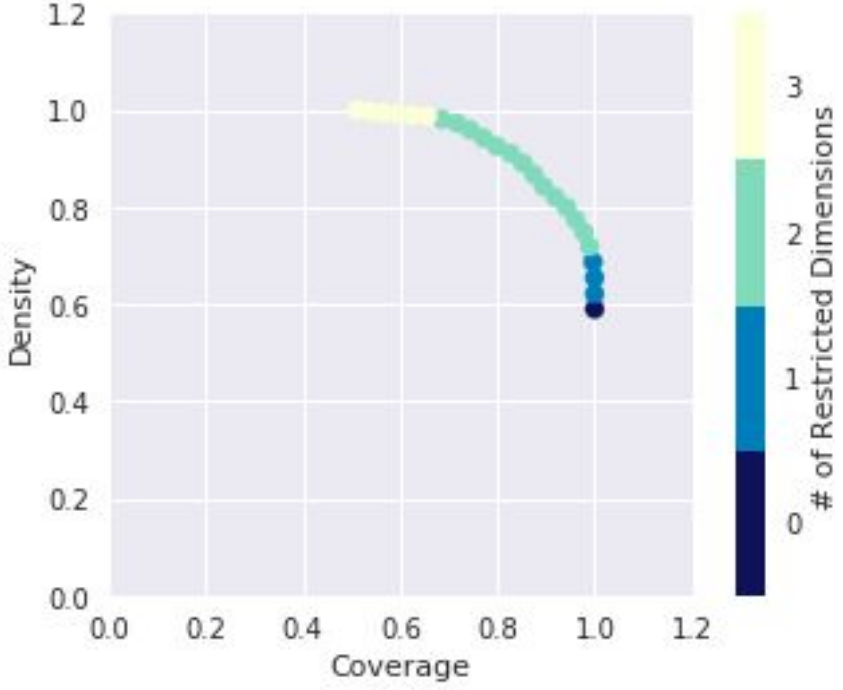
- Max P conc in lake

Maximize

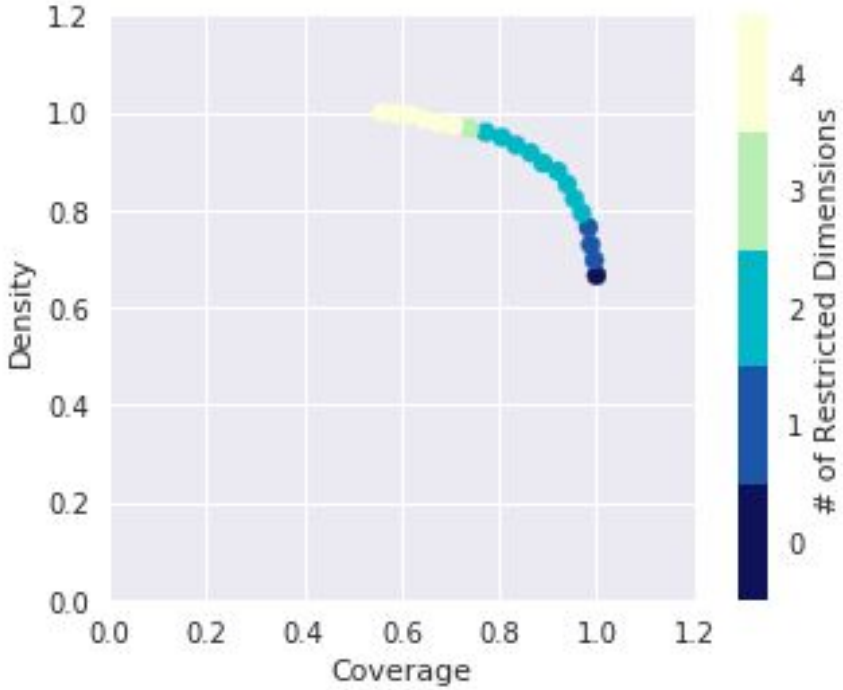
- Utility
- Reliability
- Inertia

Sensitivity Analysis

Patient Rule Induction Method to Identify Key Uncertainties

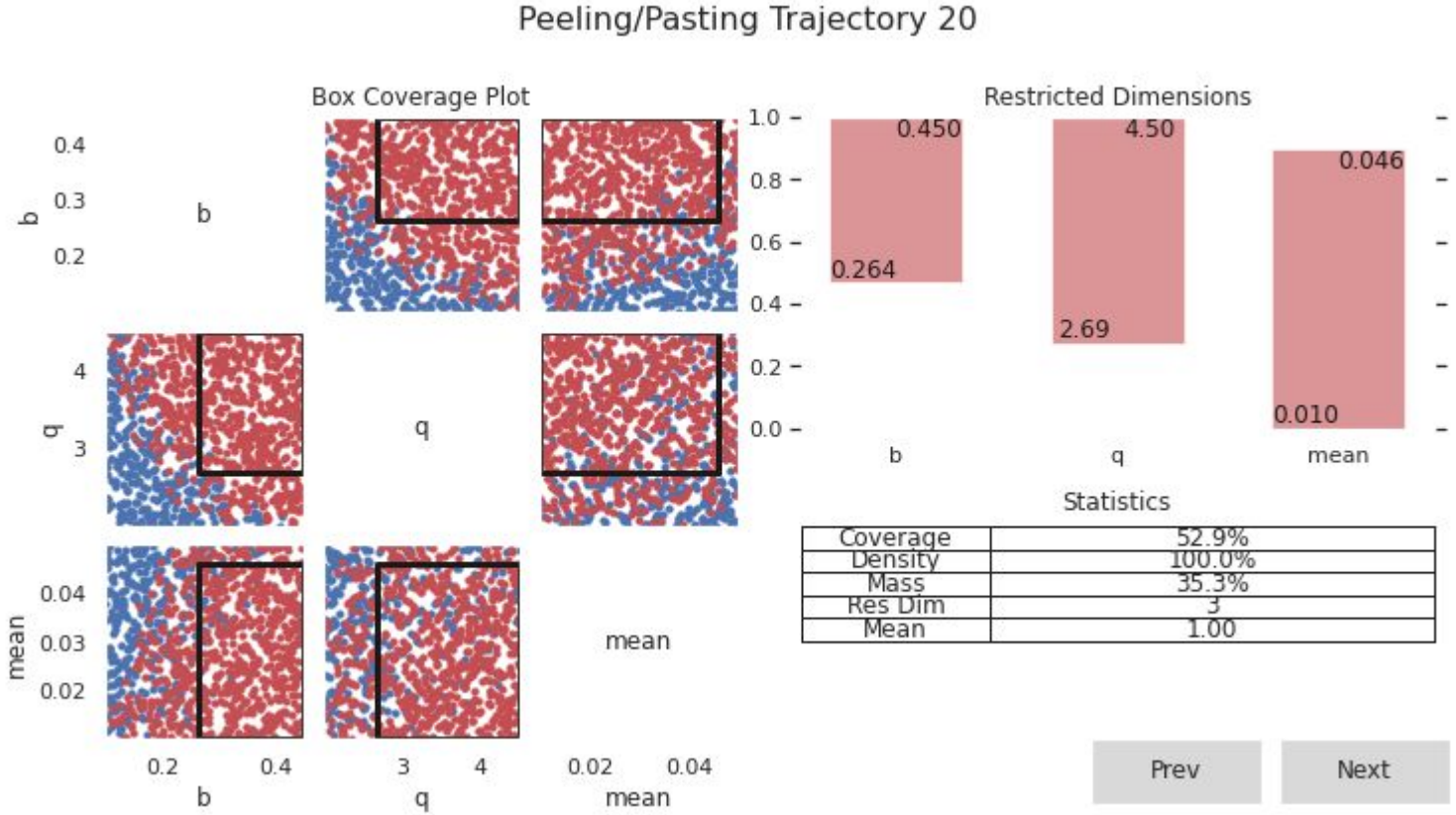


PRIM Results with Policy of Annual pollution limit of .02



PRIM Results with Policy of Annual pollution limit of .01

Patient Rule Induction Method to Identify Key Uncertainties



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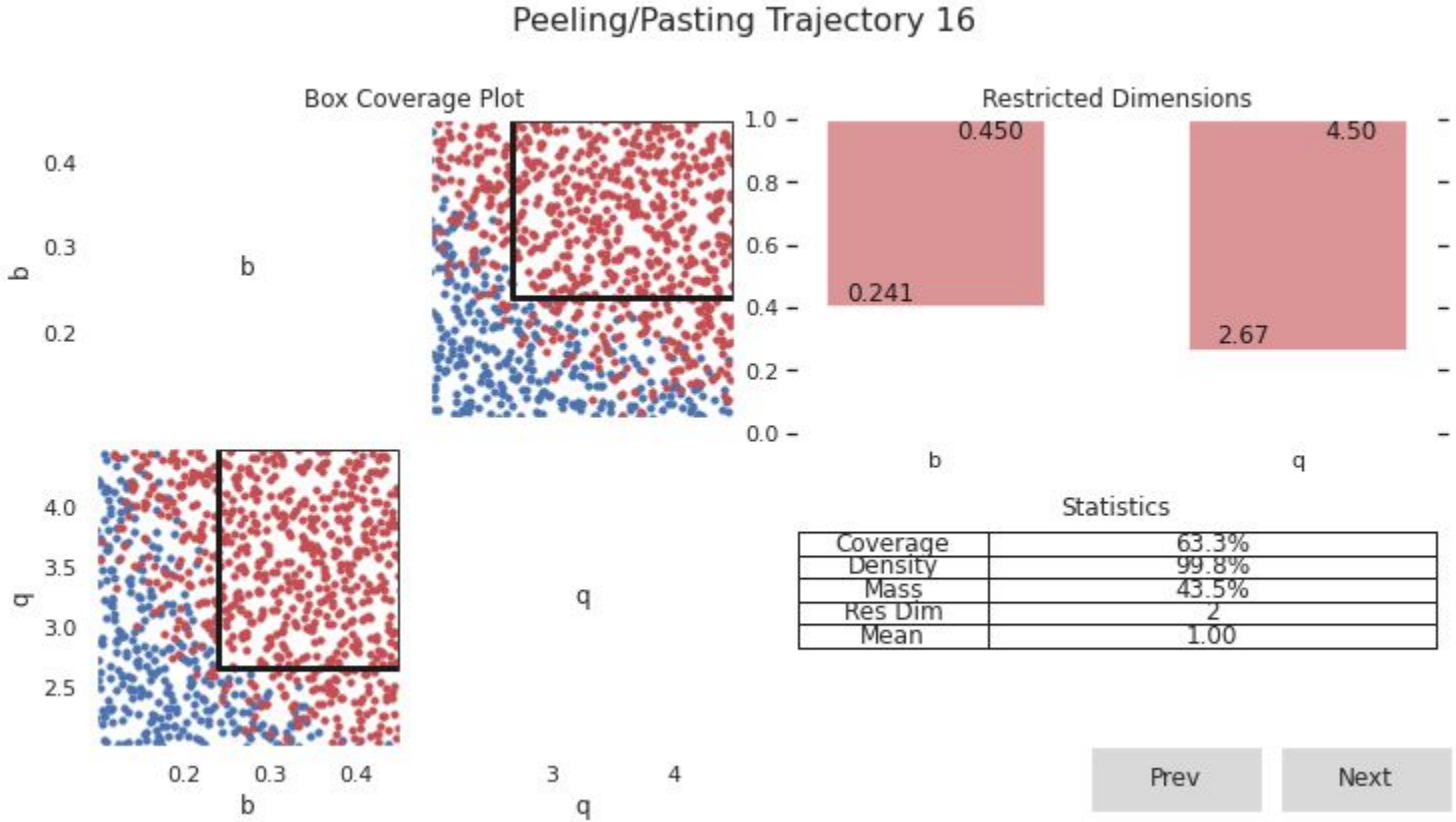
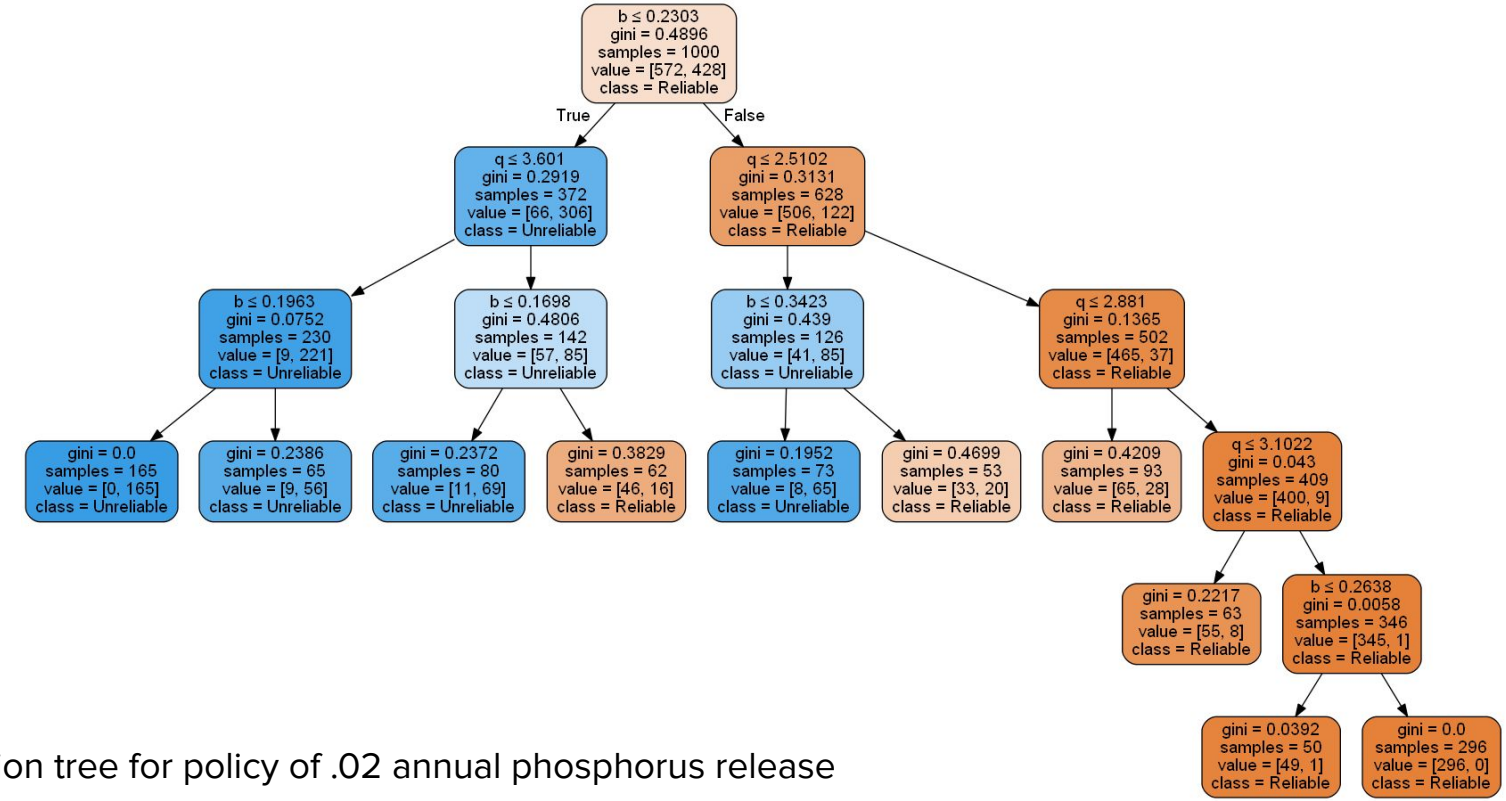
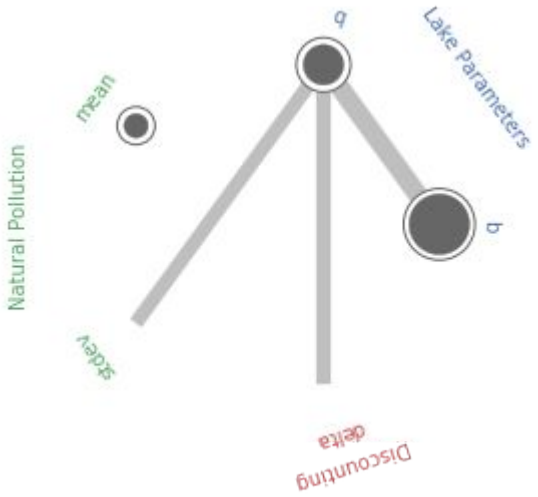


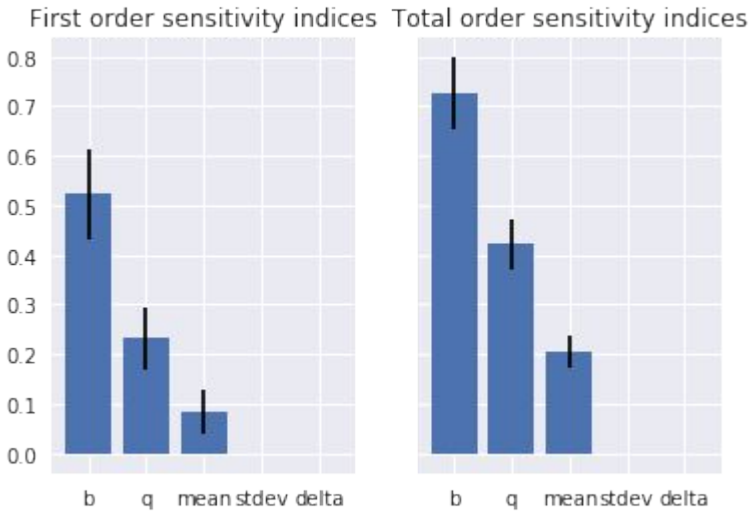
Classification and Regression Trees



Regression tree for policy of .02 annual phosphorus release

Sobol Sensitivity Analysis





Conclusion

- The decay rate (b) and recycling rate (q) seem to have the most influence
- Rhodium is very useful in multiobjective modelling and data visualization for environmental problems
- This model did not take into account the cost to implement any policy
- Jupyter notebooks aren’t the best place to run Rhodium
- It might be worthwhile to use other algorithms besides NSGA-II
- States of the world were generated by assigning uniform distributions to uncertain parameters

Thank you

Sources

Direct policy search for robust multi-objective management of deeply uncertain socio-ecological tipping points (Quinn et al 2017)

Rhodium: Python Library for Many-Objective Robust Decision Making and Exploratory Modeling

Many Objective Robust Decision Making for Complex Environmental Systems Undergoing Change (Kasprzyk et al 2012)

Many-objective robust decision making for managing an ecosystems with deeply uncertain threshold response (Singh et al 2015)

Management of Eutrophication for Lakes Subject to Change (Carpenter et al 1999)