Using Optimization to Guide Implementation Planning: From *What If* to *What's Best*

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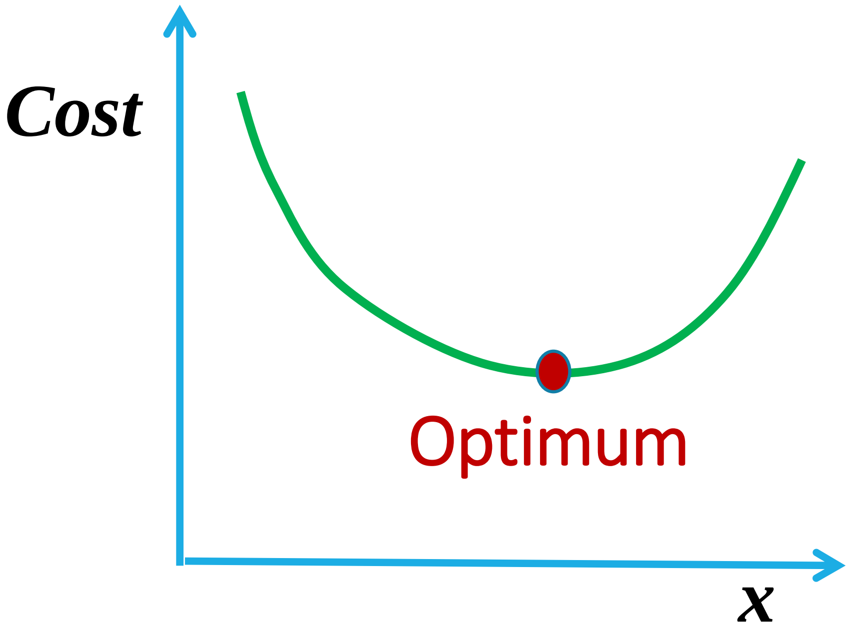

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Outline

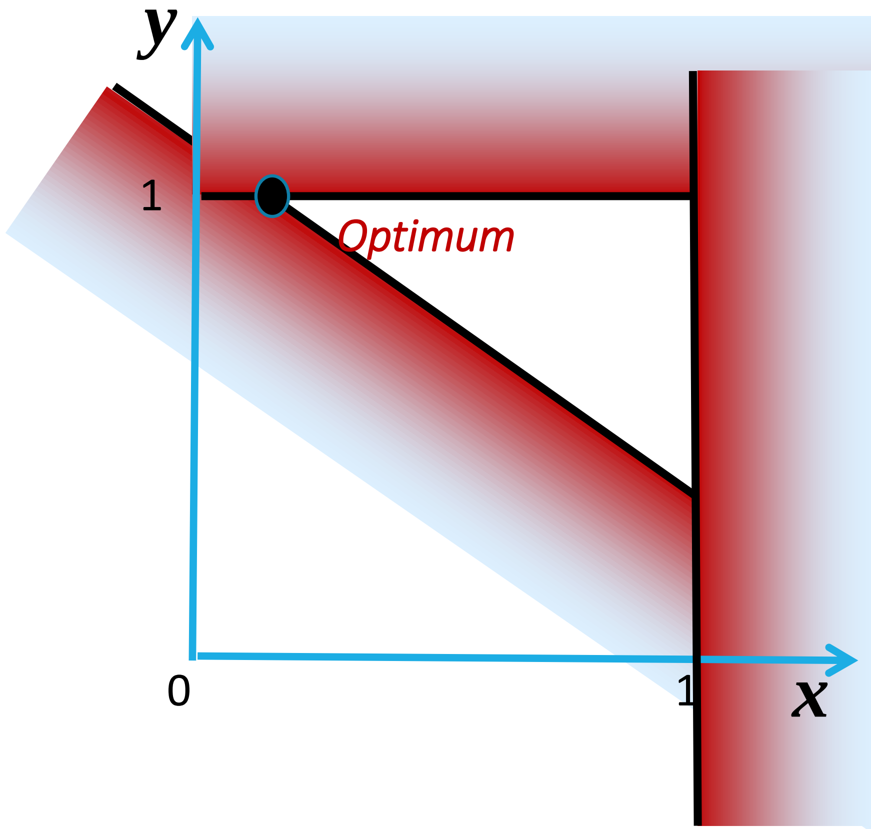
- Optimization: what and why?
- How can it help implementation planning?

What is optimization?

- Choose the "best" alternative from the feasible possibilities
- Four elements:
  - **"Best"**: defined by one (or more) *objective functions*
    E.g., MIN cost, MIN loadings
  - **"Possibilities"**: *decision variables* whose values we determine
    E.g., how much $ to invest in BMP type *i* at location *j*
  - **"Feasible"**: values of variables are limited by *constraints*
    E.g., must meet TMDL target; limited # of suitable sites; mass balances
  - **"Solver"**: a procedure, computer program

What is optimization?

- Example:
  Choose BMPs x, y (= *decision variables*)…
  … in order to MIN *Objective* = Cost = $3x + 2y$
  … subject to *constraints*:
  $$0.7(1-x) + 0.9\,(1-y) \leq 0.6 \text{ (= TMDL)}$$
  $$0 \leq x, y \leq 1$$



- Solver: Here, linear programming (can consider >10^6 variables)
  - Other types: discrete linear programming, nonlinear programming

What is optimization?

- Nonlinear Example:

  y is Conservation Till, z is Stream Grass Buffer

  MIN Cost = $3x + 2y + 1.5z$

  subject to: $0.7(1\text{-}x) + 0.9\,(1\text{-}y)(1\text{-}z) \leq 0.6$

  $0.2 \leq x, y, z \leq 1$

- Solution: $x = 0.2$, $y = 0.2$, $z = 0.94$

Why optimization?

- Optimization can suggest good alternatives for further consideration ("screening"). Accounts for:
  - A large number (even an infinity) of feasible alternatives
    - E.g., 150 possible locations X 20 different BMPs X 10 installation years
  - Complex book-keeping & interactions
    - E.g., sequences: land use X local BMP X downstream BMP
    - E.g., effects of loading location & timing on Chl(a)
  - Multiple objectives: show tradeoffs
  - Risks: derive system performance risks from individual BMP risks

Simulation vs. Optimization

- **BayFAST** (Facility Assessment Scenario Tool, www.bayfast.org):
  User selects BMPs→ model calculates loadings:
  - User can adjust BMPs to meet TMDL target

- **Optimization:**
  User selects TMDL→ model suggests “best” BMPs.
  Example inputs:
  - BMP databases (e.g., Wieland et al. 2009)
  - “Response surface” modeling (e.g., statistical fit of CBP tool outputs)

Questions optimization can address

1. What's the **least-cost** portfolio of BMPs that achieves a TMDL?
2. What portfolios efficiently address multiple objectives? What are the **tradeoffs**?
3. What portfolios are within X% of the least-cost portfolio, yet are **distinctly different**?
4. How does considering **uncertainty** affect those solutions?
5. What trades of **pollutant credits** would be environmentally & economically beneficial?

1. What's the least-cost portfolio of BMPs that achieves a TMDL?

- Example: Green Infrastructure in Philadelphia
- StormWISE (McGarity, 2012) chooses GI, BMPs to minimize cost of achieving targets for:
  - Stormwater
  - Sediment
  - N
  - P




StormWISE

stormwise.greenphilly.net

StormWISE Model Demonstration

Little Crum Creek Watershed, Delaware County, PA

Reduced Harmful Effects of Storm Runoff (Benefits)

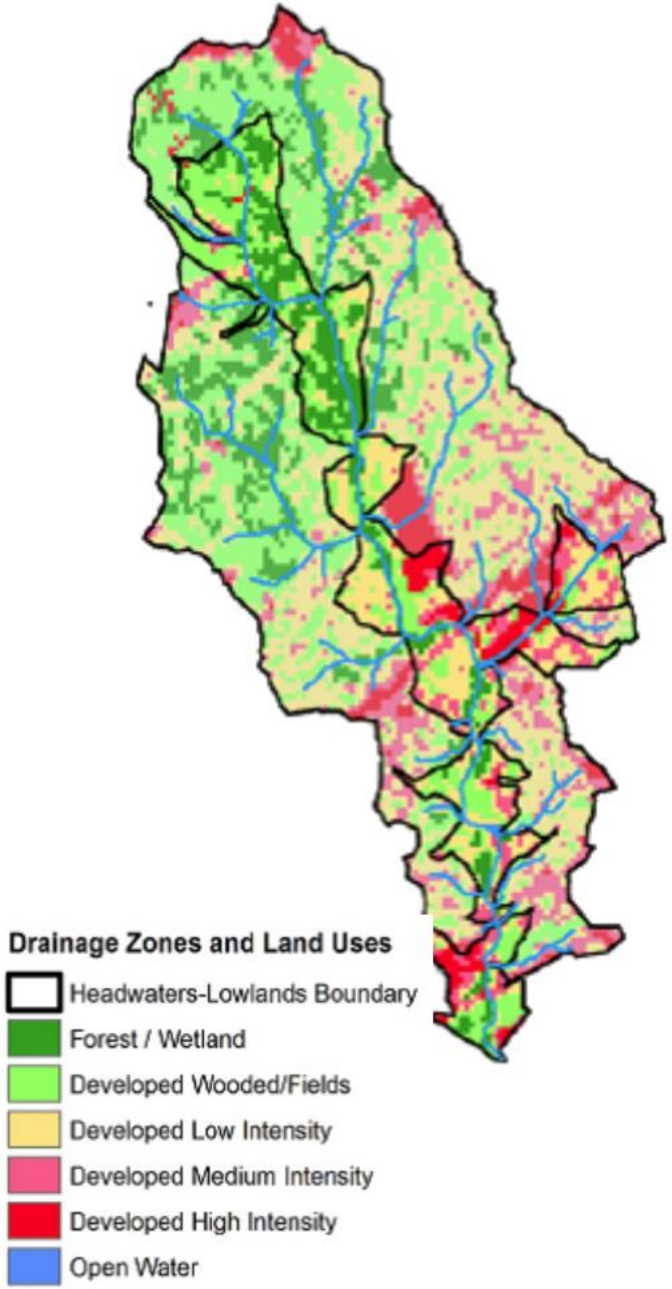
Reduction In:	Benefits if We Do Everything	You Set Benefit Goals	Benefits Actually Achieved
Runoff (million gal.)	902	0.0	0
Sediment (tons)	145	0.0	0
Nitrogen (lbs.)	4,656	0.0	0
Phosphorous (lbs.)	1,122	0.0	0

Minimize Investment Cost

Step 2

Step 1

http://stormwise.greenphilly.net



StormWISE Model Demonstration

Little Crum Creek Watershed, Delaware County, PA

50% of Maximum

Reduced Harmful Effects of Storm Runoff (Benefits)

Reduction In:	Benefits if We Do Everything	You Set Benefit Goals	Benefits Actually Achieved
Runoff (million gal.)	902	450	489
Sediment (tons)	145	72	72
Nitrogen (lbs.)	4,656	2328	2,328
Phosphorous (lbs.)	1,122	561	598

Minimize Investment Cost

Investments:

To Do Everything: $73.6 Million

To Satisfy Benefit Goals: $8.5 Million:

By Zone

Zone of Green Infrastructure	Million $
Headwaters	6.7
Low Lands	1.8

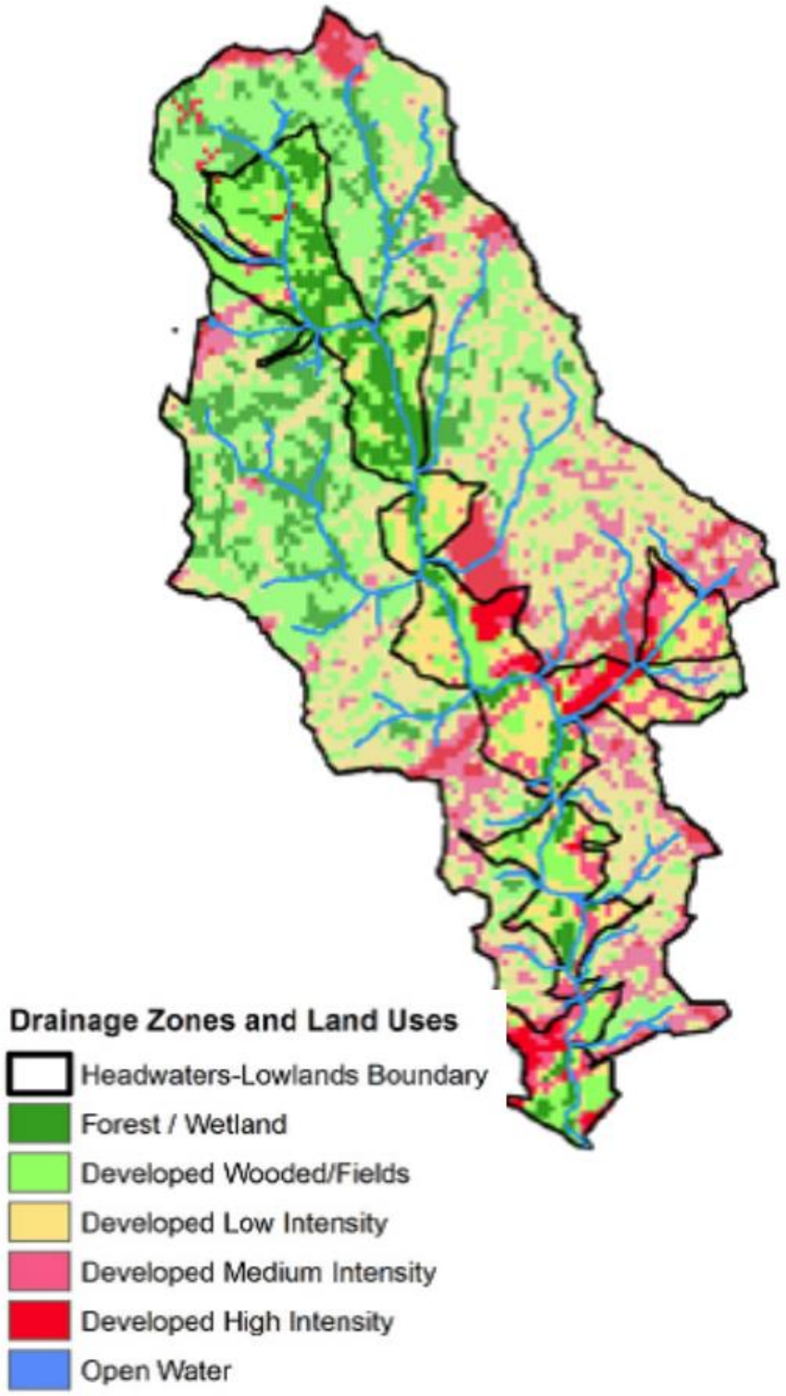
By GI Technology

GI Technology	Million $
Riparian Buffer	0.1
Constructed Wetland	4.9
Bioretention	1.4
Rain Barrel	2.2
Impervious Removal	0.0

By Land Use

Land Use	Million $
Forests & Wetlands	0.0
Wooded/Fields	2.7
Low Intensity	1.3
Medium Intensity	3.0
High Intensity	1.6

The model suggests these as deserving of more detailed analysis



StormWISE Model Demonstration

Little Crum Creek Watershed, Delaware County, PA

100% of Maximum

Reduced Harmful Effects of Storm Runoff (Benefits)

Reduction In:	Benefits if We Do Everything	You Set Benefit Goals	Benefits Actually Achieved
Runoff (million gal.)	902	901	902
Sediment (tons)	145	144	145
Nitrogen (lbs.)	4,656	4655	4,655
Phosphorous (lbs.)	1,122	1121	1,122

Minimize Investment Cost

Investments:

To Do Everything: $73.6 Million

To Satisfy Benefit Goals: $73.5 Million:

By Zone

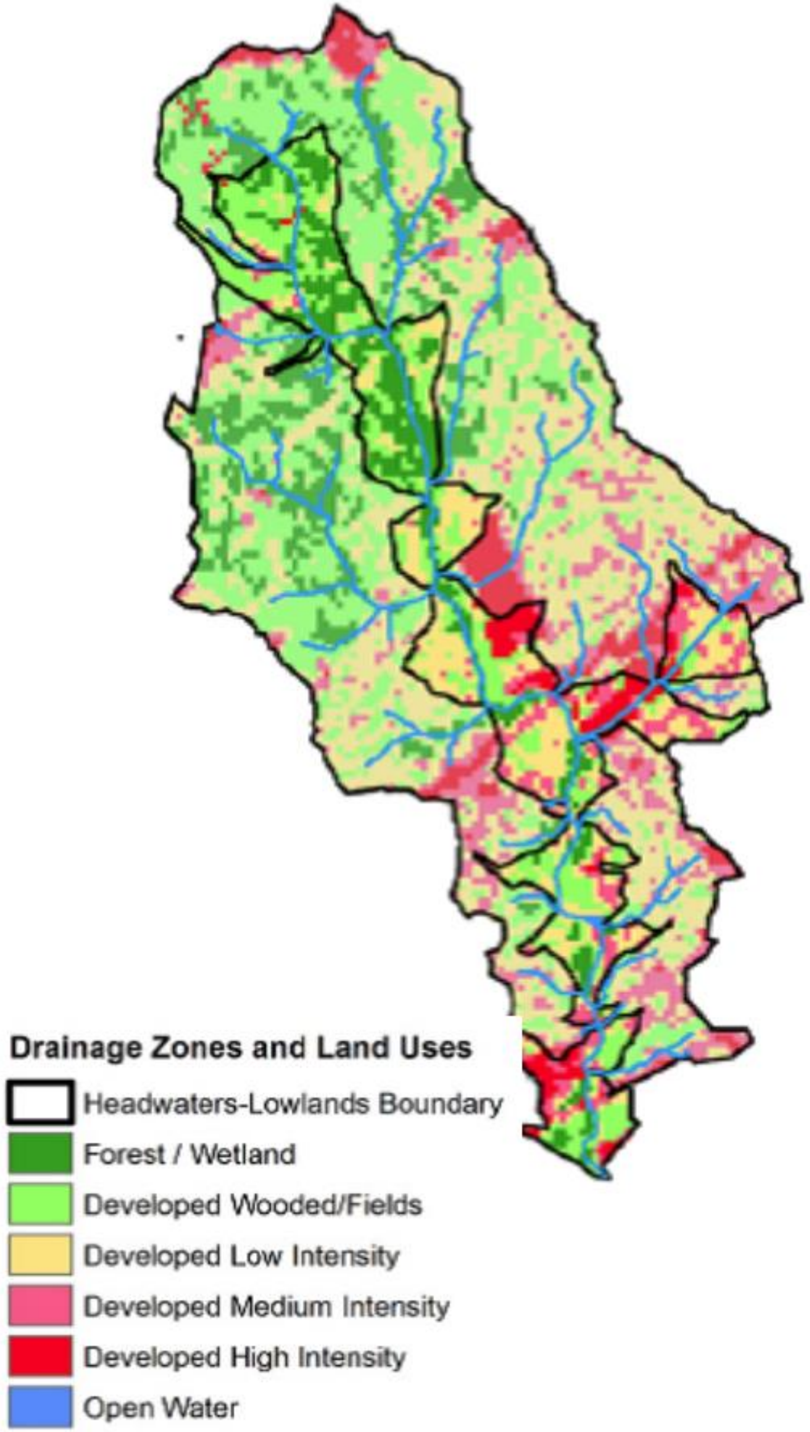
Zone of Green Infrastructure	Million $
Headwaters	54.5
Low Lands	19.0

By GI Technology

GI Technology	Million $
Riparian Buffer	3.2
Constructed Wetland	4.9
Bioretention	6.1
Rain Barrel	9.4
Impervious Removal	2.9

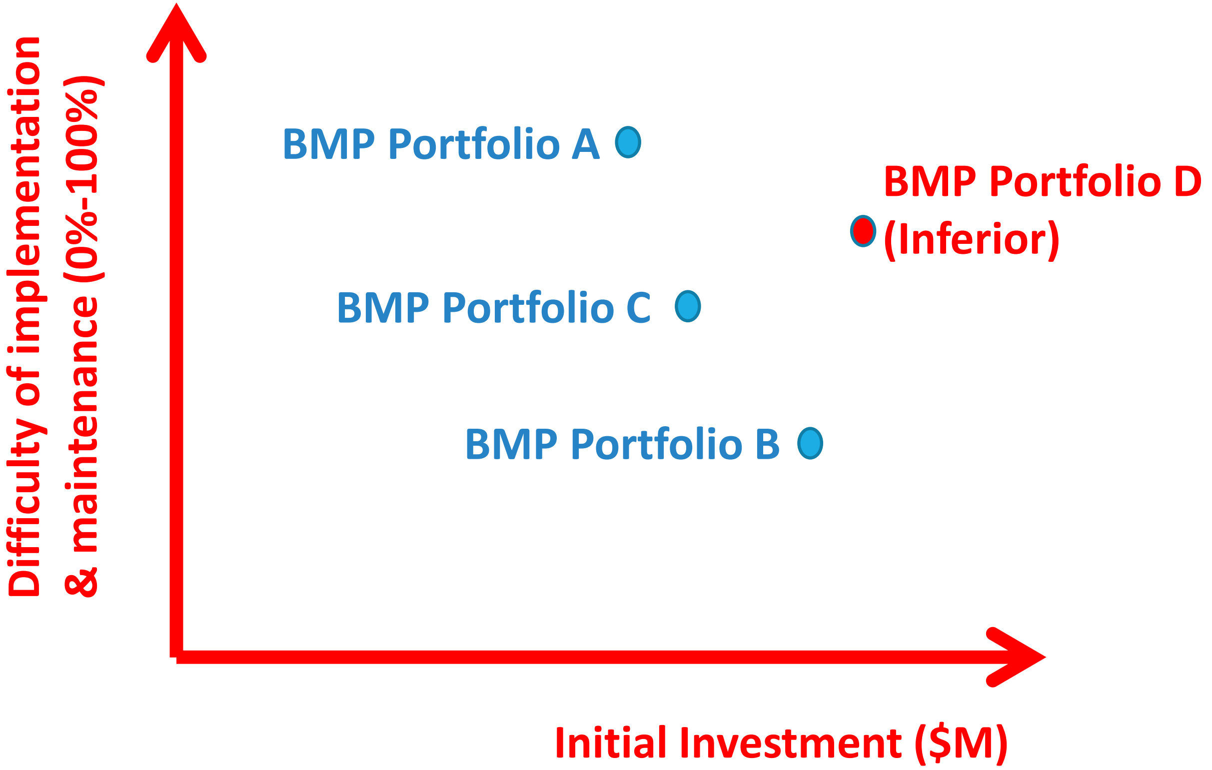
By Land Use

Land Use	Million $
Forests & Wetlands	0.0
Wooded/Fields	3.7
Low Intensity	15.0
Medium Intensity	31.4
High Intensity	23.4



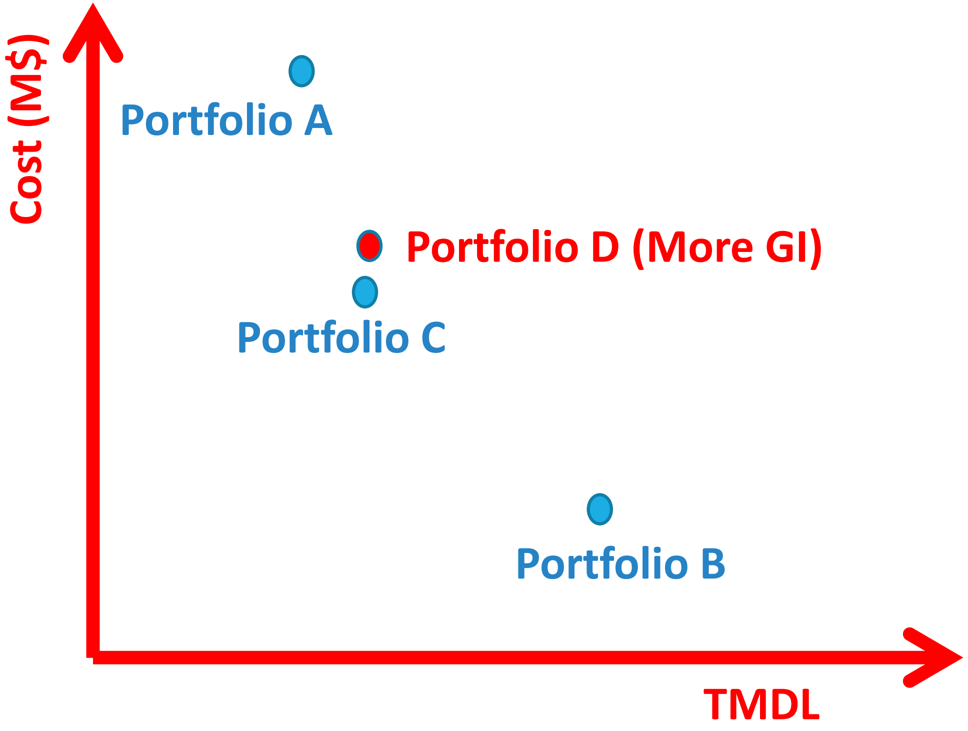
2. What portfolios efficiently address multiple objectives?

- ➢ No alternative is best in all objectives
  - So must consider tradeoffs
- ➢ Optimization can suggest alternative efficient portfolios



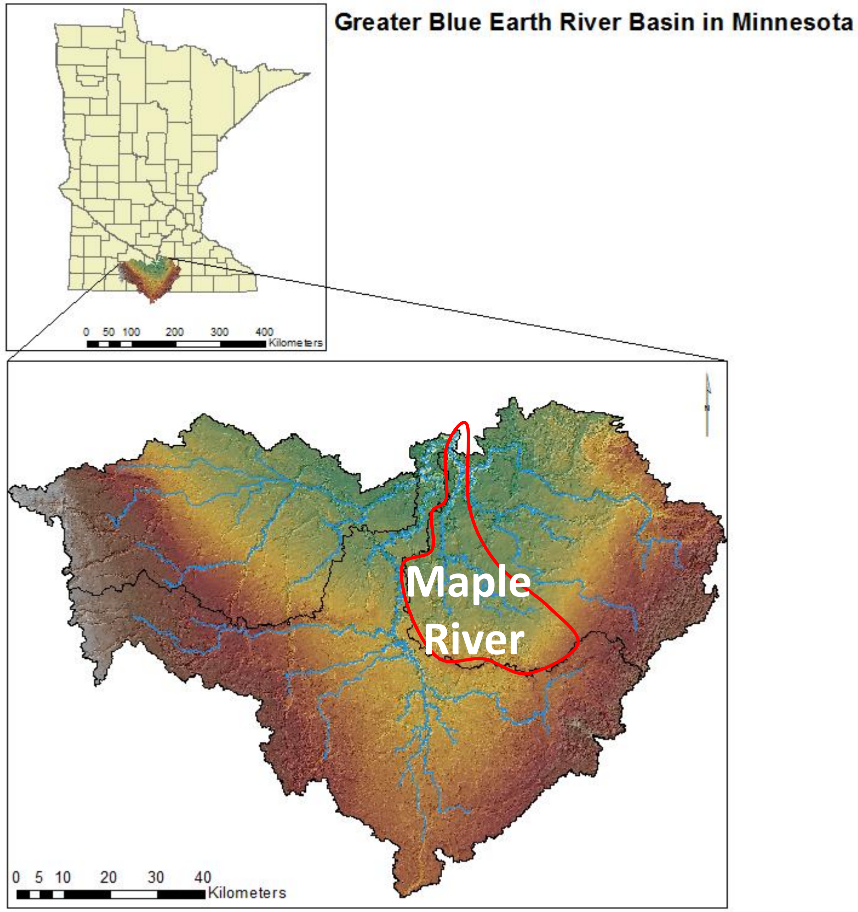
3. What portfolios are within X% of the least-cost portfolio, yet are distinctly different?

- Distinct portfolios might be attractive relative to other, unquantified objectives



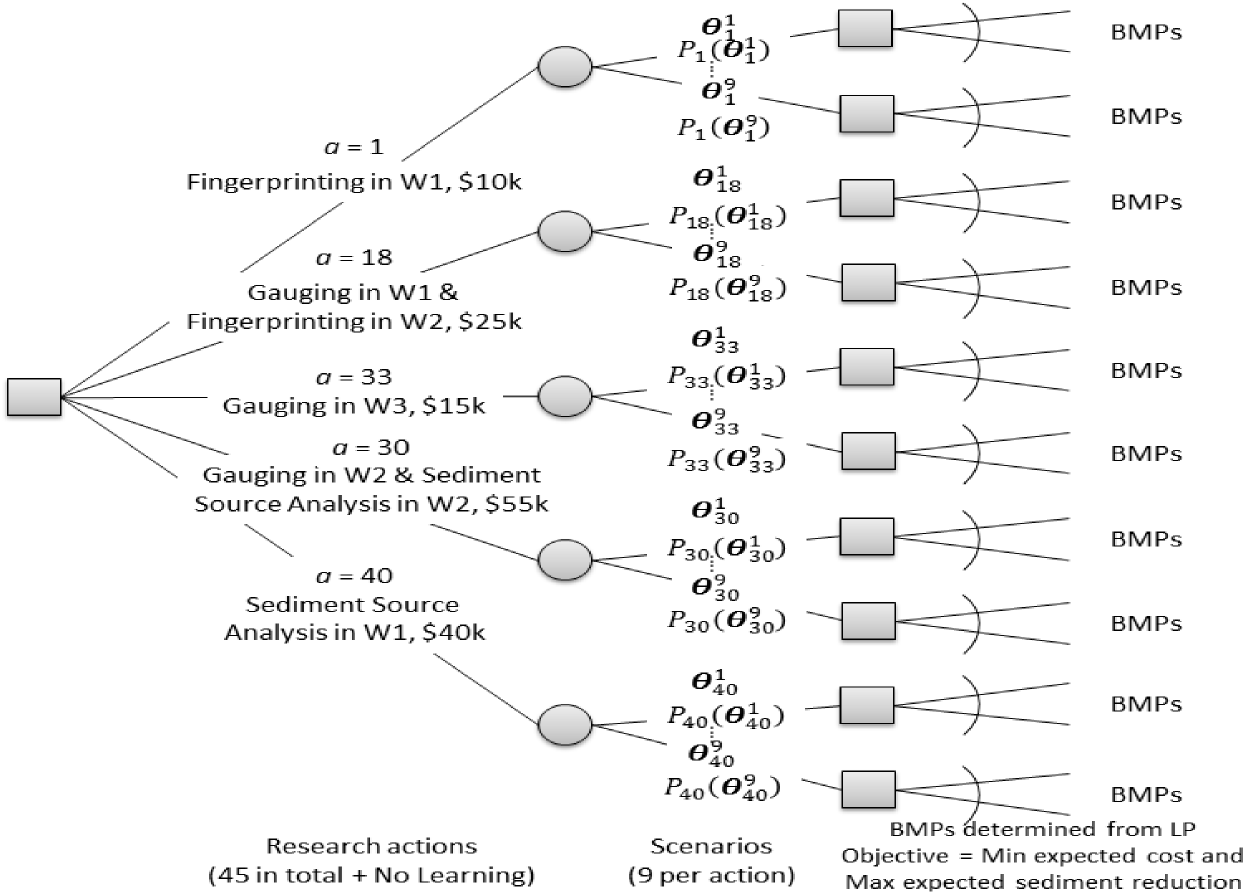
4. How does considering uncertainty affect those solutions?

1. **Chance constraint:** want a 90% chance of achieving TMDL, given uncertain BMP effectiveness
2. **Adaptive management:** Blue Earth Basin BMPs for non-point sediment (Jacobi et al. 2013)



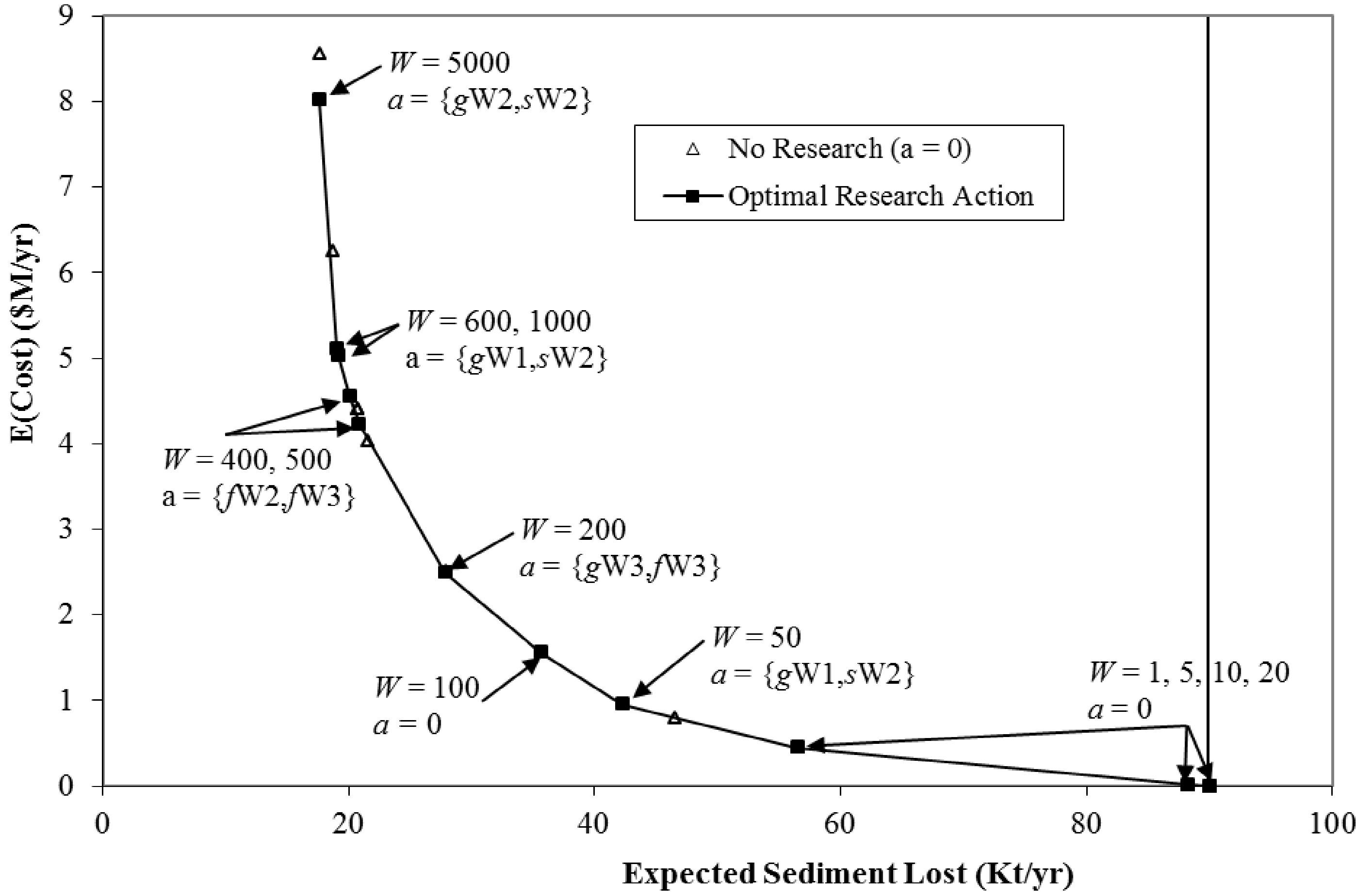
Adaptive management analysis in Maple Basin:

- First consider research / monitoring options in 3 subwatersheds (W1, W2, W3)
- Then implement BMPs
- Decision Tree:



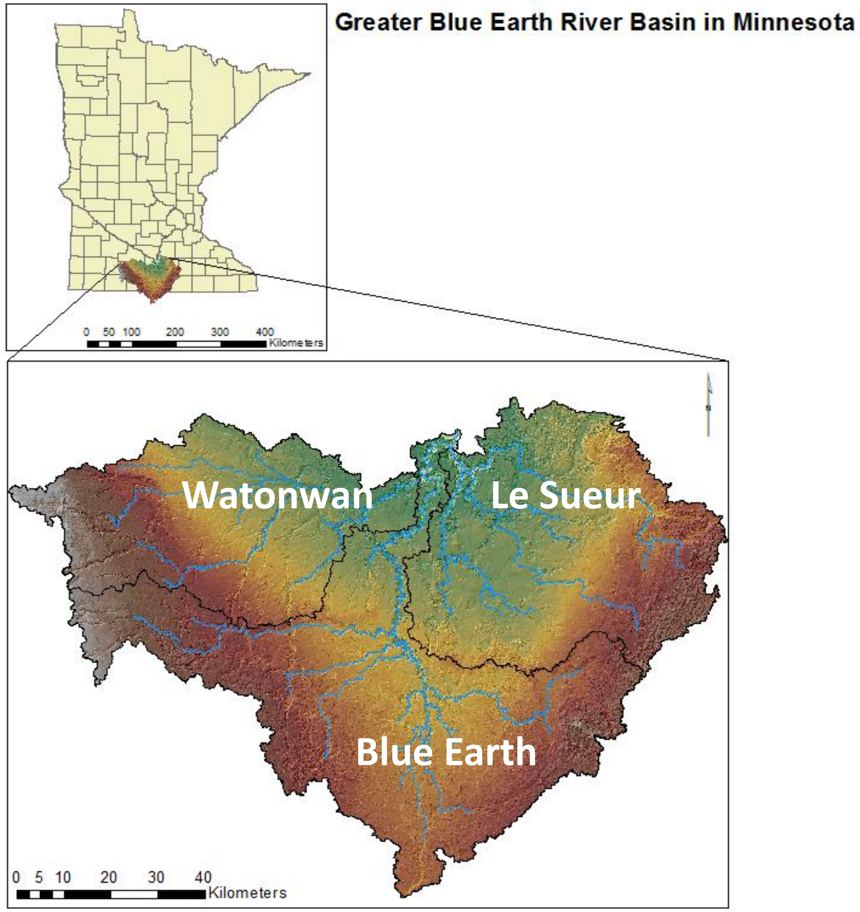
Adaptive management analysis in Maple River

- Cost-Sediment tradeoff curve
- a = optimal research / monitoring actions
  - g = gullies
  - f = field
  - s = streambank



5. What trades of pollutant credits would be environmentally & economically beneficial?

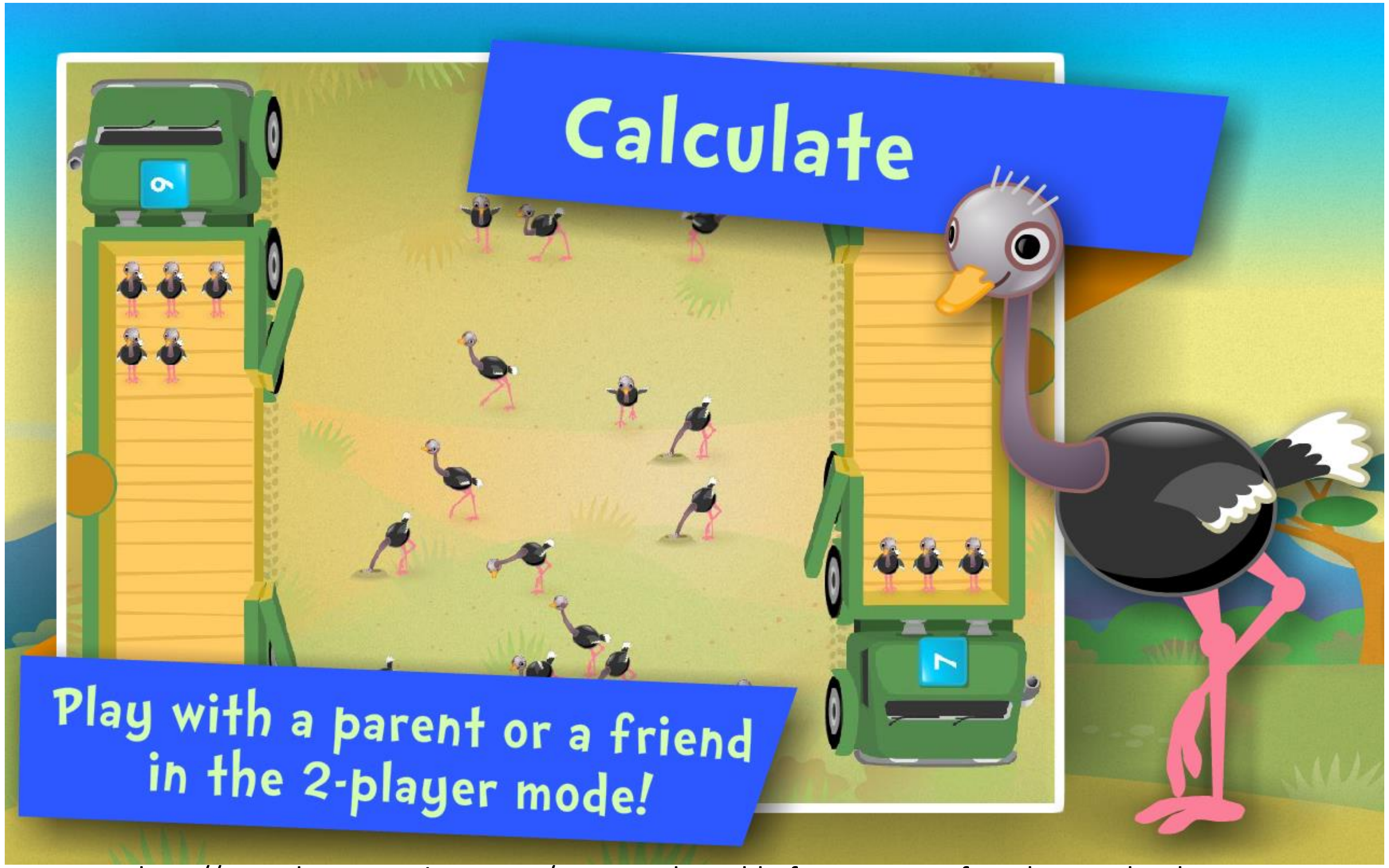
- Calculate marginal cost of load reductions by basin
- Recommend trades that lower cost while meeting loading target
    - As suggested by CBP Nutrient Trading Negotiation Team (2002)



What does it take?

- Agreement on what users want: objectives, alternatives to consider
- Data / models relating alternatives to objectives
  - CBP models, databases
  - BayFAST
- Interface and solver

Questions?



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