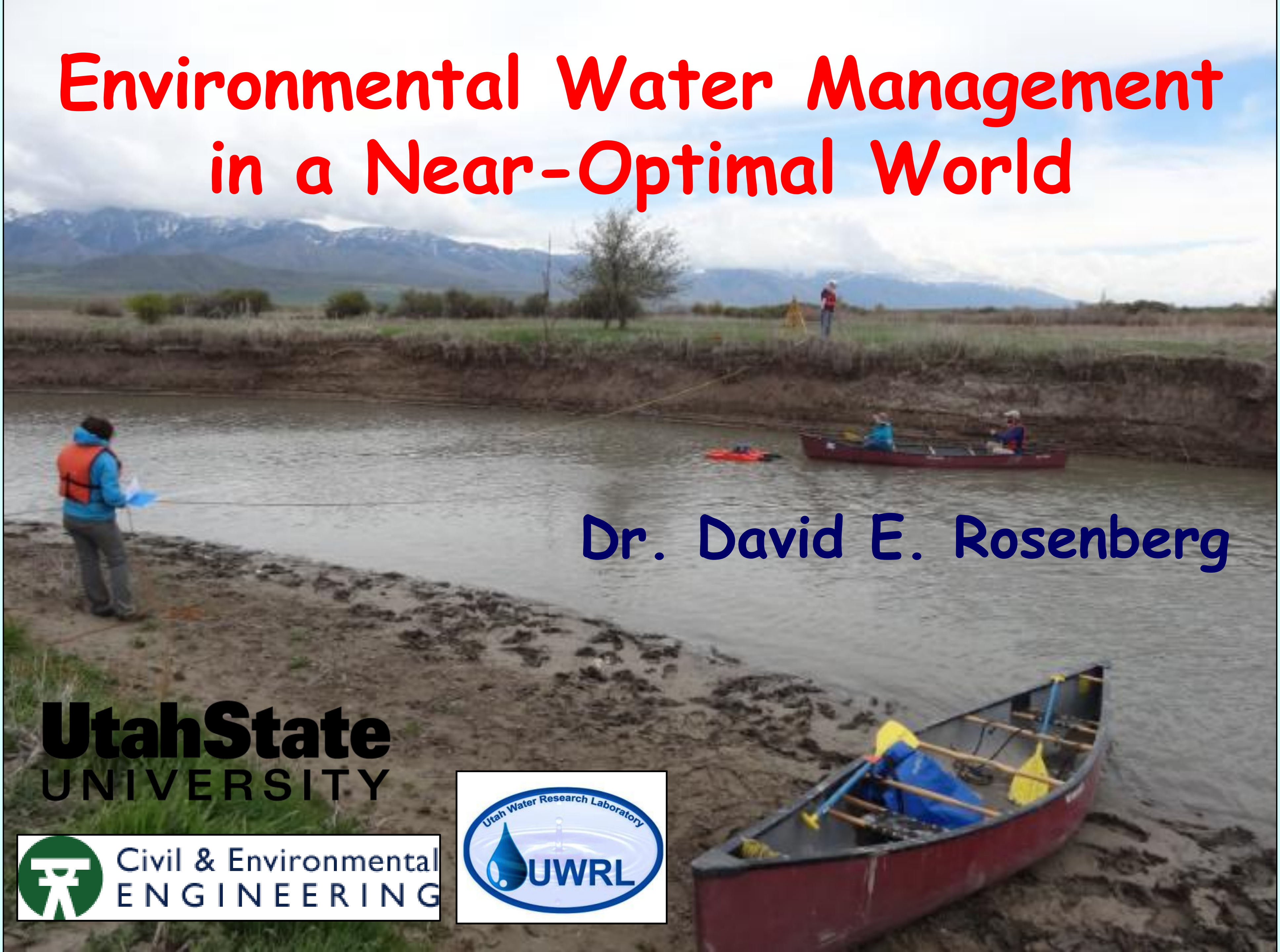
Environmental Water Management in a Near-Optimal World



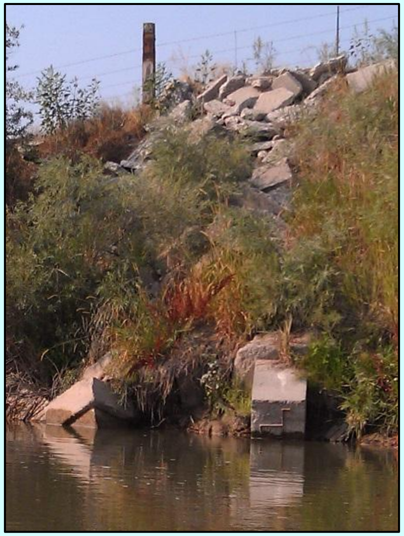
Dr. David E. Rosenberg

UtahState UNIVERSITY

Civil & Environmental ENGINEERING

Utah Water Research Laboratory UWRL

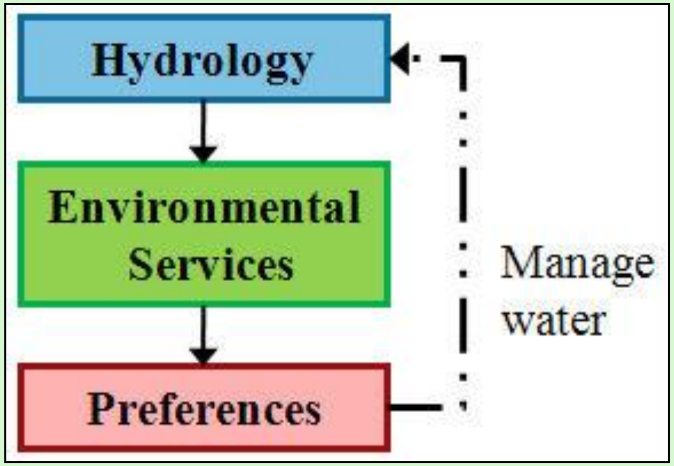
Managed and impacted



How to allocate scarce resources to improve ecosystem performance?

Tools and Applications

1. Improve habitat performance
2. Near-optimal management
3. Challenges and further work



1. Improve Habitat Performance

a. Identify Management Purpose(s)

b. Define Performance Metric

c. Specify Decision Variables

d. Relate Metric and Variables

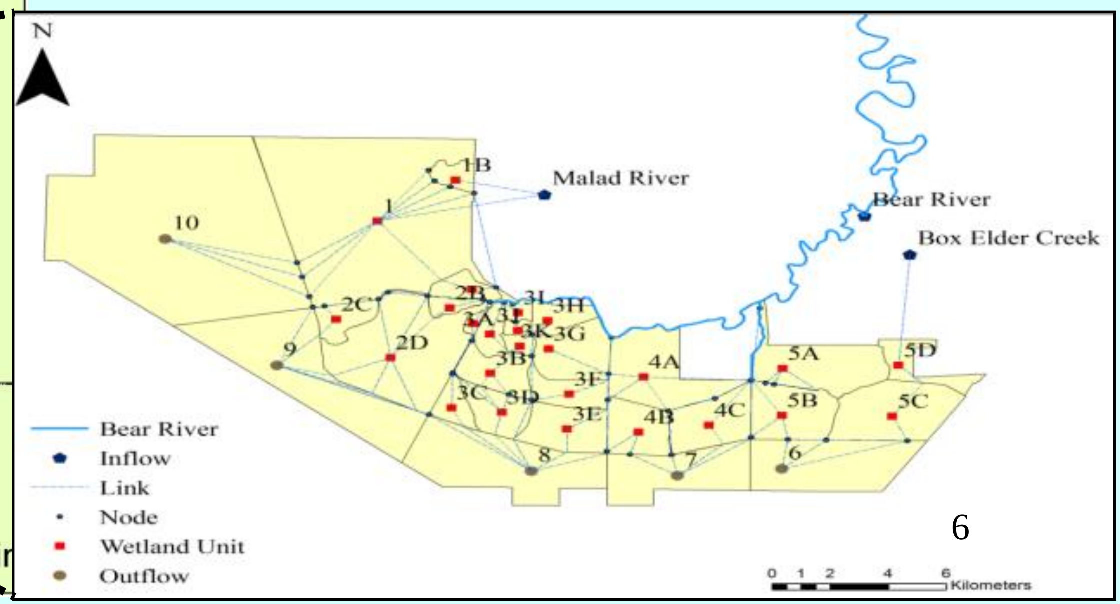
e. Identify Constraints

f. Embed Metric in Systems Model as Objective to Maximize

g. Compare current and "optimal" performance

Bear River Migratory Bird Refuge, Utah

- 300 km^2 (118 km^2 as wetlands)
- 26 wetland units
- 200+ bird species
- Managed by U.S. Fish & Wildlife Service



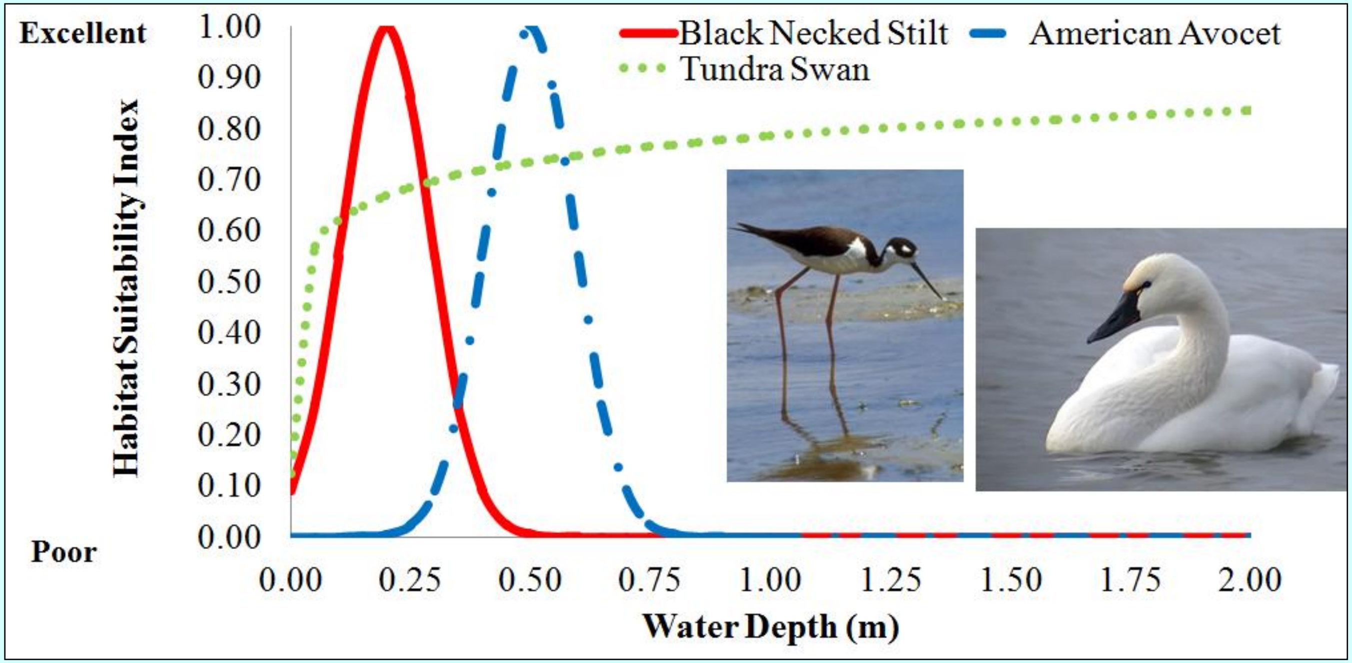
Defining the Model with Stakeholders

Component	Refuge actions	Model
Management Objective	Create diverse habitat types that support a diversity of bird species and mimic a well-functioning freshwater wetlands	
Performance indicator(s)	• Key bird species counts • Native veg. coverage • Water level targets	• Weighted unit area for wetlands (WUAW)
Decision variables	• Water flow through canals, dikes, gates, etc. • Water depth in units • Burning, chemical apps. • Predator control	• Water depth (WD) • Flow duration (FD) • Veg. coverage (VC)
Constraints	• Water availability (physical & water rights) • Conveyance network • Max. flooding depths in wetland units • Time to implement actions • $$$ to implement.	

Weighted unit area for wetlands (WUAW)

- Wetland surface area that provides suitable conditions to reach habitat management goals (m^2)

- Habitat suitability index (HSI) by attribute
  - Water depth
  - Vegetation coverage



- Weight by water surface area

Non-Linear Program Formulation

Objective Function:

$$Max\, WUAW = \sum_{i,t} cs_{i,t}\left(WD_{it}, VC_{it}\right) \cdot a_i\left(WD_{it}\right)$$

Subject to:

$$v_i\left(WD_{it}\right) = v_i\left(WD_{i,t-1}\right) + \sum_j X_{jit} - \sum_j X_{ijt} - e_{it},\ \forall i,t$$

(Mass balance in each wetland unit *i* in time *t*)

$$\sum_j X_{jit} = \sum_j X_{ijt},\ \forall i,t$$

(Mass balance at each node)

$$\sum_{u,j} X_{ujt} \le wa_t,\ \forall t$$

(Water availability)

$$\sum_{i,t}\left(t_{WD_{it}} \cdot WD_{it} + t_{FD_{it}} \cdot FD_{it} + t_{VC_{it}} \cdot VC_{it}\right) \le tt$$

(Time to implement actions)

$$\sum_{i,t}\left(c_{WD_{it}} \cdot WD_{it} + c_{FD_{it}} \cdot FD_{it} + c_{VC_{it}} \cdot VC_{it}\right) \le tb$$

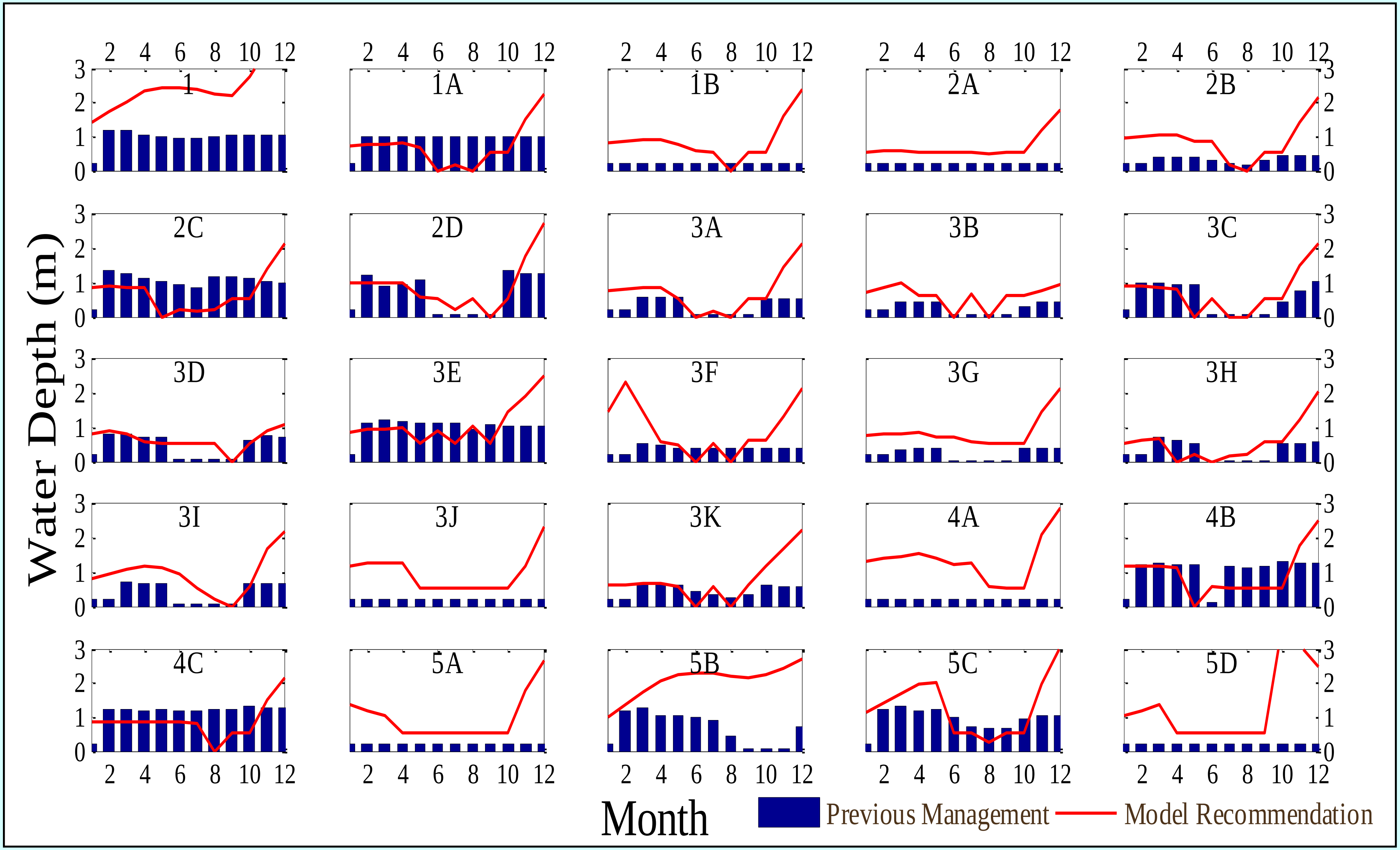
($$$ to implement actions)

$$0 \le WD_{it} \le wd_{\max i},\ \forall i,t \qquad vc_{\min i} \le VC_{it} \le vc_{\max i},\ \forall i,t$$

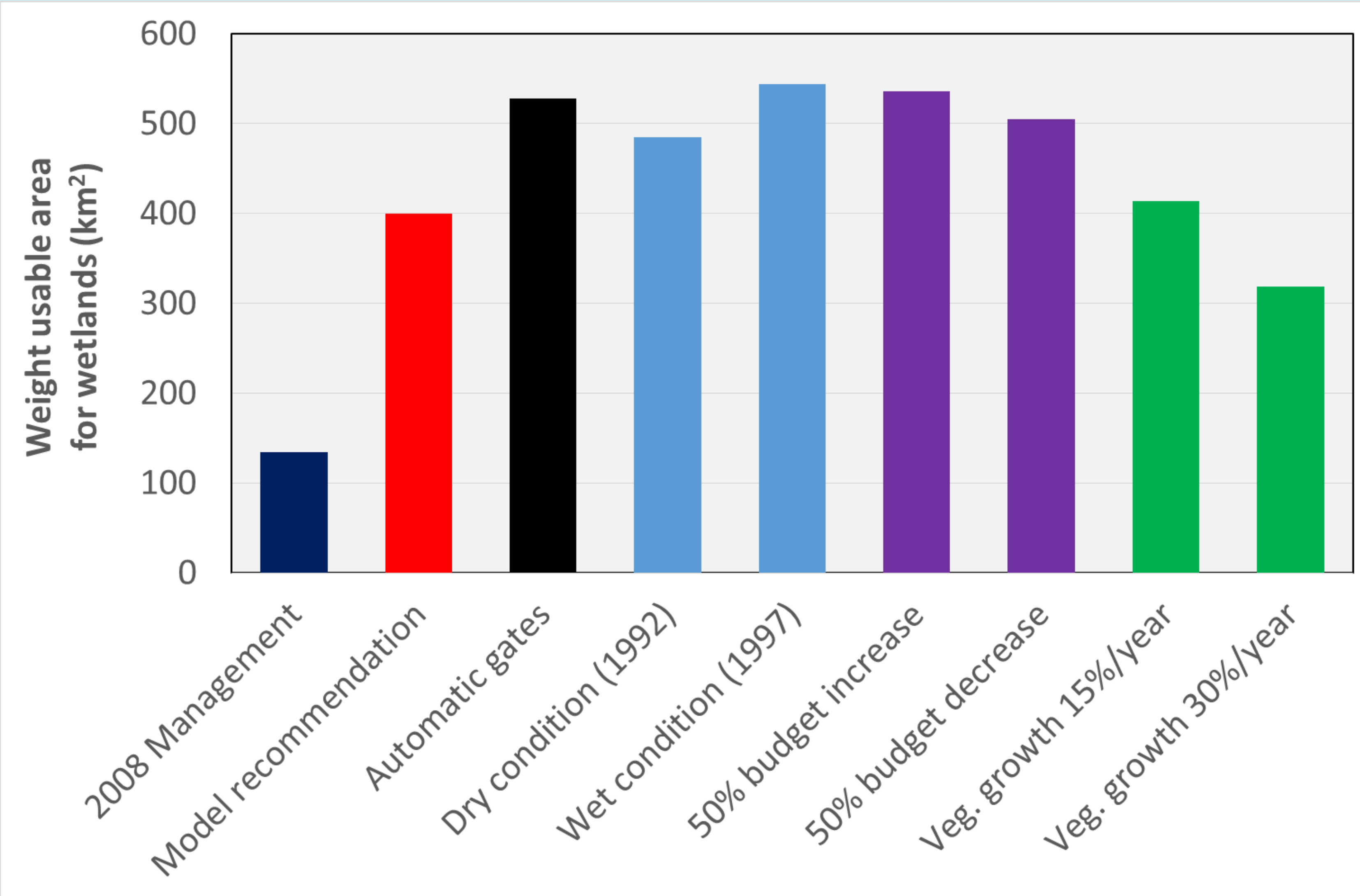
$$fd_{\min i} \le FD_{it} \le fd_{\max i},\ \forall i,t \quad 0 \le X_{ijt} \le x_{\max ij},\ \forall i,j,t$$

(Upper and lower bounds on decisions)

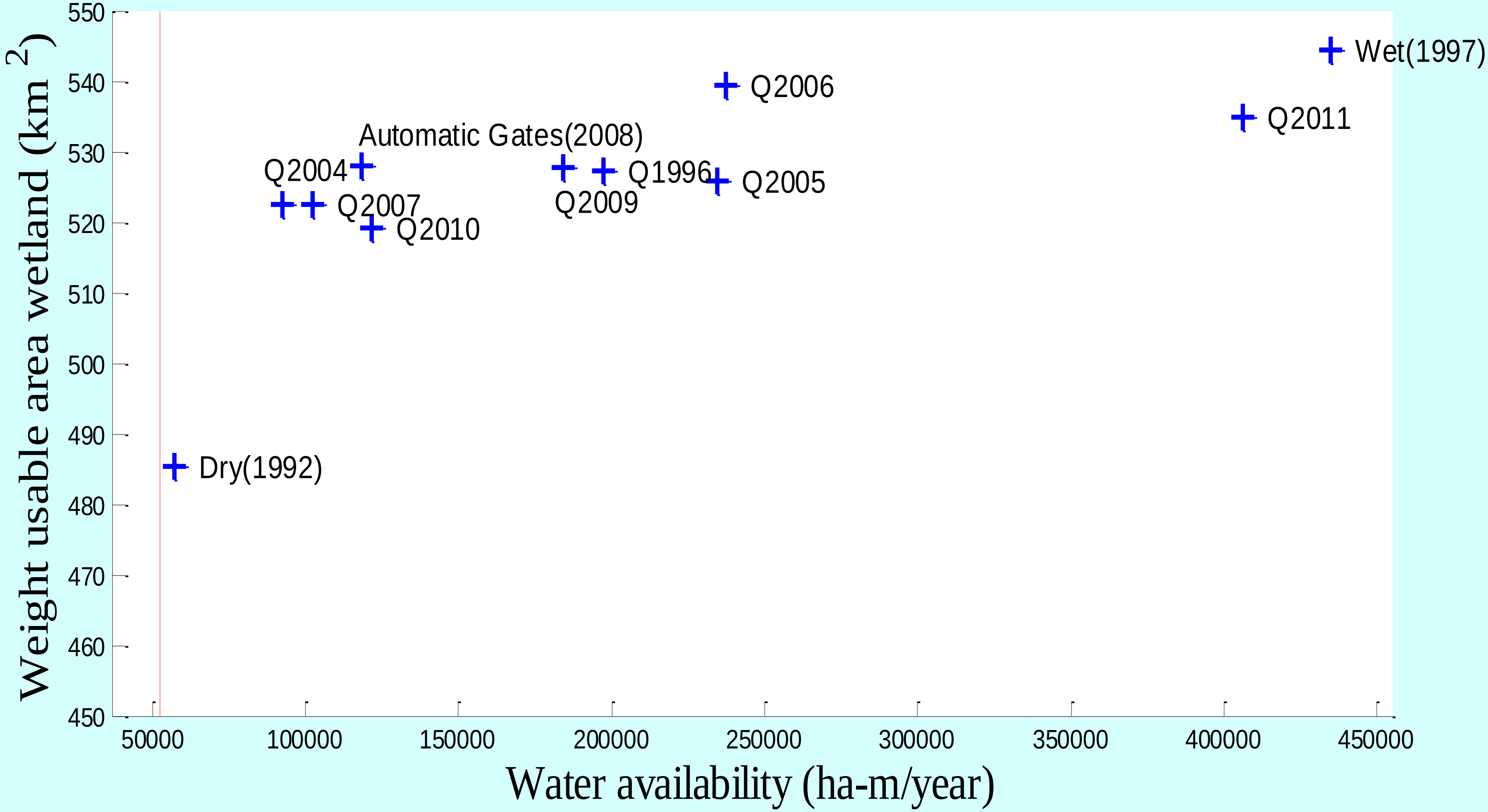
Recommended Water Levels



Modeled wetland performance

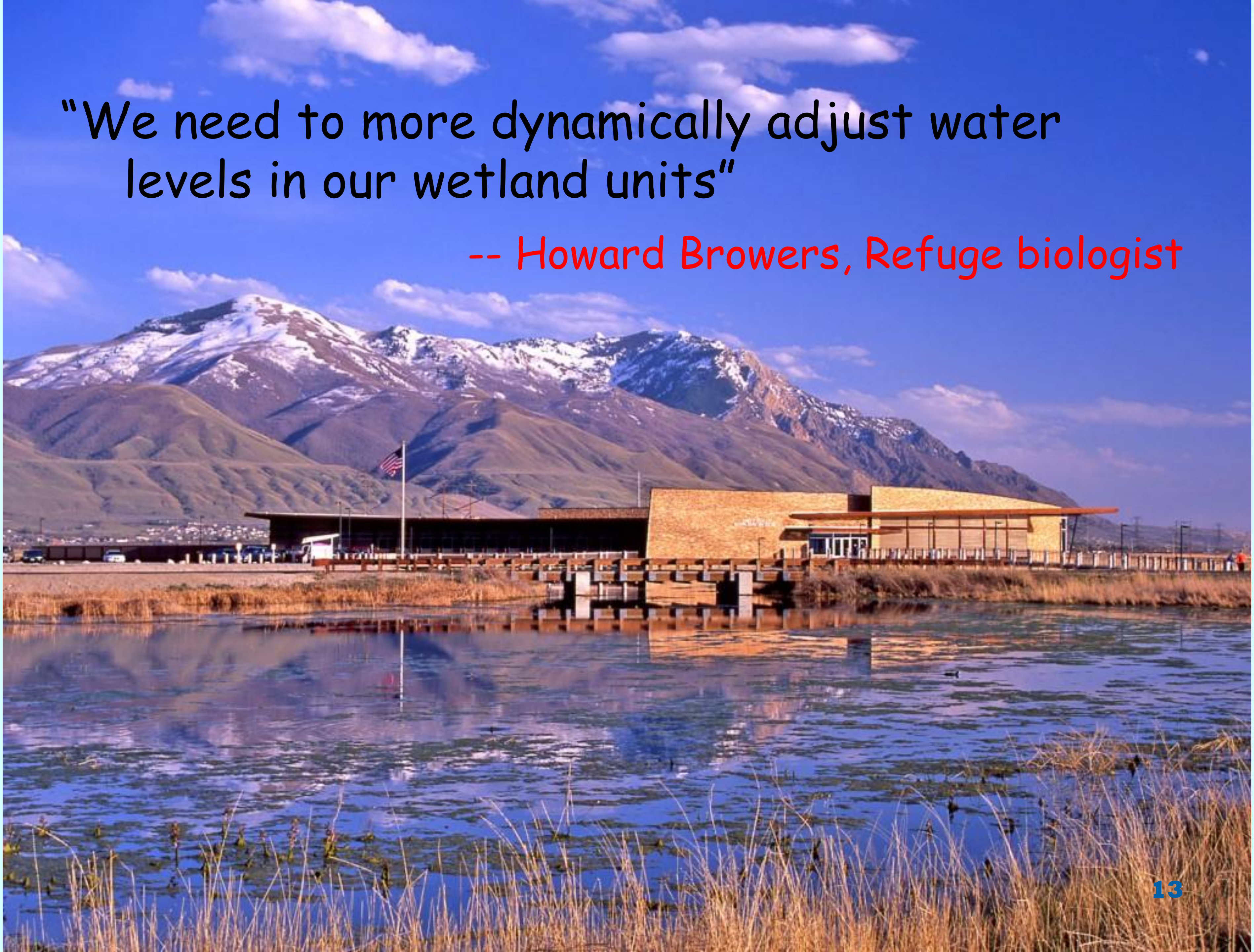


Wetland performance versus water availability



"We need to more dynamically adjust water levels in our wetland units"

-- Howard Browers, Refuge biologist



2. Near-Optimal Management

Why near-optimal?

- Complex problems
- Solutions optimal only for modeled issues
- Un-modeled issues persist
- Managers need more than single-best

> "…the best is the enemy of the good."

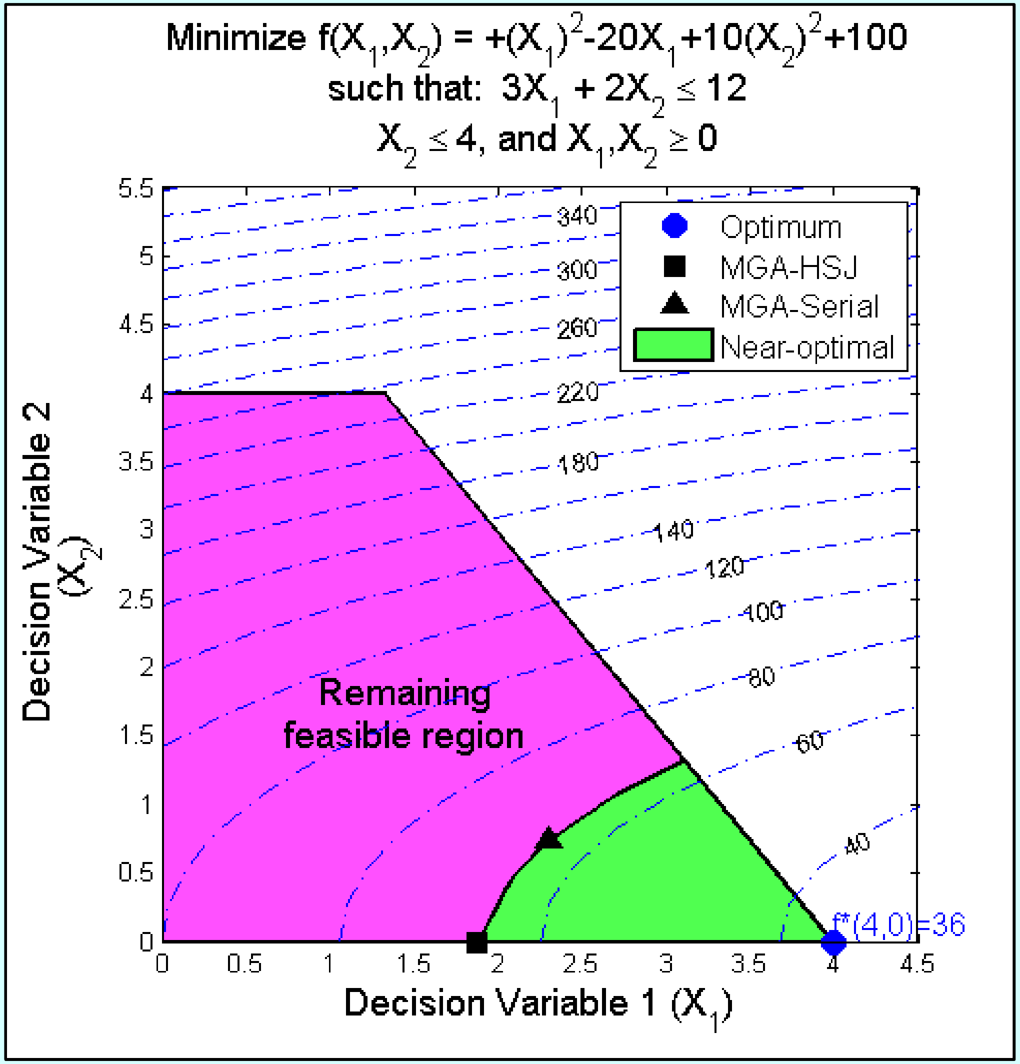
Voltaire, *La Begueule* (1772)

Near-Optimal Defined

1. Find optimal
2. Alternatives a specified tolerance (γ) from optimal

$$f\left(x_1, x_2\right) \leq \gamma \cdot f^*$$

3. MGA method
   - Find maximally-different alternatives
   - Slow
   - Partial picture

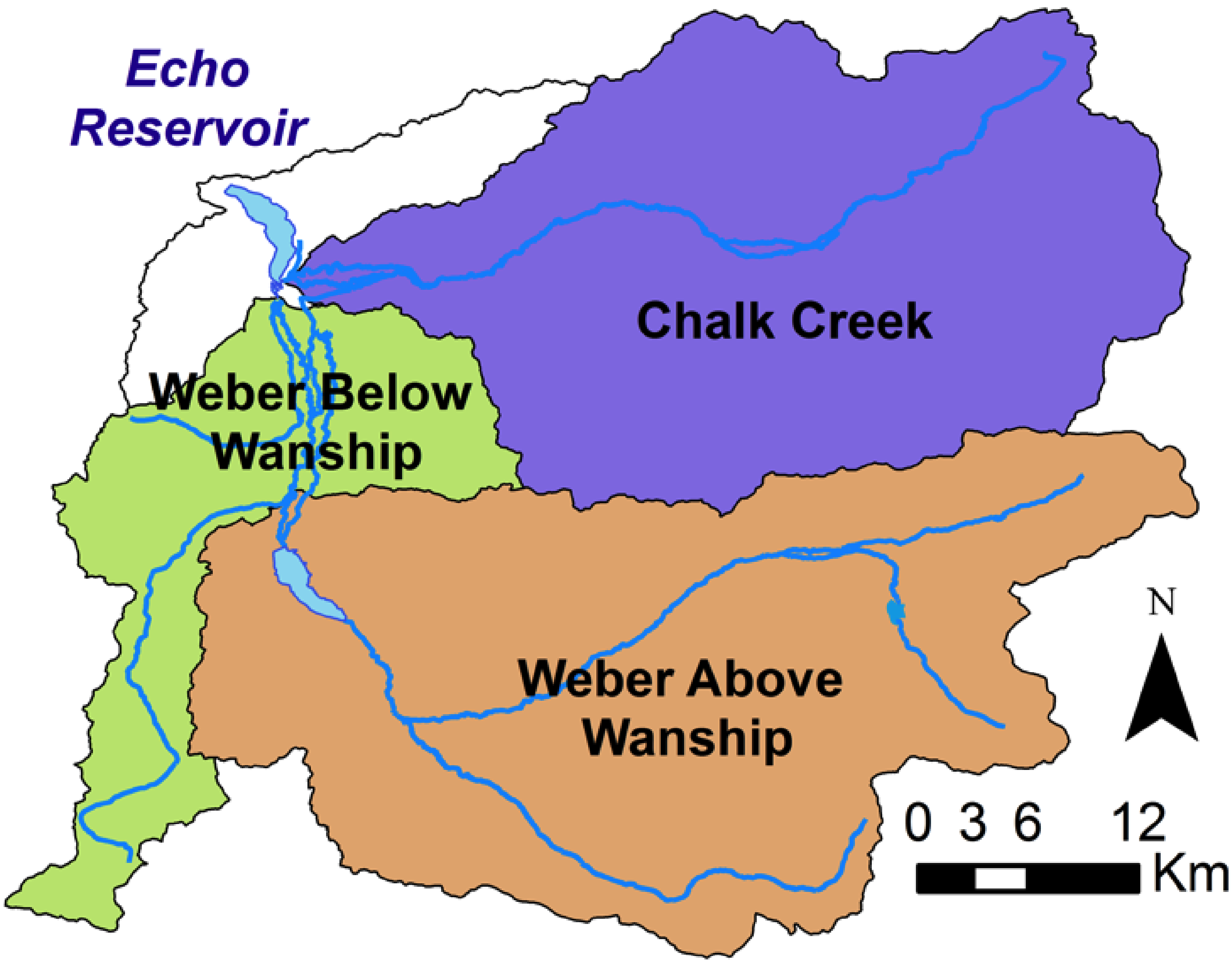


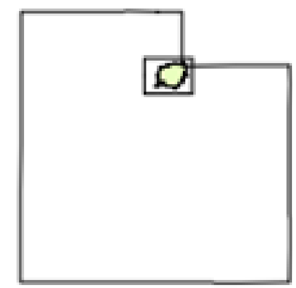
New Near-Optimal Tools

1. Alternative generation
   - Stratified Monte Carlo Markov Chain sampling
2. Visualize
   - Parallel coordinate plot
3. Interact
   - Plot controls to render, filter, generate new alts.
   - Update model formulation

Help managers find near-optimal alternatives they prefer to the optimal solution

Phosphorus removal, Echo Reservoir, Utah





Best Management Practices

1. Fence streams
2. Grass filter strips
3. Protect grazing land
4. Stabilize stream banks
5. Retire land
6. Cover crop
7. Manage agricultural nutrients

…and others

Problem Specifics and Formulation

- Pending TMDL in 2006
- Non-point source load reduction of 8,067 kg/year
- 10 practices (i)

  3 sources (s)

  3 sub-watersheds (w)
- 39 decisions!!

(Alminagorta et. al, 2013)

Decide BMP implementation levels (b_{iws}) to

Minimize costs $Z = \sum_{iws} \left(p_{iws} \times U_i\right)$

Such that

i. Define phosphorus removed,

$$p_{iws} = E_i \times b_{iws} ;\forall \; i,s,w$$

ii. Phosphorus reduction targets achieved,

$$\sum_i \left(p_{iws} \times C_{is}\right) \geqslant P_{ws} ;\forall \; w,s$$

iii. Available resources to implement BMPs,

$$\sum_s \sum_i \left(C_{is} \; D_{gi} \; b_{iws}\right) \leqslant B_{gw} ;\forall \; g,w$$

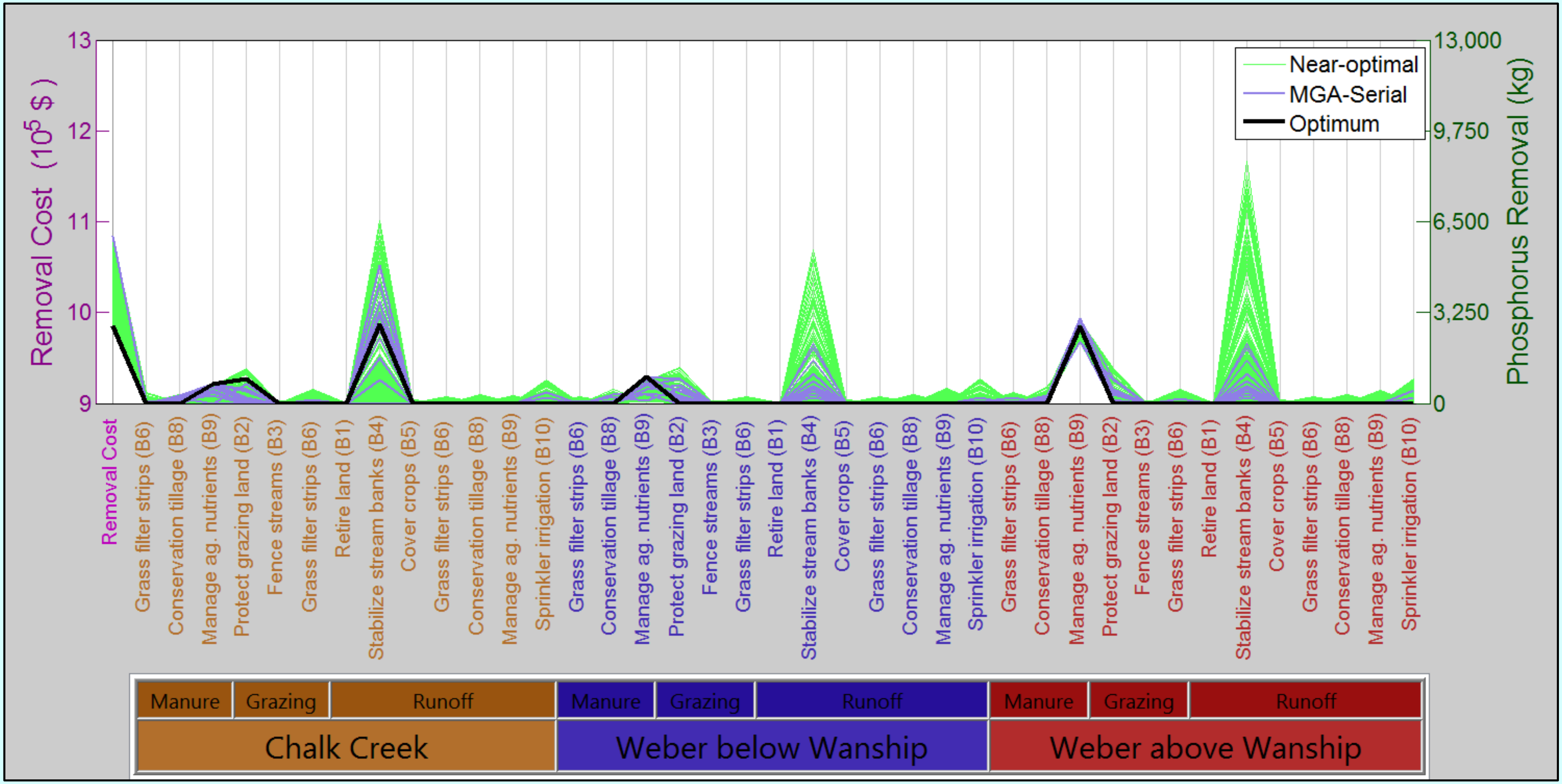
iv. Remove no more than the existing load, and

$$\sum_i \left(p_{iws} \times C_{is}\right) \leq L_{ws} ;\forall \; w,s$$

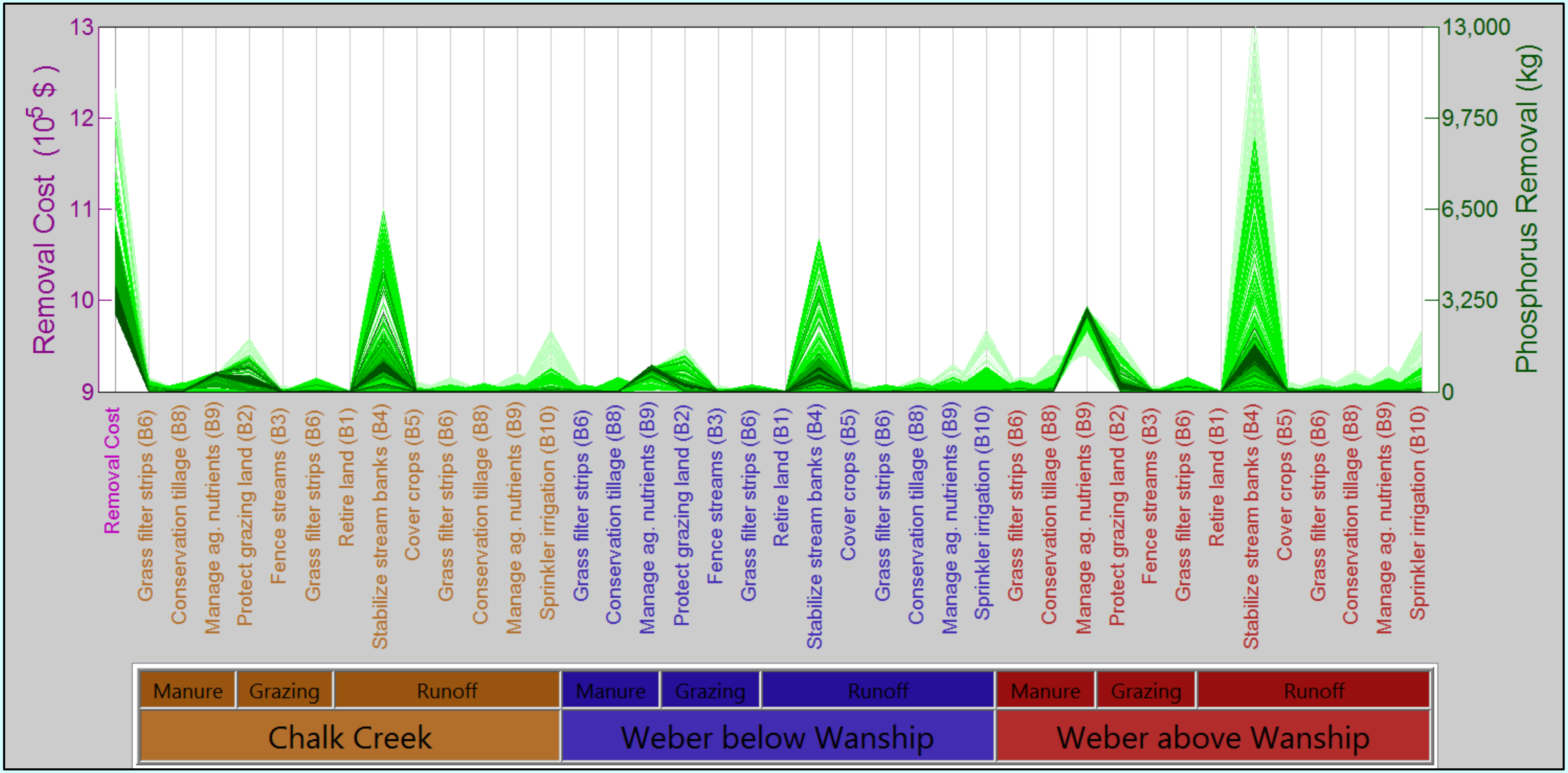
v. Non-negative variable values

$$p_{iws} \geqslant 0 ;\forall \; i,w,s \;\; ; b_{iws} \geqslant 0 ;\forall \; i,w,s$$

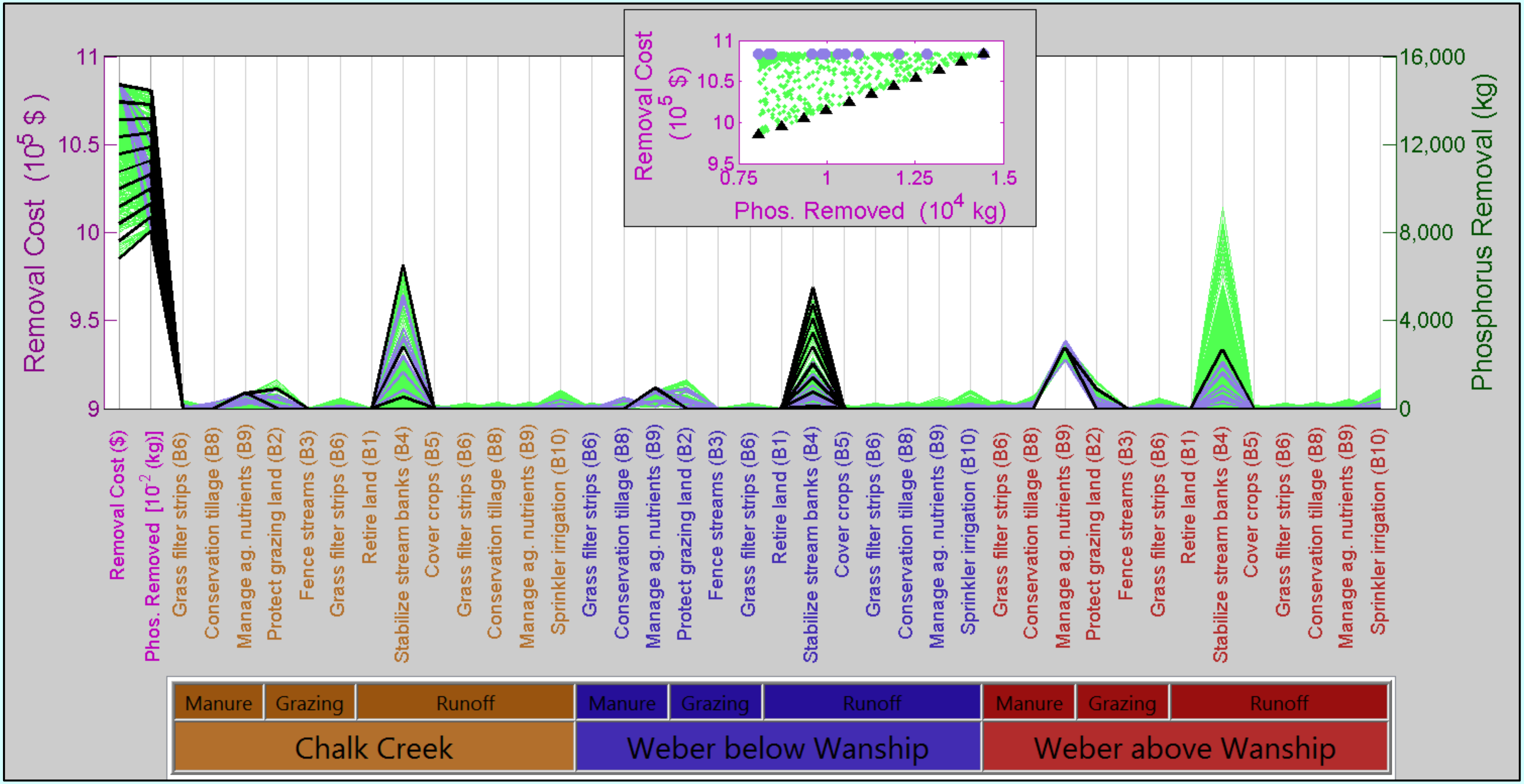
Comparing optimal solution and near-optimal alternative generation methods



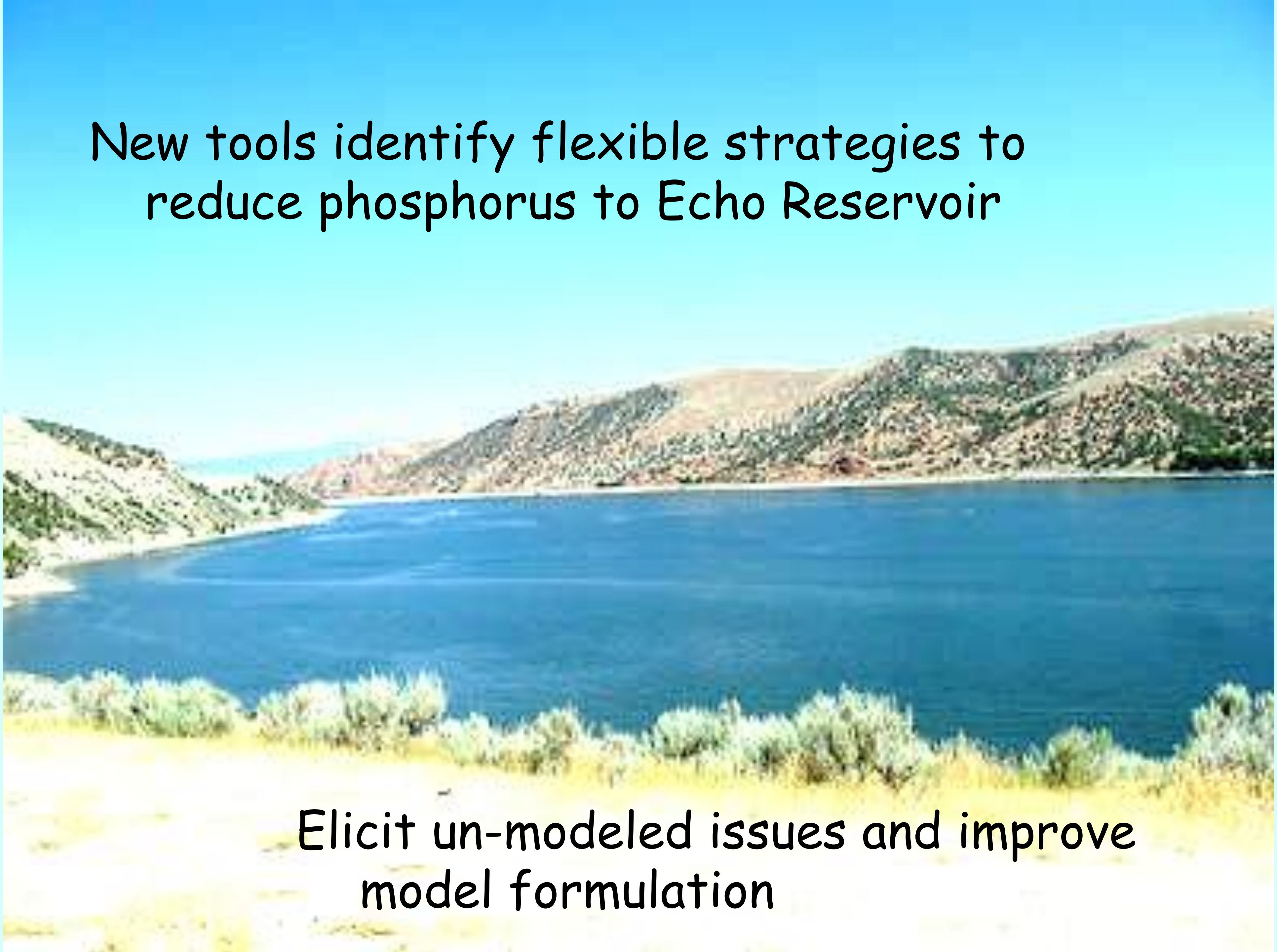
Expanding the near-optimal region



Updating the Model Formulation to Include Phosphorus Removal Objective



New tools identify flexible strategies to reduce phosphorus to Echo Reservoir



Elicit un-modeled issues and improve model formulation

3. Challenges & Next Steps

- Basin-scale
- Non-linear problems
- Embed uncertainties
- Test tool use
- Larger, more complicated problems

Conclusions

1. Embed env. metric as objective to maximize
2. Improve wetland performance three-fold
3. Faster tools to generate, visualize and explore near-optimal alts.
4. Elicit un-modeled issues => improve model
5. Continuing work

Acknowledgements

- Omar Alminagorta
- Ayman Alafifi
- Dr. Karin Kettenring

Bear River Migratory Bird Refuge

The Bear River Fellowship Program

NSF

Grant EE – 1149297

The Nature Conservancy

PacifiCorp

National Wildlife Refuge Association

USDA

Trout Unlimited

Utah DNR Wildlife Resources

Cache County 1857

Further Information

david.rosenberg@usu.edu

http://rosenberg.usu.edu

@WaterModeler

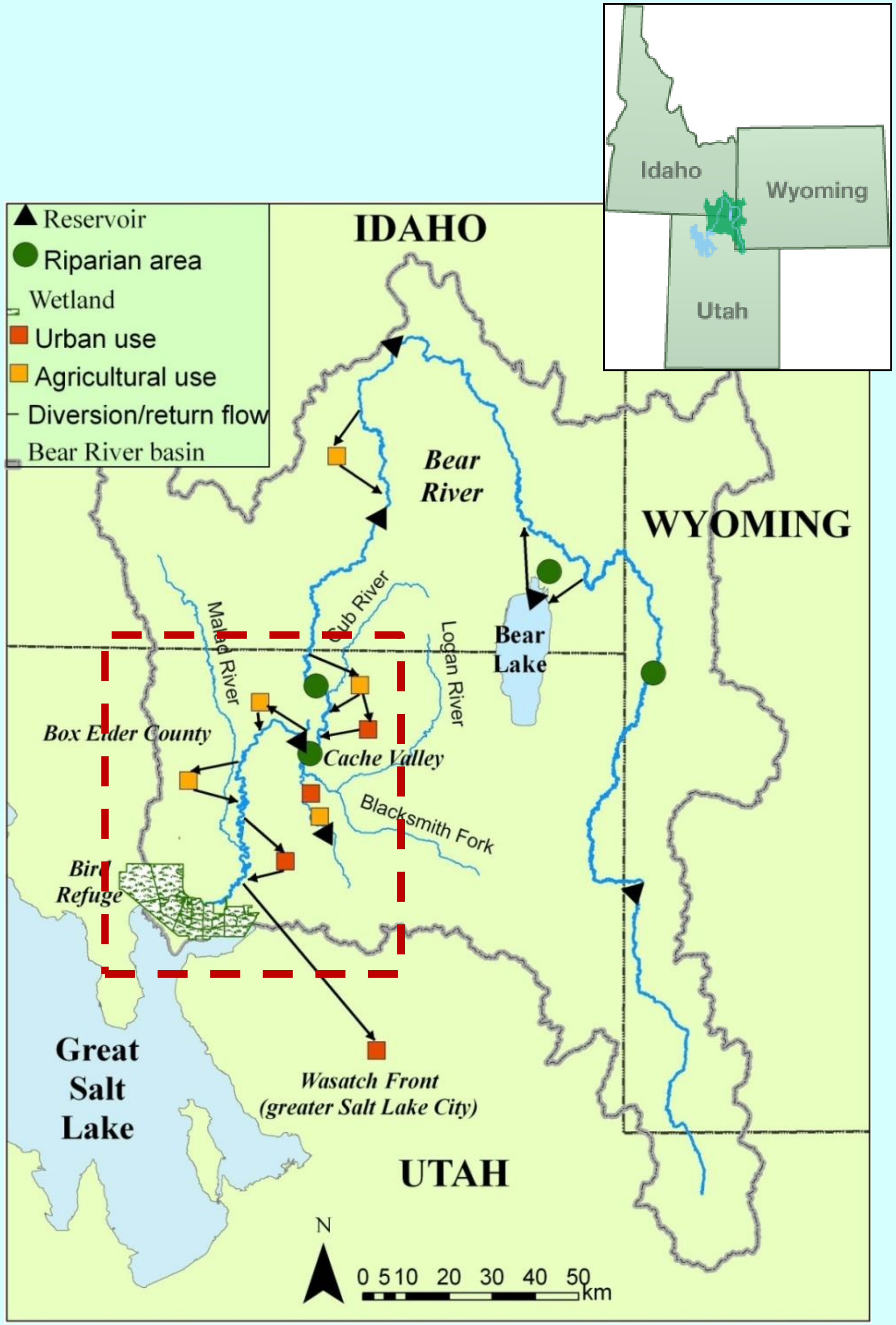
Code Repository & Documentation

- https://github.com/dzeke/Blended-Near-Optimal-Tools

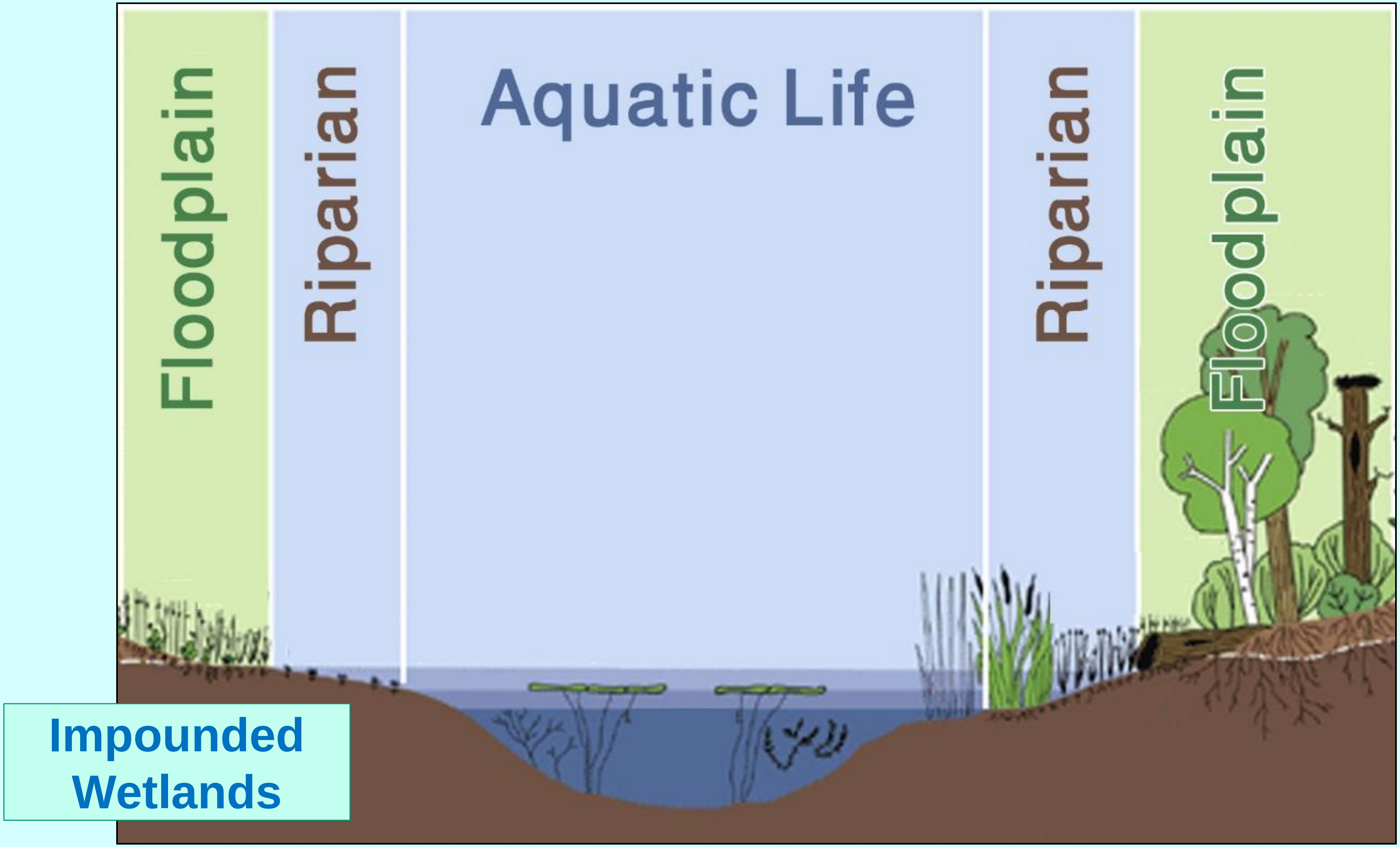
Watershed Habitat Performance

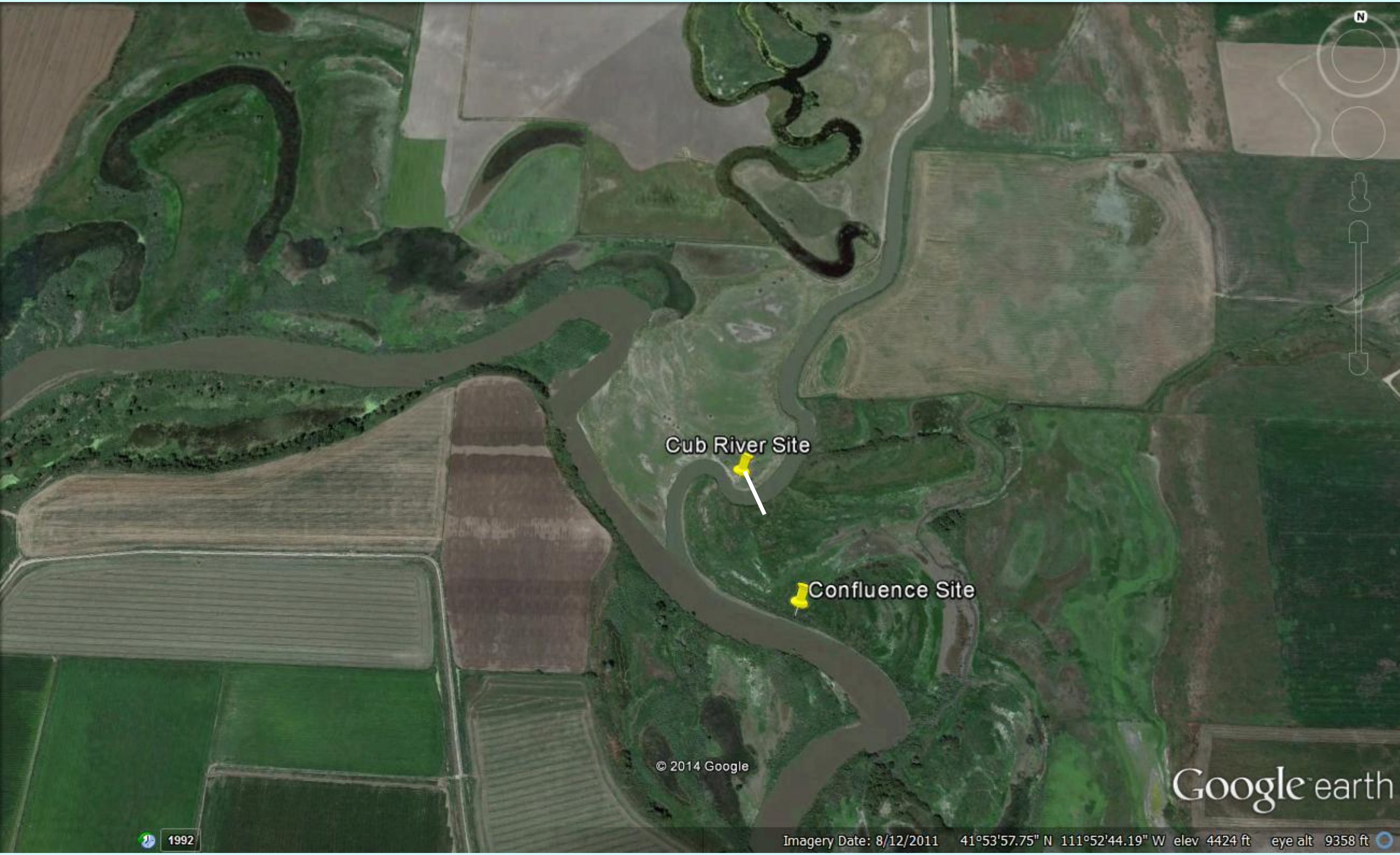
Lower Bear River, Utah

- Habitat suitability metric (unit area)
- Represent priority species, locations and seasons
- Easy-to-collect data
- Use in a systems model



Main Components



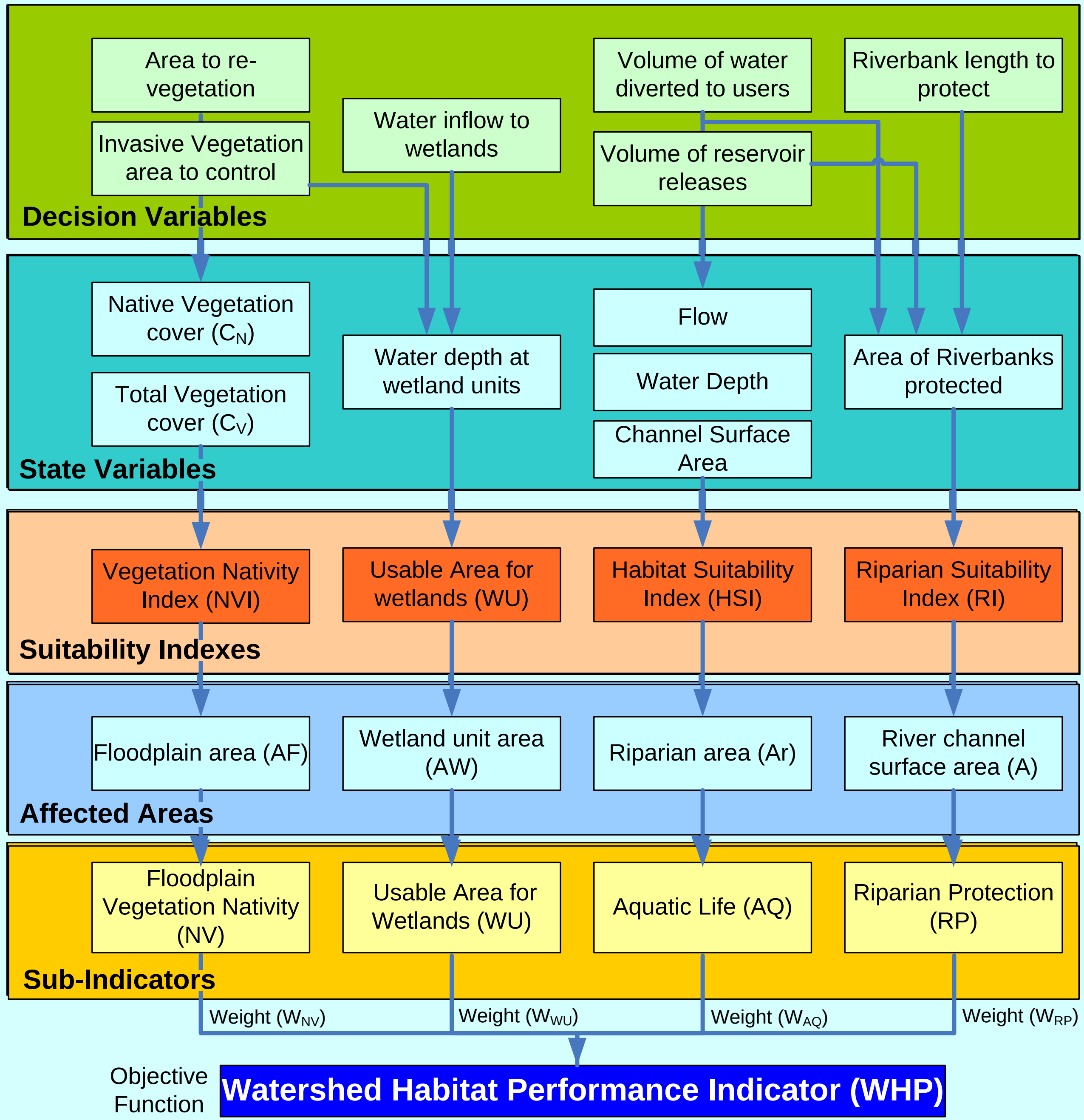

Cub River Site
Confluence Site
© 2014 Google
Google earth
1992
Imagery Date: 8/12/2011
41°53'57.75" N 111°52'44.19" W elev 4424 ft
eye alt 9358 ft

Watershed Habitat Performance

$$NVI_{i,t} = \frac{C_{N\,i,t}}{C_{V\,i,t}} \qquad \forall\, i,t$$

$$NV_{i,t} = NVI_{i,t} \times AF_i, \qquad \forall\, i,t$$

$$WHP = \sum_{s,i,t} w_{s,i,t} \times Ind_{s,i,t}$$



Simulation Results

State and Decision Variables	August 2012	May 2013	Change (%)
Instream flow (Ha-m/month)	6,507	4,429	-47%
River width (m)	28	30	7%
River depth (m)	2.30	1.95	-18%
Floodplain area (km^2)	31	31	0%
Inflow to the Refuge (Ha-m/month)	939	3,598	74%
Area of Riparian Area protected (km)	2.3	3.1	26%
Sub-Indicators			
Riparian Protection [RP] (km^2)	2,659	3,540	25%
Aquatic Life [AQ] (km^2)	37,940	40,650	7%
Floodplain Vegetation Nativity [NV] (km^2)	14	20	30%
Usable Area for Wetlands [WU] (km^2)	6	10	40%
Total WHP (km^2)	**40,619**	**44,220**	**8%**

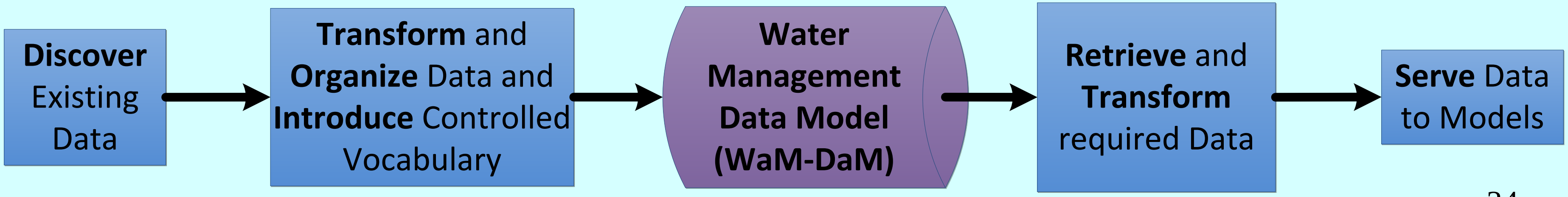
Organizing Data for Models

- Sources, formats, firmware, …
- Semantics, domains, …
- Metadata

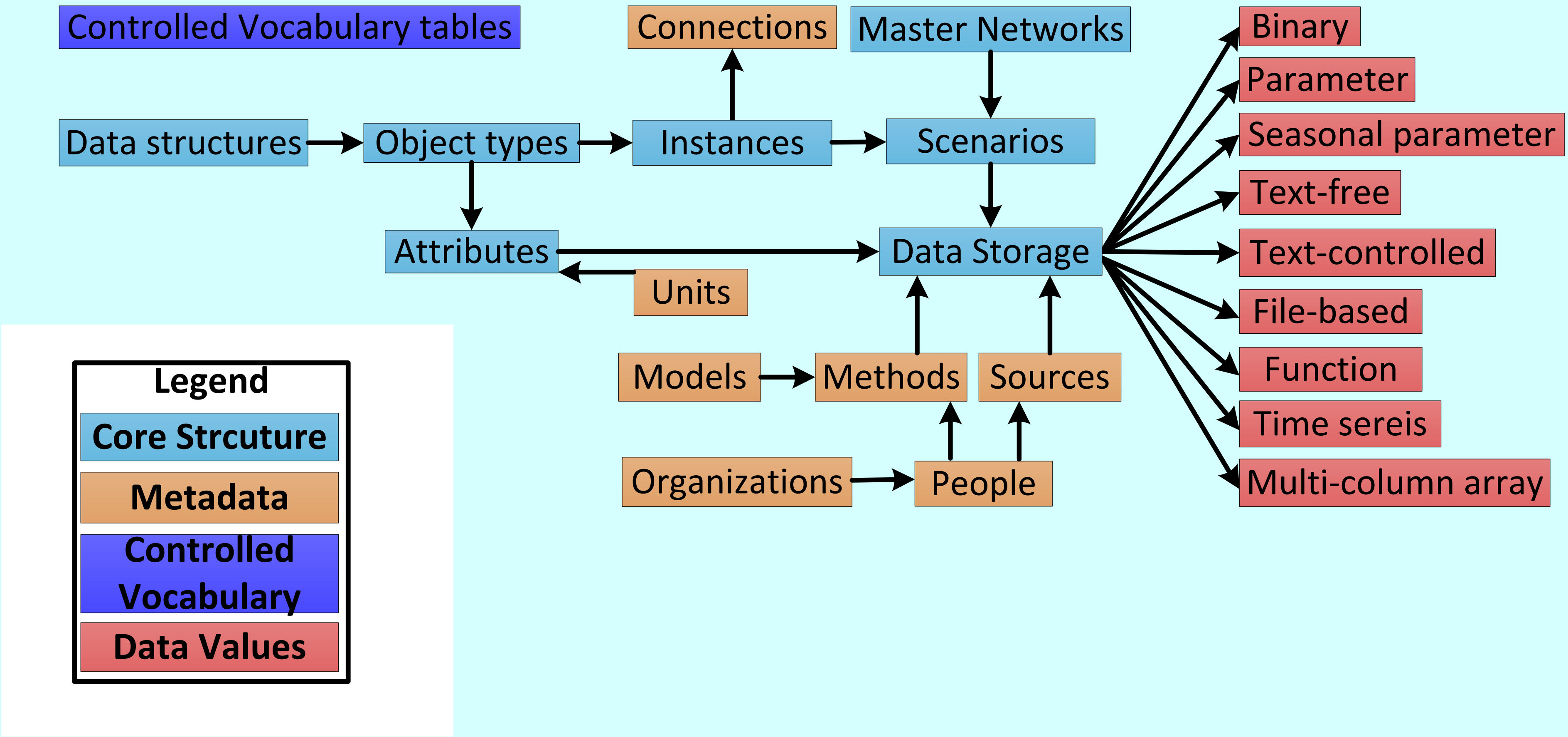
HydroDesktop

Water Management Data Model (WaM-DaM)

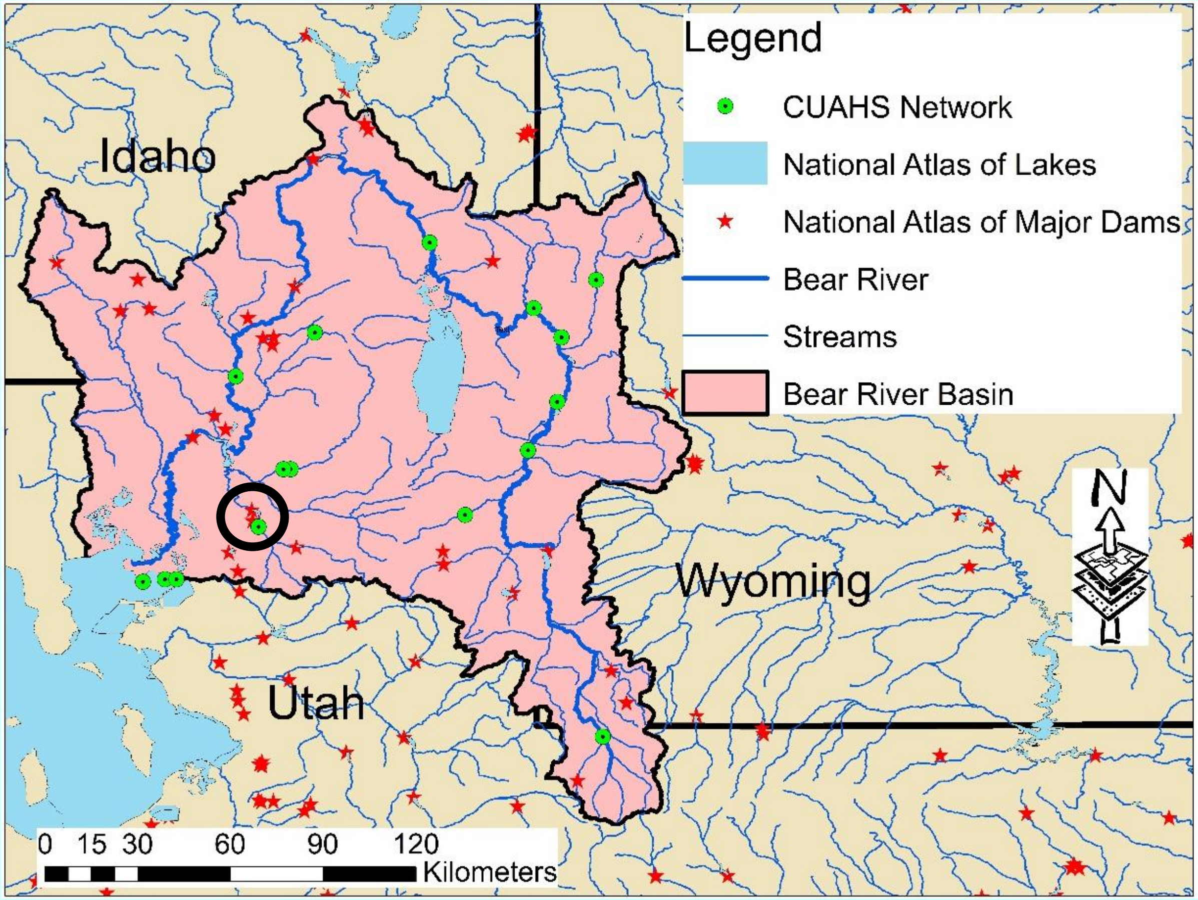
1. Organize water management data
2. Synthesize data across domains and sources
3. Compare data from different scenarios
4. Serve data to run models
5. Publish model data and share with others



WaM-DaM Conceptual Design



Use Case – Integrate and compare disparate data for the Bear River Basin



US Army Corps of Engineers

US Dams dataset
23 attributes
8,121 instances

USGS

US Water Bodies and Wetlands Dataset
15 attributes
26,872 instances

CUASHI HIS Time Series data
32 attributes

WEAP

WEAP Model Lower Bear River
53 instances

Example results

Reservoir Instance	Attribute	Value	Unit	Source
Hyrum	Area	451.558	acre	National Atlas Waterbodies
Hyrum	Area	480	acre	National Atlas Major Dams ..
Hyrum	MaxStorage	14440	acre foot	National Atlas Major Dams ..
Hyrum	MaxStorage	18684	acre foot	DavidRosenberg/WEAP
Hyrum	MaxStorage	18684	acre foot	Utah Division of Water Res..

- Discover, organize, & share data
- Send to a model