# Simple Optimization Method to Determine Best Management Practices to Reduce Phosphorus Loading in Echo Reservoir, Utah

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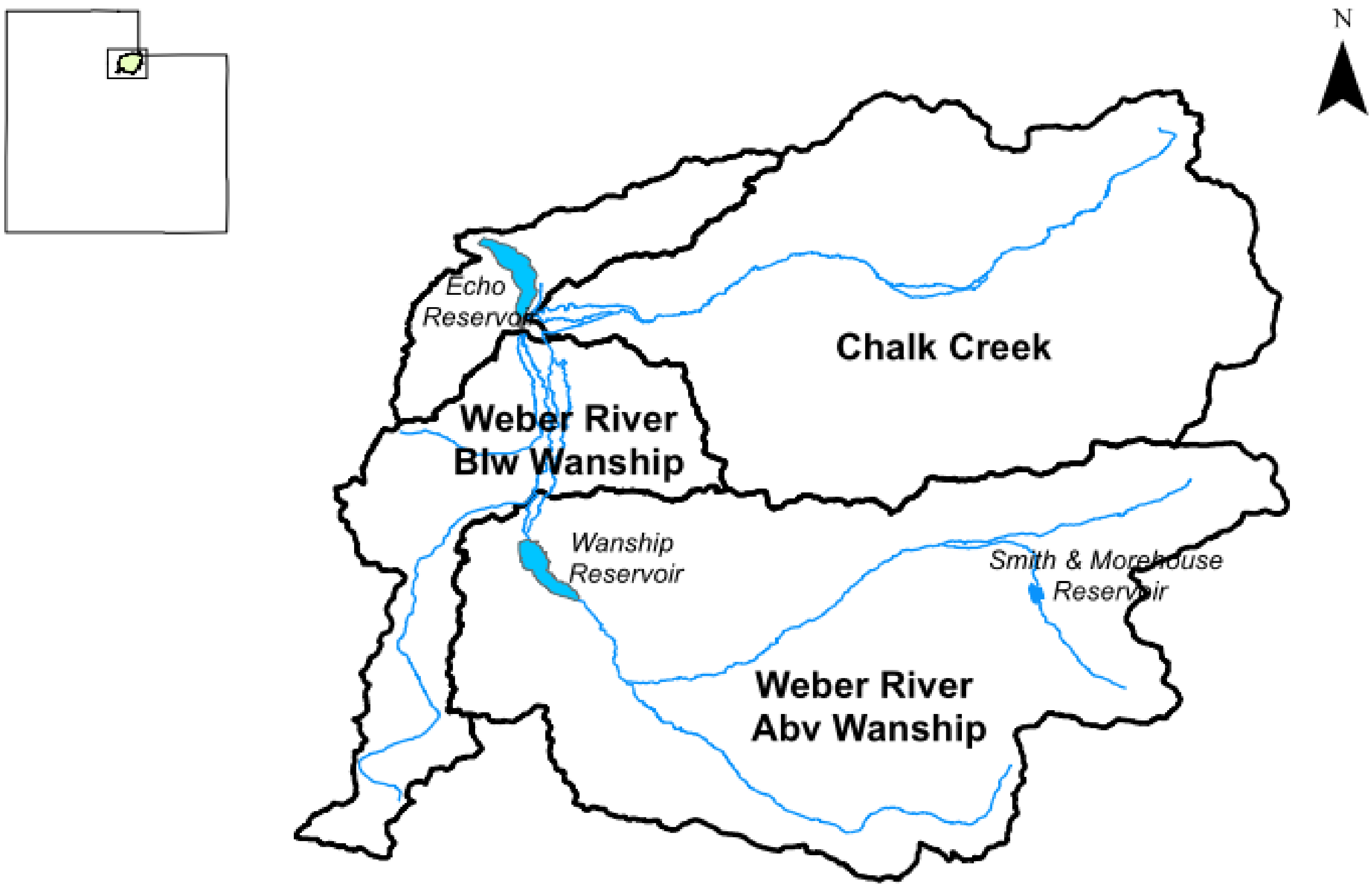
# Outline

- ✓ Problem Description
- ✓ Objective
- ✓ General Information Echo Reservoir
  - Sources P Loading
  - Best Management Practices (BMPs)
- ✓ Methodology
  - Optimization Model
- ✓ Exercise Application

# Background/Problem Description

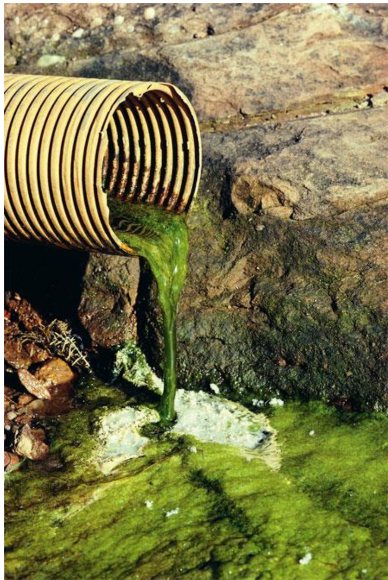
- Excessive nutrients impair many U.S. water bodies
- Phosphorus and nitrogen nutrients
  - stimulate algae growth
  - reduce dissolved oxygen
  - negatively impact aquatic habitat and water supplies

# Background/Area of Study



# Background/Water Pollution Control

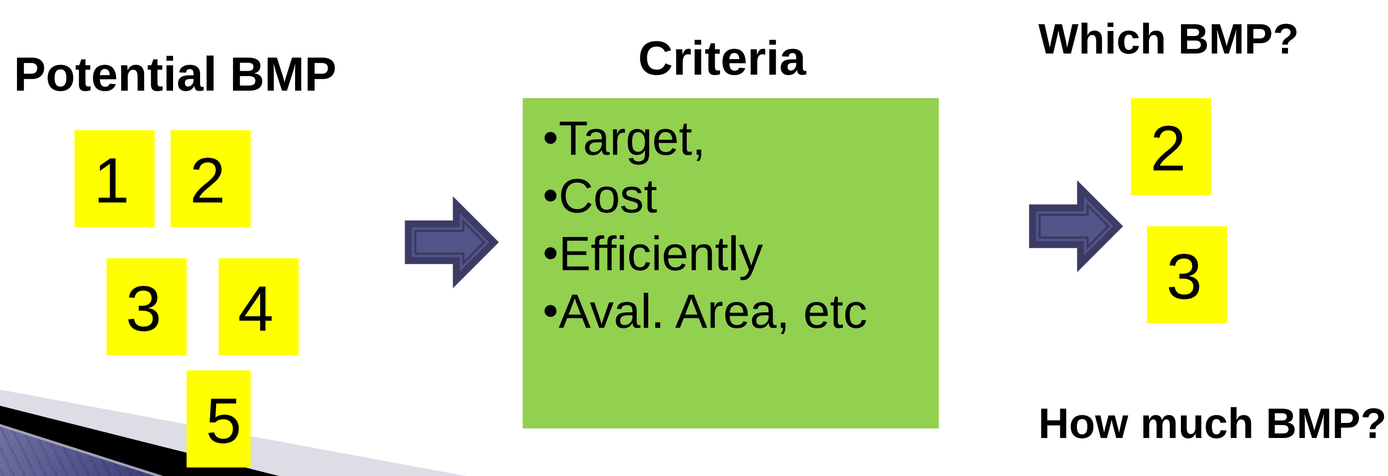
- For point sources use Best Available Technologies (BATs)
- The identification, selection, and location of Best Management Practices (BMPs) is a concern for nonpoint source management.



# Objective

Develop a simple optimization tool that identifies:

- the cost effective mix of BMPs
- to achieve the required phosphorus load reduction targets for non-point phosphorus sources in a watershed.



# Sources of Phosphorus loading

- Direct Runoff from Animal Feeding Operations
- Land Applied Manure
- Public Land Grazing
- Private Land Grazing
- Septic Systems
- Diffuse Runoff


# Cost information for BMPs

## (Horsburgh et al. estimates for Bear River Watershed 2009)

| BMP | Metric Units | P Reduction (kg/unit) | Cost ($/kg) |
|---|---|---|---|
| **Land retirement** | $Km^2$ | 185 | 7368 |
| **Grazing land protection** | $Km^2$ | 22 | 238 |
| **Stream fencing** | Km | 24 | 1373 |
| **Stream bank stabilization** | Km | 208 | 15 |
| **Cover crops** | $Km^2$ | 44 | 675 |
| **Grass filter strips** | $Km^2$ | 143 | 412 |
| **Animal waste facility** | system | 27107 | 730 |
| **Conservation tillage** | $Km^2$ | 20 | 337 |
| **Agricultural nutrient management** | $Km^2$ | 44 | 168 |
| **Sprinkler irrigation** | $Km^2$ | 2914 | 128 |

# Best Management Practices (BMPs)

1. Land retirement
2. Grazing land protection
3. Stream fencing
4. Stream bank stabilization
5. Cover crops

# Best Management Practices (cont.)

6. Grass filter strips
7. Animal waste facility
8. Conservation tillage
9. Agricultural nutrient management
10. Sprinkler irrigation

# Assignment of BMPs to Non-Point Sources

| Source | Description | Applicable BMPs |
|---|---|---|
| Direct run off from AFOs | Animal wastes containing phosphorus from watershed animal feeding operations (AFOs) directly runoff into nearby water bodies. | None |
| Land applied manure | Animal waste applied on agricultural land as a fertilizer is incorporated into the soil and subsequently washed into a nearby water body. | Grass filter strips, Conservation tillage, Manage agricultural nutrients. |
| Public land grazing | Animals grazed on public lands leave waste containing phosphorus that is subsequently washed into a nearby water body. | Protect grazing land, Fence streams, Grass filter strips. |
| Private land grazing | Animals grazed on private lands leave waste containing phosphorus that is subsequently washed into a nearby water body. | Protect grazing land, Fence streams, Grass filter strips. |
| Septic Systems | Domestic leak wastewater into nearby waterways when septic tanks are installed incorrectly or are too close to a waterway. | None |
| Diffuse Runoff | Phosphorus loading that arises from fertilizers, pesticides, trails, roads, dispersed camping sites and erosion from up slopes areas. | Retire land, Stabilize stream banks, Cover crops, Grass filter strips, Conservation tillage, Manage agricultural nutrients, Sprinkler irrigation. |

# Echo Reservoir TMDL (Clean Water Act) (Adams et al., 2006)

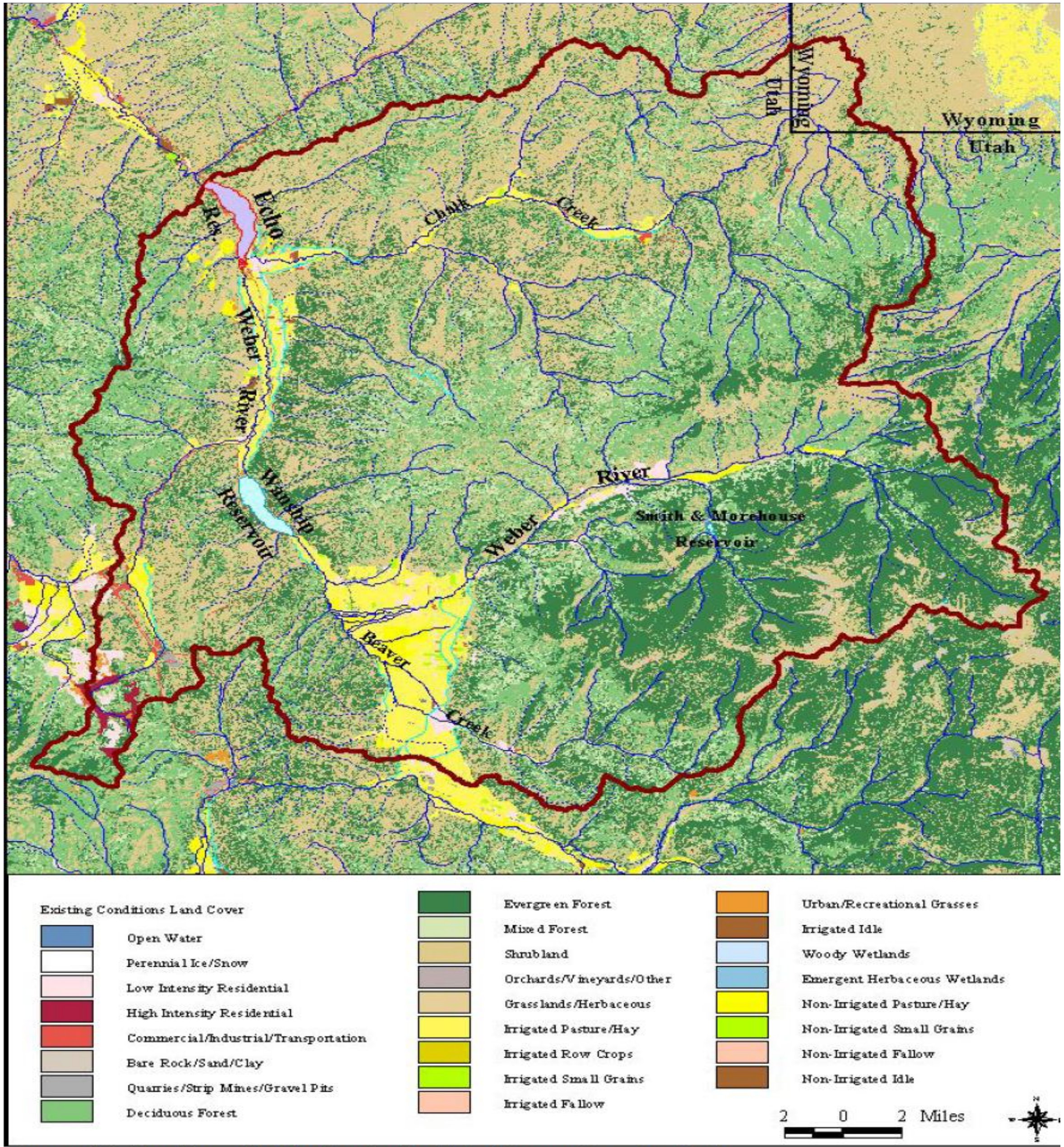
| Waterbody ID | UT-L-16020101-001 |
|---|---|
| Location | Summit County, Utah |
| Pollutants of Concern | Dissolved Oxygen, Total Phosphorus |
| Loading Assessment | •More than 50% of water column < 4 mg/l dissolved oxygen in Echo Reservoir above Dam<br>•Percent of in-lake total phosphorus concentrations exceeding 0.025 mg/l ranging from 25% – 100% |
| Water Quality Targets/Endpoints | •Target Load of 19,800 kg/yr total phosphorus from all tributary sources to Echo Reservoir.<br>•A shift away from blue-green algal dominance.<br>•TSI values for Total Phosphorus. Chlorophyll A. and Secchi depth not to exceed 50. |
| Implementation Strategy | •Reduce Point source loads through application of BATs.<br>•Implement Nonpoint Source BMPs |

# Allocation of Total Watershed Loads

## (showing non-point sources only)

| Non Point Sources | Existing Total Watershed Load (kg/yr) | Existing Total Watershed Load Allocation per TMDL (kg/yr) | Percent Reduction (%) |
|---|---|---|---|
| | **Chalk Creek** | | |
| **AFOs** | 248 | 25 | 90 |
| **Land applied manure** | 961 | 192 | 80 |
| **Public land grazing** | 0 | 0 | 0 |
| **Private land grazing** | 3,535 | 3,182 | 10 |
| **Septic systems** | 24 | 24 | 0 |
| **Diffuse runoff** | 6,539 | 5,624 | 14 |
| | **Weber River below Wanship** | | |
| **AFOs** | 66 | 7 | 90 |
| **Land applied manure** | 942 | 188 | 80 |
| **Public land grazing** | 0 | 0 | 0 |
| **Private land grazing** | 1,550 | 1,395 | 10 |
| **Septic systems** | 135 | 135 | 0 |
| **Diffuse runoff** | 5,493 | 4,944 | 10 |
| | **Weber River above Wanship** | | |
| **AFOs** | 1,181 | 118 | 90 |
| **Land applied manure** | 3,560 | 712 | 80 |
| **Public land grazing** | 196 | 196 | 0 |
| **Private land grazing** | 3,718 | 3,346 | 10 |
| **Septic systems** | 221 | 221 | 0 |
| **Diffuse runoff** | 13,517 | 12,165 | 10 |
| | | | |
| **Total Non Point** | **41,886** | **32,474** | **22.5** |

# Land use at Echo Watershed (Adams et al., 2006)



# Methodology

**TMDL Water Quality Study**

(Adams and Whitehead, 2006)

- Sub-watershed areas (*w*)
- Phosphorus sources (*s*)
- Required load reductions ($p_{ws}$)
- Available land area and stream length to do BMPs ($b_{gw}$)

**BMP Study**

(Horsburgh et al, 2009)

- 10 available BMPs (*i*)
- Removal efficiencies ($e_i$)
- Unit costs ($u_i$)

**Linear Optimization Program**

- BMPs to implement ($B_{iws}$)
- Total implementation cost (Z)
- Load reduction ($P_{iws}$)

# Optimization Components

**Objective Function**: represents the goal of the problem in terms of decision variables

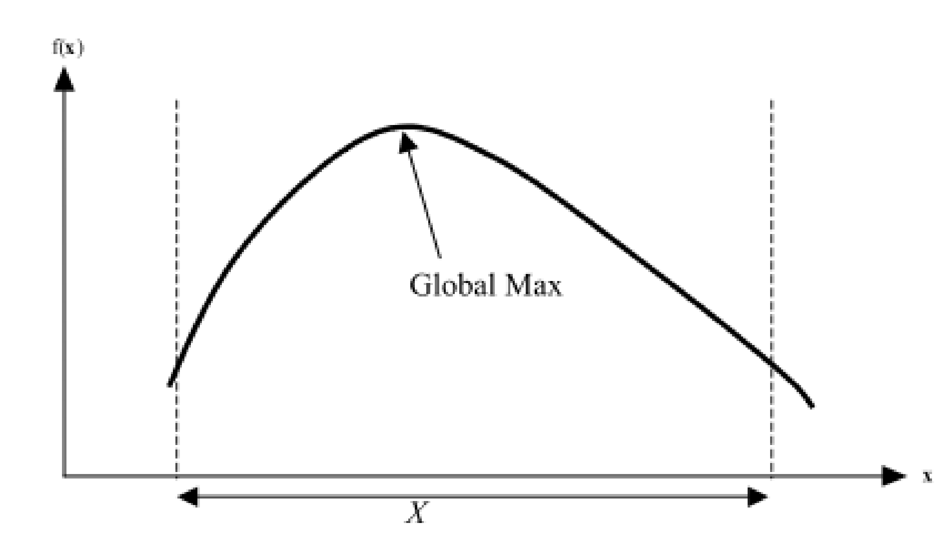
$Max=Sum(aX-bX^2)$

**Decision Variables**: factors that decision making can control

$X_1, X_2, X_3$

**Constraints**: restrictions on decision variables

$X_1+X_2+X_3 < Rt$
$X_1 < Cap1$



# Optimization Model

**Decide** BMP implementation levels ($B_{iws}$) to

**Minimize** costs $$\min \sum_{iws} \left(u_i \times P_{iws}\right)$$

**Such that**

(i) Define phosphorus removed, $$P_{iws} = e_i \times B_{iws};\ \forall\ i,s,w$$

(ii) Phosphorus reduction targets achieved, $$\sum_i \left(c_{is} \times P_{iws}\right) \geq p_{ws};\ \forall w, s$$

(iii) Available resources to implement BMPs, $$\sum_s \sum_i \left(c_{is}\ B_{iws}\right) \leq b_w;\ \forall w$$

(iv) Non-negative variable values $$P_{iws} \geq 0;\forall\ i,w,s\ ;\ B_{iws} \geq 0;\forall\ i,w,s$$

(v) Global reduction target $$\sum_i \sum_w \left(c_{is} \times P_{iws}\right) \geq \sum_w p_{ws};\ \forall s$$

*i* = BMP activity; *w* = sub-watershed; *s* = phosphorus source

# Results

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

| Scen. | Sub-watershed[a] | Required reduction (kg/yr) | Private land grazing (kg/yr) | Diffuse runoff (kg/yr) | Land applied manure (kg/yr) | | Total reduction (kg/yr) | Total cost ($1000) |
|---|---|---|---|---|---|---|---|---|
| | | | Protect grazing land | Stabilize stream banks | Conservation tillage | Manage Ag. nutrients | | |
| Each sub-watershed | Chalk creek | 2,038 | 354 | 915 | 87 | 682 | 2,038 | 242 |
| | WBW | 1,458 | 155 | 549 | | 754 | 1,458 | 172 |
| | WAW | 4,572 | 372 | 1,352 | | 2,848 | 4,572 | 587 |
| | Total | 8,067 | 880 | 2,816 | 87 | 4,283 | 8,067 | 1,000 |
| Global | Chalk creek | | 880 | 2,816 | | 682 | 4,379 | 367 |
| | WBW | | | | | 942 | 942 | 158 |
| | WAW | | | | | 2,747 | 2,747 | 460 |
| | Total | 8,067 | 880 | 2,816 | | 4,370 | 8,067 | 985 |

$$\sum_i \sum_w \left(c_{is} \times P_{iws}\right) \geq \sum_w p_{ws};\ \forall s$$

[a]WBW= Weber below Wanship, WAW= Weber above Wanship

# Sensitivity Analysis

| BMP | Cost($/kg) | | | Efficiency - Phosphorus Reduction(kg/unit) | | |
|---|---|---|---|---|---|---|
| | LOWER | CURRENT | UPPER | LOWER | CURRENT | UPPER |
| Protect grazing land | 0 | 238 | 412 | 0 | 22 | 38 |
| Stabilize stream banks | 0 | 15 | 128 | 0 | 208 | 1,726 |
| Conservation tillage | 168 | 337 | 412 | 10 | 20 | 25 |
| Manage Ag. nutrients | 0 | 168 | 337 | 0 | 44 | 88 |

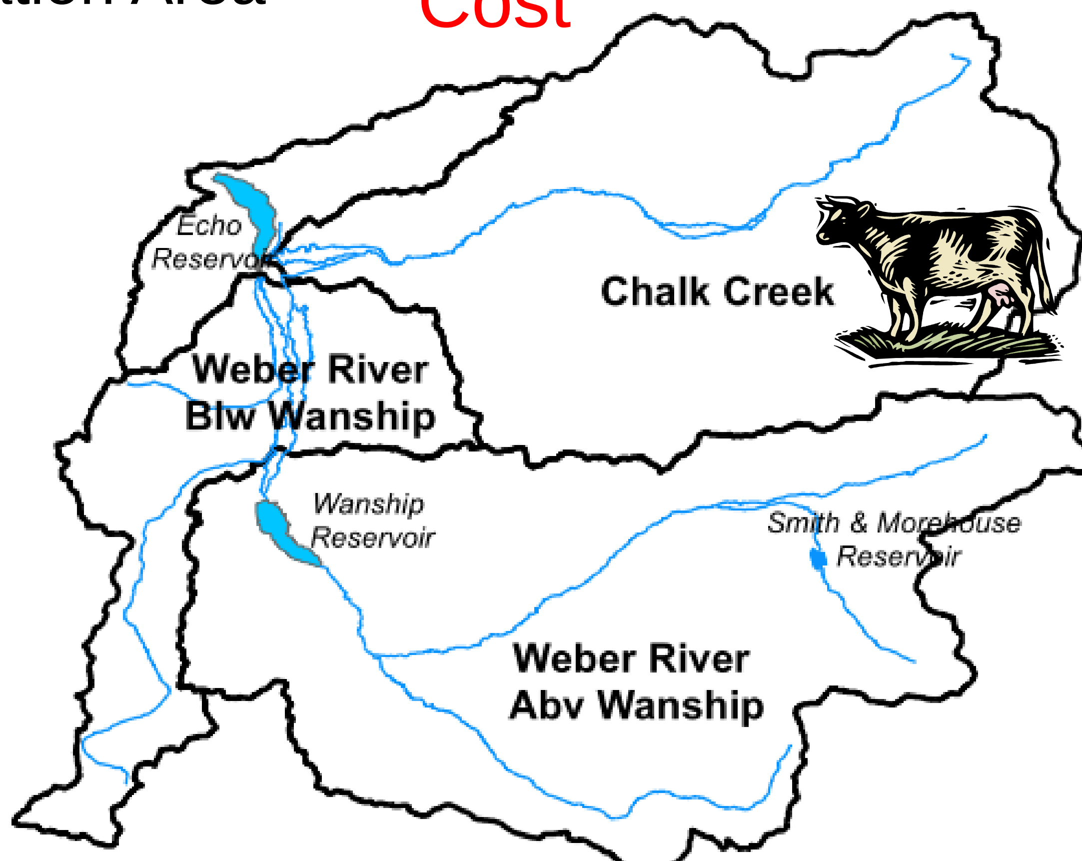
# Conclusion

- A simple linear optimization tool that identifies cost-effective BMPs was developed.
- This optimization tool offers a simple way to test the feasibility of a proposed TMDL allocation
- The tool also suggests how loads can be spatially redistributed
- Relaxing the sub-watershed reduction targets suggests a cheaper set of BMPs.

# Exercise: Find the cost effective mix of BMPs to achieve phosphorus reduction targets

BMPs and implementation Area

Minimum Cost




Sources

Targets

Go to the follow website and download the exercise spreadsheet

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