An Economic Analysis of Reservoir Sediment Management: Cropland Management vs. Dredging

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Abstract

Emphasis on finding the most cost-effective ways to reduce reservoir sedimentation is increasing. Biophysical and economic models for a large agricultural watershed are integrated to estimate the average and marginal costs of reducing sedimentation with an optimal combination of land management strategies compared to the cost of dredging.

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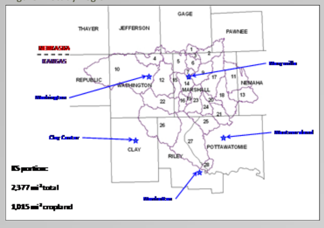
Problem Identification

- Many reservoirs built in US from 1930-1960
- Built to operate 50-200 years
- Tuttle Creek Lake (TCL) has lost 77% of sediment storage capacity and 42% of total storage (sediment pool plus multipurpose pool) capacity in 47 years
- 9,600mi^2 watershed – 25% located in KS (Figure 1), but contributes 69.5% of annual sediment load to TCL

Figure 1: Study Region



- Erosion of cropland and streambanks main sources
- TCL exhibits one of the most critical cases of reservoir sedimentation nationwide.

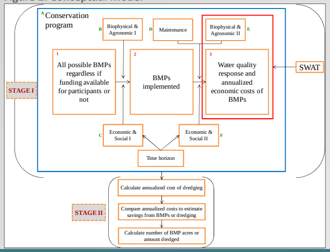
Research Question

Is economically optimal placement of three land management strategies for sedimentation reduction less costly than dredging?

Conceptual Framework

- Answer research question by integrating
  - Physically-based watershed model
  - Economic analysis of three alternative sedimentation land management reduction strategies vs. dredging from a watershed manager's perspective
- Two stage process (Figure 2)
  1. Generate marginal cost and total cost of implementing BMPs.
  2. Compare costs of dredging to those of BMP implementation.

Figure 2: Conceptual Model



Data

- BMP economics (Figure 3)
  - Filter strips, No-till, Permanent vegetation projects
  - Establishment and annual costs of each BMP
  - Include opportunity costs
  - Calculate net present values and annualize over 15-year horizon

Figure 3: "Original" BMP Annualized Costs Over a 15-year Time Horizon

County, State	Annualized Cost ($/acre) for Filter Strips per Cropland Acre Treated[1]	Annualized Cost ($/acre) for No-till	Annualized Cost ($/acre) for Land Retirement
Clay, KS	$7.66	$3.25	$162.10
Gage, NE	$11.34	$5.00	$216.30
Jefferson, NE	$11.34	$5.00	$203.86
Marshall, KS	$9.41	$3.25	$178.46
Nemaha, KS	$9.57	$3.25	$184.92
Pawnee, NE	$10.95	$5.00	$211.04
Pottawatomie, KS	$8.63	$3.25	$173.16
Republic, KS	$7.76	$3.25	$153.26
Riley, KS	$9.10	$3.25	$163.74
Washington, KS	$9.11	$3.25	$166.14

Annualized cost of filter strip divided by 25 cropland acres (treated).[1]

- Dredging economics
  - Estimate the annualized cost of dredging.
- Physiographical data
  - Soil and Water Assessment Tool (SWAT) model is used to estimate the baseline and post-BMP implementation sediment loading into TCL at a subwatershed level (Figure 4).
  - SWAT accounts for current cropping rotations and field operations.
  - SWAT calibrated against flow and observed water quality data.

Figure 4: Acre-weighted Average Pollutant Loading at Edge of HRU Across All Agricultural HRUs (tons or lbs/ac/yr)

Pollutant	Baseline	Filter Strips	100% No-till	Permanent Veg.
	Average loading at edge of HRU (tons or lbs/acre/year)			
Sediment (tons/ac/yr)	2.87	0.78	2.21	0.15
Nitrogen (lbs/ac/yr)	19.65	5.61	16.19	2.67
Phosphorus (lbs/ac/yr)	4.75	1.30	4.89	0.36
	Percentage loading reduction from baseline (%)			
Sediment (tons/ac/yr)	-	72.6%	23.0%	94.6%
Nitrogen (lbs/ac/yr)	-	71.4%	17.6%	86.4%
Phosphorus (lbs/ac/yr)	-	72.6%	-3.0%	92.5%

Empirical Methods

- Incorporate the SWAT results from 1,858 cropland Hydrologic Response Units (HRUs) as input into an economic model.
- Assume that 25% of most erosive HRUs already have BMPs implemented. These HRUs are removed from the choice set.
- Economically optimal method is used where BMPs are placed in areas of the watershed where sediment loading is reduced at lowest costs ($/ton) in sequential order.

$$Max \sum_{i=1}^{3} \sum_{j=1}^{1858} S_{ij} \times H_{ij}$$

Subject to:

$$\sum_{i=1}^{3} \sum_{j=1}^{1858} C_{ij} \times H_{ij} <= B, \text{ and}$$

$$S_{ij} > 0$$

where:

S_{ij} = annual sediment reduction in tons/acre with BMP$_i$ in HRU$_j$
H_{ij} = acres of BMP$_i$ in HRU$_j$
C_{ij} = annualized cost in \$/acre for BMP$_i$ in HRU$_j$
B = annual budget constraint
i = 1 to 3 BMPs
j = 1 to 1,858 HRUs

Cropland BMP Implementation Results

- Challenge → Which HRUs have or have not already implemented BMPs?
  - Figure 5 and Figure 6 results assume the most erosive 25% of HRUs (in terms of baseline soil erosion) across the TCL watershed have already adopted BMPs.
  - Figure 5 shows the priority areas for reducing sediment with filter strips.
  - Figure 6 shows the priority areas for reducing sediment with no-till.

Figure 5. Priority Areas for Filter Strips.

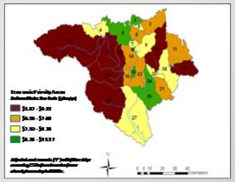
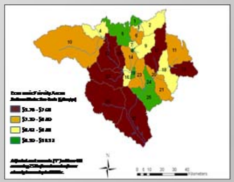


Figure 6. Priority Areas for No-till.



BMPs vs. Dredging

- The benefits of BMPs are the costs of dredging that are avoided.
  - BMPs are economically preferred to dredging for the first 287,585 tons of sediment per year (Figure 8).
  - Current cost of dredging ($6.28/ton) equals the MC of BMPs at an $881,437 annual budget (Figure 8).
  - The results are based on BMPs implemented in a highly targeted "optimal "approach.
  - If targeting of BMPs is not an option, the prescription is to dredge immediately (from a cost perspective only).

Figure 7: Sediment Reduction Results with 25% Most Erosive HRUs Eliminated and Additional BMPs Implemented Cost-effectively.

Annual Budget	Average Sediment Reduction Cost for All Land Treated by BMPs ($/ton)	Dredging and Marginal Sediment Reduction Cost for Last Acre Treated by BMPs	# of Filter Strip Projects	# of No-till Projects	# of Permanent Vegetation Projects	Total Cropland Treated by BMPs (ac.)	Percent of Land Treated by BMPs	Annual Sediment Reduction (tons)	Percent of Annual Sediment Reduction
$50,000	$1.75	$1.94	16	43	0	9,484	1.6%	28,215	1.5%
$250,000	$2.03	$2.37	82	87	0	36,957	6.0%	122,876	6.6%
$450,000	$2.26	$3.10	175	142	0	63,790	10.4%	198,542	10.7%
$623,567	$2.56	$5.00	272	239	0	98,622	16.1%	243,041	13.1%
$881,437	$3.06	$6.28	301	272	0	137,304	22.4%	287,585	15.5%
$1,172,062	$3.54	$7.00	333	298	0	172,719	28.2%	331,512	17.8%
$2,095,142	$4.68	$9.00	403	341	0	289,020	47.3%	447,564	24.0%

Figure 8: Marginal and Total Cost Curves for Sediment Reduction with Targeting

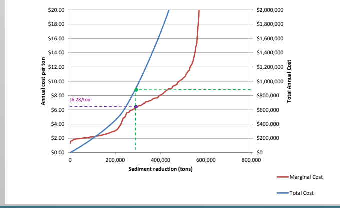
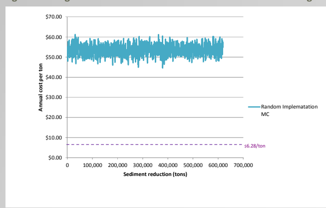


Figure 9: Marginal Cost Curves for Sediment Reduction without Targeting



Conclusions

- Both physiographical and economic factors must be considered for cost-effective conservation to occur.
- Approximately $881,437 per year, not considering "intangible" costs of BMP implementation, could be spent on targeted BMP implementation before some selected dredging may be needed.
- If "intangible" costs of BMP implementation are significant and/or BMPs cannot be targeted effectively, dredging is likely more cost-effective.
- This analysis does not consider benefits associated with BMPs other than dredging costs avoided. The benefits of BMPs and dredging would have to be known to more adequately compare the alternatives for protecting and/or restoring TCL.

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