Economic Analysis of Reservoir Sedimentation in Gavins Point Dam

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This paper will be completed upon receipt of critical information from the USACE.

Abstract

Extending a dam's life requires adopting a new design and operational paradigm that focuses on managing the reservoir and watershed system to bring sediment inflow and outflow into balance by including reservoir sediment management facilities in dam and reservoir. However, the cost of methods that remove the sediment from reservoirs is usually prohibitive and is a serious factor preventing sustainable sediment management. Traditionally, reservoirs are designed for a lifetime of 50 to 100 years. Moreover, economic analyses omitted critical costs associated with reservoir sedimentation, such as up-and downstream damages, degrading water supply benefits, and dam decommissioning, which produce non-sustainable projects.

This paper considered a case study, Gavins Point Dam, to investigate relative performance of without and with sediment management (flushing, dredging) in next 150 years, considering comprehensive sedimentation costs including prevented up-and downstream sedimentation costs. The purpose is to determine how sediment management can be effective to extend reservoir life and whether this management is economically viable. The paper applies Reservoir Sedimentation Economics Model to evaluate the benefits and costs of continued sedimentation and eventual dam decommissioning to sediment management costs and benefits. The results are compared to the sediment management plan done by the Omaha District of the U.S. Army corps of Engineers.

1. Introduction

Large dams and reservoirs interrupt the continuity of sediment transport through river systems, causing sediments to accumulate. Sediment accumulation diminishes a reservoir's capacity to store water over time, thereby limiting its service life (Randle et al. 2021). Reservoir sedimentation also has significant impacts both up- and downstream of the reservoir pool.

Reservoirs need to be evaluated for determination of either eventual decommissioning or sustainable sediment management. Dams may be decommissioned for several reasons, including problems with structural safety, economics, reservoir sedimentation, and river restoration. The dam decommissioning alternative leaves future generations with fewer, and increasingly more expensive, reservoir storage options to meet their water demands. In the case of reservoirs, sustainability means balancing sediment inflows and outflows across a dam while maximizing its long-term benefits (Morris and Fan 2010). Sustainable management can be achieved by several well-established alternatives for removing reservoir sediments and achieving sediment transport continuity. Evaluation of these strategies should include hydraulic and sedimentation analyses to model physical attributes and economic analysis to model benefits and costs (Niu and Shah 2021; Yang 2006).

Reservoir planning and economic studies commonly employ exponential discounting and either a 50- or 100-year period of analysis (POA) (Morris and Fan 2010). Furthermore, historical economic analyses rarely considered important costs, such as up- and downstream damages, and dam decommissioning; nor did they consider depleted benefits from decreased water supply, recreation area, and hydropower flexibility. With 92,000 dams already in the national inventory, replacing all these dams at alternate locations likely is not possible and the consequences of lost reservoir benefits to future generations was not considered (Anari et al. 2022).

The purpose of this paper is to determine how sediment management can be effective to extend reservoir life and whether this management is economically viable. The paper applies Reservoir Sedimentation Economics Model to evaluate the benefits and costs of continued sedimentation and eventual dam decommissioning to sediment management costs and benefits. The results are compared to the sediment management plan done by the Omaha District of the U.S. Army corps of Engineers.

2. Case Study Description

Lewis and Clark Lake on the Missouri River upstream from Gavins Point Dam has been chosen as a model for this study. Although benefits and costs will be reservoir-specific, the knowledge gained, and the technologies developed will be useful for many other reservoirs.

Lewis and Clark Lake of the Missouri River is the smallest and the most downstream of a system of six reservoirs and was created in 1955 by the construction of Gavins Point Dam. Lewis and Clark Lake receives a major influx of sediment from the local Niobrara River.

Aerial photographs taken since 1957 (dam closure) indicated the average bed rise about 3 m in 2000 (an annual rise of about 7 cm⁄yr) between the original lake headwaters and the mouth of the Niobrara River (Coker et al. 2009). The rising bed level is also causing flooding farmland and other local problems such as impending need to raise several miles of a local state highway 2-3 m (George et al. 2016). The rising bed level has both positive and negative impact on recreation. Wetland-based recreation (bird hunting, for example) is enhanced, but open-water recreational opportunities are reduced (Coker et al. 2009).

Omaha District of the U.S. Army corps of Engineers predicted the Lake will become 100% full of sediment by approximately year 2150, and the Corps will have to decide the future of the hydropower facility by about year 2100 (Cavanaugh 2022).

3. Economic Model Description

There are only a few widely available numerical models that can assist in the economic analysis of reservoirs. These models simulate how different parameters affect reservoir operations and forecast the consequences of different reservoir sediment management alternatives. The most widely used is RESCON (Efthymiou et al. 2017); a more recent model was developed by Niu and Shah (2021) to optimize for storage capacity while maximizing lifetime net benefits. Moreover, a new model was recently developed, the Reservoir Sedimentation Economics Model, RSEM, (Randle, T. J., T. L. Gaston, and R. Anari. Reservoir sedimentation economics model (RSEM), U.S. Department of the Interior, Bureau of Reclamation, Technical Service Center, Denver, CO, Unpublished report).

RSEM can be applied to evaluate the economics of a new and existing reservoir for two general scenarios: without and with sediment management, while comprehensively accounting for all benefits and costs (upstream, downstream, and within the reservoir). The model computes net present value and a benefit-cost ratio for a range of discounting approaches. This paper applies RSEM to evaluate and compare costs and benefits of sediment management alternatives for the case study.

4. Method

The reservoir storage reduction due to sedimentation is a relatively slow process (Huffaker and Hotchkiss 2006) and produces a low rate of benefit loss (Coker et al. 2009). Sedimentation impacts along the upstream channel, and degradation impacts along the downstream channel, tend to be experienced more rapidly, but the economics of those impacts have not been considered historically (Anari et al. 2023). However, a comprehensive treatment of benefits and costs is required for objective economic assessment of reservoir sediment management alternatives.

All benefits and costs serving as inputs for the case study are estimated at a 2022 price level and reported in Table A of the Appendix. The methods for determining detailed estimates of benefits and costs are beyond the scope of this study. The interested readers can apply these available references, (American society of professional estimators 2012; Anchor QEA 2020; D. C. Baird et al. 2015; PR&Gs 2014; The Los Angeles County Flood Control District 2013; USEPA 2000; WEDA 2021)).

The Exponential, Hyperbolic and Inter-generational discounting approaches were applied to compare economic results across the following reservoir management alternatives (these alternatives are considered by Omaha District, as well):

- Without sediment management: This assumes no action taken as Lewis and Clark Lake slowly fills in with sediment
- With sediment management: This assumes two sub-alternatives;
    a. annual flushing
    b. dredging

5. Results and Discussion

5.1 RSEM Results

Table 1. Benefit cost ratios of without and with sediment management alternatives for the Gavins Point Dam *

		Discounting approach		
Alternative	POA (years)	Exponential	Hyperbolic	Intergenerational
Without sediment management	50			
	100			
	150			
	300			
With sediment management (Flushing)	50			
	100			
	150			
	300			
With sediment management (Dredging)	50			
	100			
	150			
	300			

* This table will be completing upon acquiring all required input

5.1 Comparison to the sediment management plan done by the Omaha District of the U.S. Army corps of Engineers.

6. Conclusion

Appendix

Table A: Input Data Values Used in the Case Study Economic Assessment *

Parameter	Value		Note
Base year for economic analysis (BYA)	2022		
Year that all dollar value inputs are indexed to (price level)	2022		Discount rate?
Present reservoir age	65-year		Commissioned in 1957 (https://erdc-library.erdc.dren.mil/jspui/handle/11681/15270)
Reservoir Elevation Inputs			
Top of live storage	1,210	ft	
Top limit of sedimentation	1,210	ft	
Recreation pool elevation		ft	
Normal W.S. elevation	1,208	ft	Multi-Use Zone (Elevation): 1,208 feet msl - (https://www.nwo.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487639/gavins-point-project-statistics/)
Incremental sedimentation height limit above dam outlet	20.0	ft	
Top of dead storage	1,180	ft	https://wdr.water.usgs.gov/wy2011/pdfs/06467000.2011.pdf
Original streambed elevation	1,160	ft	https://www.nwd.usace.army.mil/Media/Images/igphoto/2002102192/
Original reservoir storage capacity input			
Total storage volume at top of live storage	504,000	acre-ft	https://wdr.water.usgs.gov/wy2011/pdfs/06467000.2011.pdf
Dead pool volume	23,000	acre-ft	https://wdr.water.usgs.gov/wy2011/pdfs/06467000.2011.pdf
Reservoir inflow characteristics			
Mean Annual Reservoir Inflow		acre-ft/year	
Standard deviation of mean annual inflow		acre-feet/year	
Original reservoir dimensions			
Reservoir valley length at full pool	25	mi	https://www.nwo.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487639/gavins-point-project-statistics/
Reservoir surface area at full pool	31,000	acre	https://www.nwo.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487639/gavins-point-project-statistics/
Reservoir average surface width at the top surface of a full pool		ft	

Parameter	Value		Note
Boat Ramps / Marinas			
Number of boat ramps/marinas			
Boat ramp/marina #1 length from dam		mi	
Boat ramp/marina #2 length from dam		mi	
Dam characteristics			
Dam type (drop down list)	Rolled-earth & chalk fill		
Volume of dam material	7,308,000	yr^3	https://erdc-library.erdc.dren.mil/jspui/handle/11681/15270
Hydraulic height	45	ft	https://erdc-library.erdc.dren.mil/jspui/handle/11681/15270
Dam crest length across river	8,700	ft	https://www.nwo.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487639/gavins-point-project-statistics/
Sediment Inflow Rate Inputs			
Annual storage percent loss		per year	
Fine sediment portion (clay and silt)		%	
Reservoir Sedimentation Profile Slope Inputs			
Delta topset slope factor	0.75		Assumption
Delta foreset slope factor	6.0		Assumption
Bottomset slope factor	0.1		Assumption
Reservoir profile plotting interval	10		
Predam River Channel and Degradation Inputs			
Channel sinuosity	1.0		Assumption
Average bank full channel width		ft	
Average bank height		ft	
Average channel roughness (Manning's n coefficient)		0.022	Assumption
Portion of bed material is armor size or coarser		15%	Assumption
Armor layer thickness	0.5	ft	Assumption
Percentage of original downstream channel slope that would remain after stability has been achieved	95%		Assumption
Reservoir benefits			
Water Yield as a Percentage of Storage Capacity		100%	
Percentage of Consumptive Uses:			
Agricultural irrigation use			
M&I water use			
Fish & wildlife and other			
Unit Values for Consumptive Use Benefits			
Agricultural irrigation use		$/acre-ft	
M&I water use		$/acre-f	
Fish & wildlife and other		$/acre-ft	

Parameter	Value		Note
Flood risk reduction		$/acre-ft	
Hydropower production			
Average annual energy production	132.3	MWh/yr	https://en.wikipedia.org/wiki/Gavins_Point_Dam
Average energy benefit rate		$/MWh	
Annual hydropower benefit		/year	
Recreation Use Benefits in Base Year			
Average annual visitor days	2,000,000	visitor days/year	https://sdmissouririver.com/follow-the-river/the-four-lakes-and-dams/lewis-and-clark-lake/
Benefit per visitor day (net consumer surplus)	4.34	$/day	The lake currently provides around $8,680,000 in recreation benefits a year **
Benefit dependent on all boat ramps/marinas		100%	Since the available recreation benefits are as total benefits (not specifically boat ramps).
Benefit reduction from loss of 1 boat ramp/marina		88%	After the lake is filled in, it will provide around $1,026,000 in recreation benefits a year
Dam & Reservoir Planning, Design, and Construction Costs			
Total construction cost	$50,000,000 (1957 USD)		https://erdc-library.erdc.dren.mil/jspui/handle/11681/15270
Design, Construction, and Contract Contingencies Cost Additives			
Increase for unlisted items		10%	Assumption
Increase for mobilization and demobilization		5%	Assumption
Increase for design contingencies		20%	Assumption
Increase for procurement strategy		5%	Assumption
Increase for overhead and profit		15%	Assumption
Increase for construction contingencies		20%	Assumption
Operations, Maintenance, and Replacement (OM&R) Costs			
Annual OM&R cost		$450,000	Assumption
5-year recurring costs		$100,000	Assumption
Dam Decommissioning Costs and Benefits			
Dam removal unit cost		$/yr^3	
Sediment management unit cost		$/yr^3	
River diversion cost		$	
Coffer dam cost		$	
Salvage benefits		$	
Other river restoration costs		$	
Dam decommissioning cost		$	
Annual dam removal benefit		$	
Upstream sedimentation costs			
Deposition threshold for land impacts	3.0	ft	Assumption
Unit land devaluation cost	3,814	$/acre	Omaha District study
Unit highway/railroad relocation cost		$/mi	Total upstream costs including City of Niobrara relocation and Highway 12 maintenance is $257,945,000

Parameter	Value		Note
Unit fish & boat passage cost		$/mi/year	(2015 USD) (George et al. 2016) that this value will be used to calibrate model and find unit cost of this row.
Downstream channel degradation costs			
Median riprap rock size	2.1	ft	Assumption
Degradation threshold (min. vertical erosion when economic impacts begin)	2.0	ft	Assumption
Streambank side slope (1:z)		2	
Streambank protection factor		3	
Unit cost of streambank protection with additive costs			$/yd3
Without sediment management alternative			
Project decommissioning age	193	years	Decommissioning has been considered 2150
Forced sediment management parameters			
Begin forced sediment removal (years after end of sediment design life)			years
Maximum portion of sediment inflow that will be removed in the year prior to dam decommissioning			%
Forced fine/coarse sediment removal cost		$\$/yd^3$	
Dam age when boat ramp / marina #1 is lost		years	
Dam age when boat ramp / marina #2 is lost		years	
Sediment management alternative			
Annual fine sediment removal		%	
Annual coarse sediment removal		%	
Sediment management capital cost before additives	$ 200,000	for sluicing	$ 44,595,000 for dredging
Equipment life	10 years for sluicing		? years for dredging
Sediment management begins at dam age	65 years for sluicing		65 years for dredging
sediment removal cost	$ 50,000 (sluicing)	$/yr	$ 106,981,000 $/yr (dredging)
water used for sediment management as % of capacity			%

* This table is not complete and requires more information.

** The red lines are cited from USACE, Omaha District study

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