LEWIS AND CLARK LAKE SEDIMENT MANAGEMENT PLAN STUDY

PHASE TWO REPORT

OMAHA DISTRICT

NORTHWESTERN DIVISION

IN PARTNERSHIP WITH

MISSOURI SEDIMENTATION ACTION COALITION

November 2023

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Table of Contents

List of Figures

List of Tables

List of Acronyms

AIS	Aquatic Invasive Species
ARPA	Archaeological Resources Protection Act
BCC	Birds of Conservation Concern
BoR	Bureau of Reclamation
EPA	Environmental Protection Agency
ESA	Endangered Species Act
HEC-RAS	Hydrologic Engineering Center River Analysis System
IPaC	USFWS Information for Planning and Consultation
LCLSMP	Lewis and Clark Lake Sediment Management Plan
LF	Linear Feet
MNRR	Missouri National Recreation River
MSAC	Missouri Sedimentation Action Coalition
NAGPRA	Native American Graves Protection and Repatriation Act

NEPA	National Environmental Policy Act
NGPC	Nebraska Game and Parks Commission
NHP	Natural Heritage Program
NHPA	National Historic Preservation Act
NPS	National Park Service
NPV	Net Present Value
NRCS	Natural Resources Conservation Service
NRHP	National Register of Historic Places
ORV	Outstandingly Remarkable Values
PA	Programmatic Agreement for the Operation and Management of the Missouri Reservoir Mainstem System for Compliance with the National Historic Preservation Act
PAS	Planning Assistance to States and Tribes
PMP	Project Management Plan
RM	River Mile
SDGFP	South Dakota Game, Fish and Parks
SHPO	State Historic Preservation Office
SME	Subject Matter Expert
TCP	Traditional Cultural Properties
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WRDA	Water Resources Development Act
WRP	Wetland Reserve Program
WSR	Wild and Scenic River
WSRA	Wild and Scenic Rivers Act of 1968, 16 USC 1271

LEWIS AND CLARK LAKE
SEDIMENT MANAGEMENT PLAN STUDY
PHASE TWO REPORT

EXECUTIVE SUMMARY

The U.S. Army Corps of Engineers (USACE), Omaha District, in partnership with a consortium of local sponsors, including the Missouri Sedimentation Action Coalition (MSAC), City of Yankton, SD, counties, and other groups have identified the need for a comprehensive Lewis and Clark Lake Sediment Management Plan (LCLSMP) to address the continual loss of project benefits to sedimentation, and develop strategies to mitigate current sedimentation impacts throughout the watershed and minimize future impacts. The study expects to mimic the goals and objectives from the WRDA 2016 Section 1179a authorization, as amended.

USACE is conducting a Section 22 Planning Assistance to States and Tribes (PAS) study to develop the LCLSMP for the watershed around Gavins Point Dam. The study summarizes the evolution of the delta and related sediment impacts at the project and upstream river reach and provides a review of current and emerging sediment management methodologies and their applicability at Lewis and Clark Lake.

An effective Sediment Management Plan for Lewis and Clark Lake and upper reaches will encompass several different components, working together, to achieve a sediment balance. Known methods such as watershed management and bedload collection directly reduce the incoming sediment. Methods that manage incoming sediment can be paired with methods for removing previously deposited sediment in the lake, which has collected since dam closure in 1955. The deposition has impacted the benefits generated by the project. Those impacts include, but are not limited to:

- Increased surface and ground water elevations have resulted in lost land productivity, transportation limitations, housing relocations, and increased flood risk.
- Sediment deposition in Lewis and Clark Lake limits recreation, storage volume in all reservoir pools, and the ability to reliably utilize reservoir water for water supply and irrigation.
- Downstream degradation (because of sediment-depleted releases) has increased bank height and erosion, reduced aquatic and sandbar habitat, and required bank stabilization.

Economic development on and around Lewis and Clark Lake will be hampered by continued sedimentation. Importantly, open water-based recreation will be affected as the surface area of the lake diminishes. Recreational opportunities, in the short term, will continue to grow due to investments planned by the States of South Dakota and Nebraska, such as the expansion of the Weigand Marina on the Niobrara River, funded by the Nebraska STAR WARS recreation and tourism initiative. These states plan to build new recreation facilities on and adjacent to Lewis and Clark Lake, effectively growing recreation in the short term; however, long term, as sedimentation begins to reduce recreational opportunities on the lake, the number of visitors will be reduced.

For a reservoir, the end-goal of any Sediment Management Plan is to move the reservoir toward sustainability. Full sustainably, the ideal end-state, is an equilibrium condition of sediment entering and exiting the reservoir. This condition would result in an infinite project life of the storage volume limited only by infrastructure age. While full sustainability is ideal, incremental changes in the reservoir sediment balance that increase its life span are necessary steps in that direction. The magnitude of the application of any method can result in varying levels of sustainability. Limitations such as cost, schedule, impacts to benefits, environmental and social considerations, and life safety all dictate how methods can be applied. For Lewis and Clark Lake, it is expected that a combination of methods will be required to move toward sustainability.

The timeline for impacts associated with sedimentation is always difficult to predict. Changes in hydrology, land use, and management all affect rate of change. In Section 2, a brief history of the project is included with future projections of sedimentation. These projections are leveraged in the economic analysis to estimate future lost benefits. Lewis and Clark is already experiencing loss of benefits, which will accelerate as impacts to hydropower production, water supply, flood risk reduction, navigation, and recreation increase in the future.

The Phase Two study was initiated with a reservoir sedimentation Subject Matter Expert (SME) Workshop in June 2021 (summarized in Section 3). The workshop resulted in the identification of four methods to be considered for application at Lewis and Clark Lake. Those four were screened during the workshop with input from a wide section of stakeholders, State and Federal management agencies. Section 4 provides a detailed assessment of each method, which include: 1) Hydraulic and Mechanical Dredging, 2) Watershed Sediment Management, 3) Sluicing, and 4) Bedload Sediment Collection.

In addition to the established methods identified at the SME workshop, emerging technologies like D-Sediment and Hulskins Sediment's Sedi-Mover Technology could be implemented to extend the lifespan of Lewis and Clark and assist with achieving sustainability throughout the entire study area. Multiple emerging technologies are considered in Section 4.2.

Extensive economic analyses were also completed as part of the study (included in Section 5, with the economic inventory in Appendix A). This included the development of a benefits inventory, the estimation of near-term (20 years) cost associated with sedimentation, consideration of dam and reservoir end-of-life cost scenarios, and a life-cycle economic model for reservoirs. The cost of decommissioning Gavins Point dam is a critical economic factor that has not been estimated in detail but will be substantial. Maintaining the reservoir and its benefits supports avoiding decommissioning.

A brief evaluation of potential environmental effects was developed for each method proposed in Section 6. Environmental impacts are a significant consideration for all proposed methods, as use of the reservoir, native species, and water quality will all be impacted and require mitigation.

The analysis completed in Phase Two does not fully develop an implementation plan for any method, rather it looks generally at how each method could move sediment and the impediments to effective implementation. Each method has significant obstacles to overcome before application at Lewis and Clark Lake would result in progress toward sustainability.

Hydraulic and Mechanical dredging are expensive and disruptive to lake uses. Watershed Sediment Management covers a large geographical area and multiple large projects are required to reduce more than a small portion of the incoming sediment. Sluicing is not effective with the current arrangement of gates on the dam and has many environmental impacts. Bedload Sediment Collection provides a very local benefit and is difficult to scale up due to the need to transport sediment away from the collection point.

None of these obstacles should prevent the judicious and economically feasible application of these methods at Lewis and Clark Lake. A combination of systems in the right locations at the right times will result in extending the life of the reservoir. Possible application of new methods in the future could further improve the reservoir's sustainability.

The analysis done in this Phase Two report is intended to identify the general categories of sediment management methods that could be successful, provide a life-cycle economic analysis to determine what methods may be considered viable, and give the background needed to refine the future analysis in Phase Three to develop a sediment management plan with proposed actions and expected outcomes.

As USACE and the sponsor team scope for additional study and move toward a comprehensive plan, there are a number of issues to consider. The failure of Spencer Dam on the Niobrara River significantly increased sediment delivery to the Missouri River for at least a few years, growing the Niobrara River delta faster than in previous decades. Any watershed management to be instituted will require extensive coordination and collaboration with Federal, Tribal, state, local, and private organizations. The methods considered here are all expected to return sediment to the downstream Missouri River channel below Gavins Point Dam. That sediment return could have impacts on downstream communities and will need to be further evaluated; coordination with stakeholders in South Dakota, Nebraska, Iowa, Kansas, and Missouri will be necessary.

1 INTRODUCTION

1.1 Project Authority and Funding

This study is authorized by Section 22 of the 1974 Water Resources Development Act (WRDA) known as Planning Assistance to States and Tribes (PAS). This program authorizes the U.S. Army Corps of Engineers (USACE) to use its technical expertise in management of water and related land resources to help states and Tribes with their water resource problems. Upon request, USACE will cooperate with states and Tribes in the preparation of plans for the development, utilization, and conservation of water and related land resources; however, USACE is not permitted to prepare site-specific structural designs or construction specifications under this program authority.

1.2 Project Purpose and Elements

A consortium of local sponsors, including the Missouri Sedimentation Action Coalition (MSAC), City of Yankton, SD, counties, and other groups have identified the need for a comprehensive Lewis and Clark Lake Sediment Management Plan (LCLSMP) to address the continual loss of project benefits to sedimentation, develop strategies to mitigate current sedimentation impacts throughout the watershed, and minimize future impacts. The study expects to mimic the goals and objectives from the WRDA 2016 Section 1179a authorization, as amended.

Section 1179(a)(3) Plan Elements. A sediment management plan under paragraph (2) shall

a) *Provide opportunities for project beneficiaries and other stakeholders to participate in sediment management decisions;*
b) *Evaluate the volume of sediment in a reservoir and impact on project purposes, including storage capacity;*
c) *Identify sediment management options, including sediment dikes and dredging;*
d) *Identify constraints;*
e) *Assess technical feasibility, economic justification, and environmental impacts;*
f) *Identify beneficial uses for sediment; and*
g) *To the maximum extent practicable, use, develop, and demonstrate innovative, cost-saving technologies, including structural and nonstructural technologies and designs, to manage sediment.*

Section 1179(a)(4) Justification. In determining the economic justification of a sediment management plan under paragraph (2), the Secretary shall

a) *Measure and include flooding, erosion, and accretion damages both upstream and downstream of the reservoir that are likely to occur as a result of sediment management within the reservoir compared to the damages that are likely to occur if the sediment management plan is not implemented; and*
b) *Include lifecycle costs and a 100-year period of analysis.*

USACE Omaha District is conducting a Section 22 PAS study to develop the LCLSMP for the watershed around Gavins Point Dam. The study will summarize the evolution of the delta (Figure 1) and related sediment impacts at the project and upstream river reach and provide a review of current and emerging sediment management methodologies and their applicability at Lewis and Clark Lake.

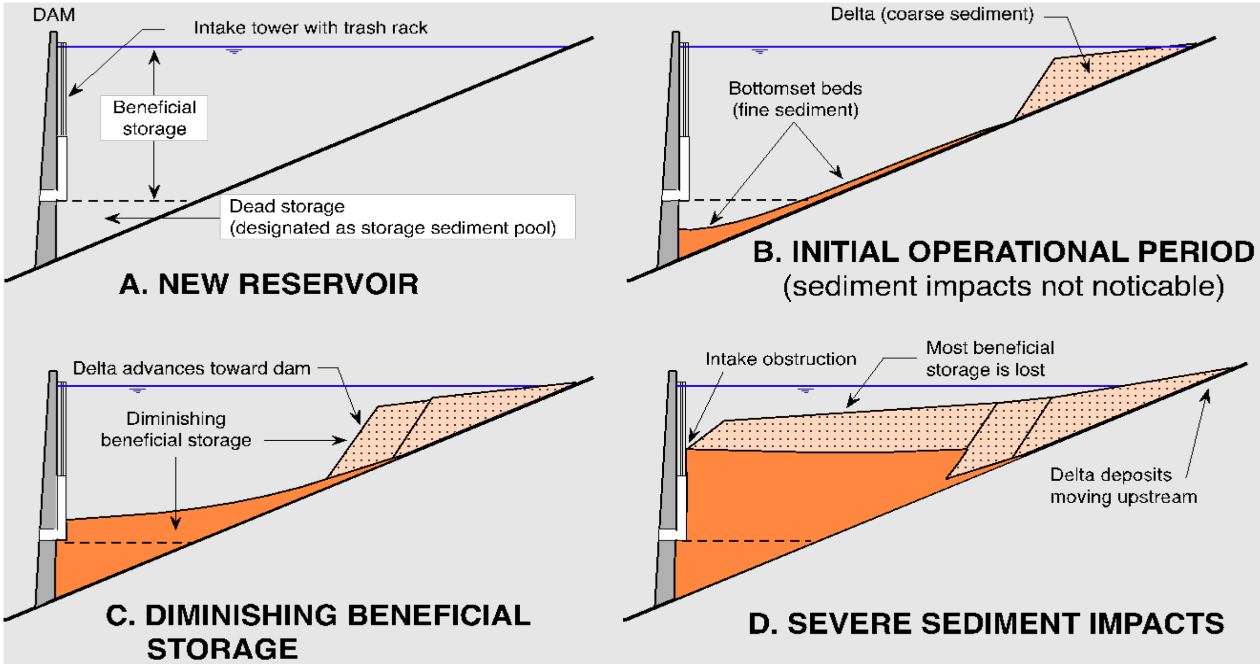

Figure 1. Delta Development in Reservoirs (Morris, 2018)

The PAS study will not in itself lead to construction of a project, but if a construction or management project is identified through this process, other study authorizations may be considered for a future project. A request for a Section 1179a New Start is a possibility that could be used to complete later phases, construction/implementation, or both. USACE and the sponsors will continually evaluate the best pathways forward for subsequent phases, and request project appropriations if needed.

1.3 Problem Framework and Study Objectives

The problem framework identified for the study is:

Cause: The interruption of dynamic flows on the Missouri River due to the construction and management of Gavins Point Dam.

Symptoms:

- Chronic sediment delivery from the watershed has resulted in sediment deposition in Lewis and Clark Lake, the Missouri and Niobrara Rivers, and Bazile and Ponca Creeks.
- Lewis and Clark Lake was measured to have lost 26 percent of the total storage capacity as of 2011, and the Missouri River and tributaries have all exhibited bed aggradation that may affect river stage-discharge relationships.
- The absence of sediment in the downstream Missouri River channel has resulted in channel degradation, reduction in fish and wildlife habitat, and other infrastructure impacts.

Impacts:

- Increased surface and ground water elevations have resulted in lost land productivity, transportation limitations, housing relocations, and increased flood risk.

- Sediment delta in Lewis and Clark Lake limits recreation, storage volume in all reservoir pools, and the ability to reliably utilize reservoir water for water supply and irrigation.
- Downstream degradation has increased bank height and erosion, reduced aquatic and sandbar habitat, and required bank stabilization.

Actions:

- No long-term management plan is in place to mitigate the loss of benefits due to sedimentation or prevent future symptoms and impacts.

The study objectives are identified as follows:

- Provide opportunities for project beneficiaries and other stakeholders to participate in sediment management decisions.
- Evaluate the volume of sediment in the reservoir and impact on storage capacity.
- Assess the economic benefits of all project purposes.
- Assess the economic impact of previous and future sedimentation.
- Identify sediment management options.
- Identify constraints to implementation.
- Assess technical feasibility and environmental impacts.
- Identify beneficial uses for sediment.
- To the maximum extent practicable, use, develop, and demonstrate innovative, cost-saving technologies, including structural and nonstructural technologies and designs, to manage sediment.
- Develop a Sediment Management Plan with recommendations of sediment management actions that conserve the greatest benefits and attempt to establish a sustainable reservoir.

The study will be conducted in three phases. The first phase consisted of a scoping effort that included (following a kick-off meeting) assembling existing information, identifying data gaps, conducting a scoping workshop, completing project management activities, and developing a Project Management Plan for handling the second and third phases. This report is the result of the second phase of the PAS study. The second phase focused on leveraging existing sediment management studies coupled with the application of economic models to consider the costs and benefits associated with sediment management. The third phase will expand the technical analysis to consider emerging technologies, integrate the environmental benefits and impacts, and develop a detailed Sediment Management Plan for Lewis and Clark Lake.

1.4 Summary of Phase One

The MSAC team and USACE Omaha District's Planning Branch discussed the WRDA 2016 Section 1179a authority and its applications multiple times in 2017-18 while USACE Headquarters developed guidance for the execution of the new authority. Section 1179a directed USACE to develop Sediment Management Plans for Upper Basin Missouri River

Reservoirs at the request of a project sponsor. Both a study and construction authorization were afforded if there was an identified Federal interest and an economically beneficial project.

The inception of a project under Section 1179a requires a New Start within the budgeting schedule that USACE employs. New Start projects are very limited each fiscal year and likely would have significantly delayed the project start and carried numerous funding uncertainties. MSAC chose to use the Section 22 Planning Assistance to States (PAS) program, as it provides extensive flexibility on products and analysis. Section 22 does not contain construction authorization, and pending the outcome of Phase Three, a project under the Section 1179a authority may be revisited for construction.

MSAC and the sponsor team members engaged with USACE in multiple virtual and in-person scoping meetings in 2019 as part of Phase One. The Phase One effort was cost-shared under the Section 22 PAS authority designed to develop the detailed scope for Phase Two and an outline for Phase Three.

The result of Phase One was the Project Management Plan (PMP) which served as the scope for Phase Two. The scoping effort was intentionally extensive, to ensure that an all-inclusive group of stakeholders had been consulted and so that many questions could be vetted to inform the Phase Two scope.

The four primary questions that were debated in scoping were:

1. Who could best provide an expert opinion on ways to manage sediment at Lewis and Clark Lake?
2. Should economic analysis or engineering design be the Phase Two priority?
3. How can non-traditional economic analysis be effectively addressed?
4. What is the best way to quantify the value of any management action at Lewis and Clark Lake?

The feedback on these questions helped develop the tasks identified for the Phase Two work that is detailed in this report.

2 LEWIS AND CLARK LAKE AND GAVINS POINT DAM

2.1 Study Footprint

Gavins Point Dam impounds Lewis and Clark Lake at River Mile (RM) 811 of the Missouri River. The top of the flood control pool (elevation 1210.0 feet NGVD 1929) extends approximately 25 miles upriver, just above Springfield, SD.

Sedimentation inputs from within and outside the project footprint have combined to create current conditions. Approximately 50-60 percent of the supply is from the Niobrara River, 30 percent from the Missouri River, and the remaining 10 percent from smaller tributaries (Ponca Creek, Bazile Creek, etc.), bank erosion, and the local watershed (Figure 2.1). To create a more complete assessment of sediment impacts, the upstream footprint will extend up the Missouri River to Fort Randall Dam, the lower 15 miles of the Niobrara River, and the lower reaches of Ponca and Bazile Creeks.

The reach of the Missouri River below Gavins Point Dam is not within the Gavins Point Dam Project boundary but is heavily impacted by the lack of sediment delivery from upstream. The Missouri River downstream to Ponca, NE (RM 753) and the lower reaches of the James and Vermillion Rivers will be included in the study footprint (Figure 2.2).

Figure 2.1 Sediment Sources of the Lewis and Clark Lake Delta (Sweeney et al., 2018)

Figure 2.2 Approximate Extents of Sedimentation Impacts

2.2 Project History and Sedimentation Impacts

The Gavins Point Dam Project, and all mainstem projects on the Missouri River, are managed to support eight Congressionally authorized project purposes: flood control, navigation, hydropower, water supply, water quality, recreation, fish and wildlife conservation, and irrigation. The dam is located on the border of South Dakota and Nebraska near Yankton, South Dakota. The project was initiated in 1952, with dam closure in 1955. The reservoir at Lewis and Clark Lake is the smallest of the mainstem Missouri River reservoirs.

2.2.1 Storage Depletion due to Sedimentation

Lewis and Clark Lake storage is divided into three storage pools. A permanent pool below elevation 1204.5 feet (NGVD 1929), a multipurpose and flood control pool up to 1208.0 feet (NGVD 1929), and an exclusive flood control pool up to 1210.0 feet (NGVD 1929). The reservoir pool is normally managed in a narrow range within the Flood Control and Multipurpose pool, only varying a few feet, outside of times when the Exclusive Flood Control pool is utilized. This pool management results in growth of the delta face that is consistent and predictable. Since closure, the visible face of the delta has moved approximately 550 feet per year between 1982 and 1998 (USACE, 2011). The rate of movement has slowed as the delta moves to deeper areas of the lake, but the rate of storage loss remains similar.

Thirty-three (33) permanent sediment ranges were established along the aggradation reach downstream of Fort Randall Dam and upstream of Gavins Point Dam. These survey locations were established to provide an adequate measurement of sediment deposition. These sediment ranges are maintained by the USACE Omaha District River and Reservoir Engineering Section. They have been the basis for the surveys that calculate the area-elevation and volume-elevation relationships provided in this report.

The original storage volume to the top of the exclusive flood control pool (1210 feet (NGVD1929)) at Lewis and Clark Lake in 1955 was reported as 574,930 acre-feet. The lake originally had 25 miles of open water, with 90 miles of shoreline. That volume has dropped to 425,829 acre-feet, and approximately 17 miles of open water as of 2011. Tables 2.1 and 2.2 provide a summary of storage volume changes in Lewis and Clark Lake from 1955 to 2011.

Table 2.1 Lewis and Clark Lake – Summary of Reservoir Capacity Changes through 1985 (USACE, 2013)

Storage Zone with Top of Pool Elevation (ft, NGVD29)	1955	1965			1975			1985		
	Capacity (ac-ft)	Capacity (ac-ft)	Rate, *1955-1965* (ac-ft/yr)	Percent of Original	Capacity (ac-ft)	Rate, *1965-1975* (ac-ft/yr)	Percent of Original	Capacity (ac-ft)	Rate, *1975-1985* (ac-ft/yr)	Percent of Original
Exclusive Flood Control 1210	574,930	537,072	-3,786	93.42%	526,386	-1,069	91.56%	491,701	-3,469	85.52%
Flood Control & Multipurpose 1208	509,813	473,873	-3,594	92.95%	464,149	-972	91.04%	432,026	-3,212	84.74%
Permanent 1204.5	406,404	374,626	-3,178	92.18%	367,271	-736	90.37%	339,770	-2,750	83.60%

Table 2.2 Lewis and Clark Lake – Summary of Reservoir Capacity Changes through 2011 (USACE, 2013)

Storage Zone with Top of Pool Elevation (ft, NGVD29)	1995			2007			2011		
	Capacity (ac-ft)	Rate, *1985-1995* (ac-ft/yr)	Percent of Original	Capacity (ac-ft)	Rate, *1995-2007* (ac-ft/yr)	Percent of Original	Capacity (ac-ft)	Rate, *2007-2011* (ac-ft/yr)	Percent of Original
Exclusive Flood Control 1210	468,001	-2,370	81.40%	450,046	-1,496	78.28%	425,829	-6,054	74.07%
Flood Control & Multipurpose 1208	409,473	-2,255	80.32%	393,221	-1,354	77.13%	370,361	-5,715	72.65%
Permanent 1204.5	320,379	-1,939	78.83%	307,441	-1,078	75.65%	287,670	-4,943	70.78%

2.2.2 Sedimentation Impacts

Lewis and Clark Lake, behind Gavins Point Dam, disrupts the continuity of water and sediment along the Missouri River, causing inevitable impacts both directly and indirectly.

The original intent of developing reservoirs across the nation was to mitigate basin runoff extremes, such as floods or drought and provide additional benefits that were essential to the growth and development of the country. Supporting navigation, hydropower, recreation, irrigation, water quality, and water supply all improved quality of life, boosted local and regional economies, and attracted new residents and investment in the areas surrounding the reservoir projects.

In general, the fate of sediment in the system was well understood, if not well addressed in the design and proposed management of reservoir projects. Early design memorandum reports on Gavins Point dam made long-term estimates of the expected sediment inflow to the reservoir. These pre-dam estimates agree reasonably well with sediment measurements made over the past 60 years, but because the predicted sediment volumes trapped would still result in a project life exceeding the 50-year economic design lifespan, sediment management was not considered necessary.

As Lewis and Clark Lake nears 70 years of age, the economic lifespan has been met and surpassed, with the project still providing extensive benefits. Some of those benefits have been impacted by sedimentation and will continue to be, but the larger category of impacts is the costs associated with mitigating the damage caused by sedimentation. The combination of reduced benefits from the project and the expenses and life quality reduction associated with addressing sedimentation gives a more complete picture of the true 'cost' of sediment collecting in the Missouri River, Niobrara River, and Lewis and Clark Lake.

The goal of the economic analysis provided in Section 5 is to inventory benefits, project how those benefits may be reduced in the future and capture a summary of all the costs associated with sedimentation.

The broad categories of those impacts include:

- Loss of open water in Lewis and Clark Lake.
- Increased river stages changing land use.
- Reduced recreation access (boat ramps and trails).
- Increased groundwater elevations (led to relocation of the Village of Niobrara).
- Sediment-choked tributary reaches.
- Burying of irrigation and municipal water intakes.
- Channel degradation downstream leading to bank instabilities.
- Reduction and conversion of habitat for local species (flora and fauna).

As part of this study, the sponsor group led by MSAC has commissioned a historical narrative on the social and economic impacts of the construction and operation of the Gavins Point Dam project as part of the Missouri River Mainstem System. The narrative includes some historical perspective and references to many popular press articles discussing opinions on the design, construction, operations, and impacts of the project. Readers are encouraged to read the piece at: http://www.msaconline.com/award-winning-author-writes-historical-narrative-for-phase-2/.

2.3 Current Sedimentation Conditions at Lewis and Clark Lake

The reservoir at Lewis and Clark Lake has a total capacity of approximately 426,000 acre-feet (as of the fall 2011 survey), which is less than one percent of the total mainstem storage. Approximately 138,000 acre-feet of project storage is committed to *exclusive flood control* and to *flood control and multiple use*. This also constitutes less than one percent of total Mainstem System storage committed to these purposes. System flood control storage is not likely to be greatly diminished by sediment during the 50-year planning period. Diminished reservoir capacity was considered in the design of the Lewis and Clark Lake project. For this reason, the partial loss of storage capacity due to sedimentation would not cause a significant increase in flooding on the Missouri River during the study period.

A summary of the engineering data for Gavins Point Dam is given in Table 2.3.

Table. 2.3 Summary of Engineering Data – Gavins Point Dam / Lewis and Clark Lake

Item No.	Subject	Gavins Point Dam-Lewis and Clark Lake	Remarks
	GENERAL		
1	Location of Dam	Near Yankton, SD	
2	River Mile – 1960 Mileage	Mile 811.1	
3	Total and incremental drainage areas in square miles	279,480, 6,000	Includes 4,280 square miles of non-contributing areas
4	Approximate length of full reservoir in valley miles	25, ending near Niobrara, NE	
5	Shoreline in miles	90 (elevation 1204.5)	With pool at base of flood control
6	Average total and incremental inflow in cfs	32,000, 2,000	
7	Maximum discharge of record near dam site in cfs	480,000 (April 1952)	
8	Construction started – calendar year	1952	
9	In operation – calendar year	1955	Storage first available for regulation of flows
	DAM AND EMBANKMENT		
10	Top of dam elevation in feet, NVGD29	1,234	
11	Length of dam in feet	8,700 (including spillway)	
12	Damming height in feet	45	Damming height is height from low water to maximum operating pool.
13	Maximum height in feet	74	Maximum height is from average streambed to top of dam.
14	Maximum base width, total and without berms, in feet	850, 450	
15	Abutment formations (under dam and embankment)	Niobrara chalk and Carlile shale	
16	Type of fill	Rolled earth and chalk fill	
17	Fill quantity in cubic yards	7,000,000	
18	Volume of concrete in cubic yards	308,000	
19	Date of closure	31-Jul-1955	
	SPILLWAY		
20	Location	Right bank-adjacent	
21	Crest elevation in ft, NVGD29	1,180	
22	Width (including piers) in feet	664 gated	
23	Number, size, and types of gates	14, 40’ x 30’ Tainter	
24	Design discharge capacity in cfs	584,000 at elevation 1221.4	
25	Discharge capacity at maximum operating pool in cfs	345,000	
	RESERVOIR DATA		Based on latest available storage data (Fall 2011)
26	Maximum operating pool elevation and area	1,210 ft, NGVD29, 29,000 acres	
27	Maximum normal operating pool elevation and area	1,208 ft, NGVD29, 26,000 acres	
28	Base flood control elevation and area	1,204.5 ft, NGVD29, 22,000 acres	

Item No.	Subject	Gavins Point Dam-Lewis and Clark Lake	Remarks
29	Minimum operating pool elevation and area	1,204.5 ft, NGVD29, 22,000 acres	
	STORAGE ALLOCATION & CAPACITY		Based on latest available storage data (Fall 2011)
30	Exclusive flood control	1,210 – 1,208 ft, 55,000 a.f.	
31	Flood control and multiple use	1,208 – 1,204.5 ft / 83,000 a.f.	
32	Carryover multiple use		
33	Permanent	1,204.5 – 1,150 ft / 288,000 a.f.	
34	Gross	1,210-1,160 ft / 426,000 a.f.	
35	Reservoir filling initiated	AUG-55	
36	Initially reached minimum operating pool	22-Dec-55	
37	Estimated annual sediment inflow	2,600 a.f. / 180 years	
	OUTLET WORKS		
38	Location		
39	Number and size of conduits	None	
40	Length of conduits in feet		River regulation is obtained by flows over low-crested spillway and through turbines
41	Number, size, and type of service gates		
42	Entrance invert elevation (ft, NVGD29)	1,180 ft	Spillway crest
43	Average discharge capacity per conduit and total		
44	Present tailwater elevation (ft, NVGD29)	1,155-1,163 ft / 5,000-60,000 cfs	
	POWER FACILITIES AND DATA		
45	Average gross head available in feet	48	
46	Number and size of conduits	None: direct intake	
47	Length of conduits in feet		Length from upstream face of outlet or to spiral case
48	Surge tanks	None	
49	Number, type, and speed of turbines	3 Kaplan / 75 rpm	
50	Discharge capacity at rated head in cfs	48’	
51	Generator nameplate rating in kw	44,100	
52	Plant capacity in kw	132,300	
53	Dependable capacity in kw	74,000	Based on 8th year (1961) of drought drawdown (from study 8-3-1985)
54	Average annual energy, million kWh	727	1967-2009 average
55	Initial generation, first and last unit estimated cost September 1999		
56	Completed project	$49,617,000	Source: Annual Report on Civil Works Activities of the Corps of Engineers. Extract Report Fiscal Year 1999.

The original storage capacity of Lewis and Clark Lake, from the 1955 survey data, was 574,930 acre-feet at the maximum operating pool (elev. 1210.0 feet, NGVD 1929). The latest survey in 2011 indicates a capacity of 425,829 acre-feet. The loss of 149,101 acre-feet represents a 26 percent reduction in the original storage capacity and an average sediment depletion rate of 2,663 acre-feet per year over 56 years of operation. Incremental deposition rates between survey years varied from a maximum of 6,054 acre-feet per year between 2007 and 2011 to a minimum of 1,069 acre-feet per year between the 1965 and 1975 surveys.

For the flood control and multipurpose zone, the storage capacity decreased from 103,410 acre-feet in 1955 to 82,691 acre-feet in 2011, or an average of 370 acre-feet per year. Between the two most recent surveys, 2007 and 2011, the capacity of this zone decreased 3,089 acre-feet, averaging 772 acre-feet per year.

Sedimentation occurs throughout most of Lewis and Clark Lake. The operation of the reservoir keeps the pool level fairly consistent year to year. This operational pattern has created conditions conducive to a vegetated delta front that continues to move in the downstream direction as sedimentation accumulates in the reservoir. The visible delta front is currently located at 1960 River Mile 826. The delta front has historically moved at a rate of 550 feet per year, but as sediment begins to deposit into increasingly deeper water that rate is expected to decrease.

During the historic Missouri River flood of 2011, a great deal of sediment moved both into and within the reservoir. The reservoir depletion rates based on pre- and post-flood surveys show that the flood generally doubled the rate of reservoir depletion irrespective of reservoir zone when compared to the average depletion rate over the life of the reservoir. While the 2011 flood brought in a larger than normal amount of sediment into the reservoir, in general, the particle sizes found in the reservoir did not change significantly at the surveyed locations.

A visual representation of the delta deposits in Lewis and Clark Lake is shown in Figure 2.3. At sediment rangeline 867.4 (1960 RM 827.5 – just upstream of the current delta location) sediment deposition has filled most of the historical floodplain with approximately 10 feet of sediment, and the historic channel on the Nebraska side of the Missouri River valley has been filled with up to 30 feet of sediment.

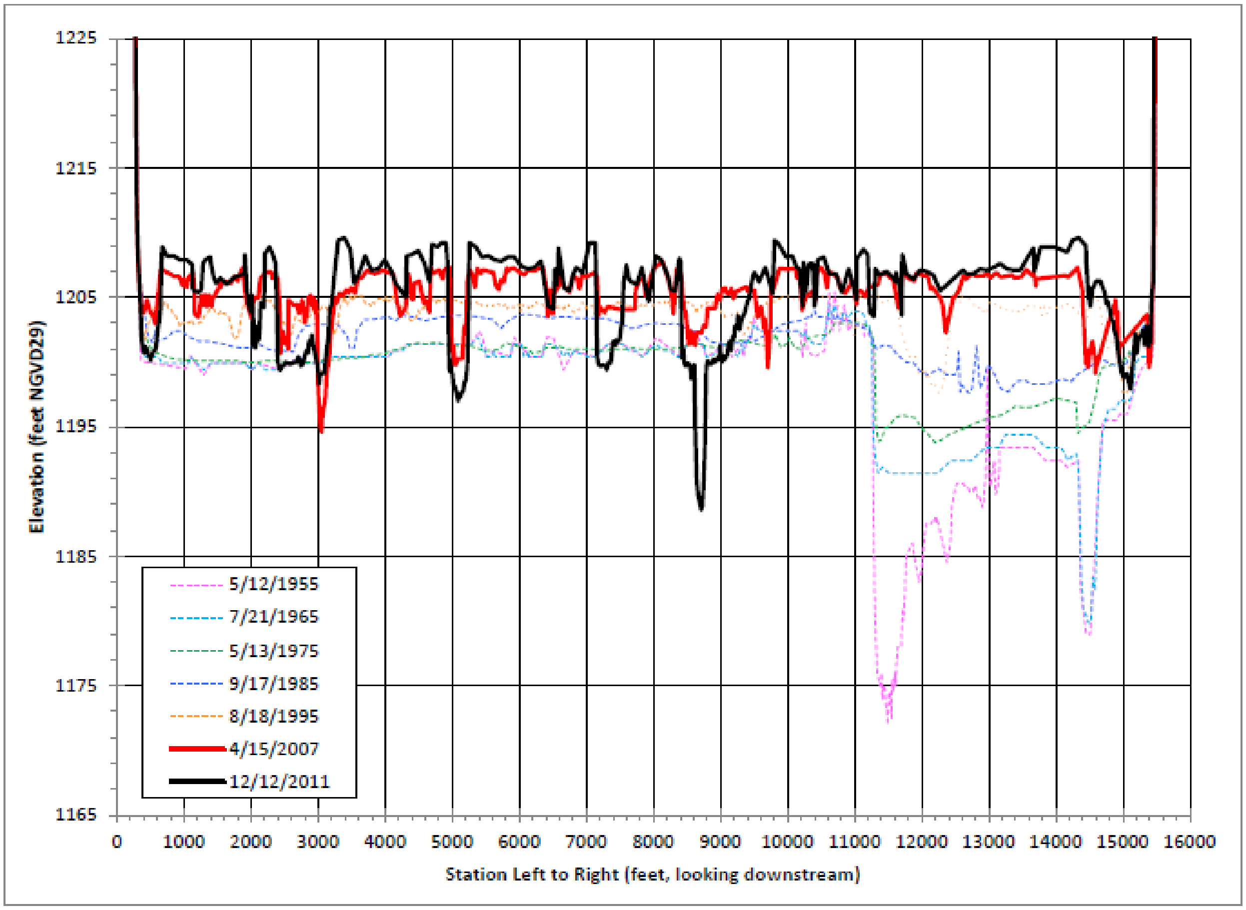

Figure 2.3 Sediment Deposition observed at Sediment Rangeline 867.4 (1960 RM 827.5)

While the depth and distribution of sediment varies, all areas of the lake have experienced some sediment deposition, varying from burial with sand of the historic channel under the delta in the Springfield, SD to Santee, NE area, to an even veneer of fine silt covering the entire historic floodplain near the dam.

2.4 Future Sedimentation Conditions at Lewis and Clark Lake

USACE Omaha District monitors the changes in sediment deposition and location within and above Lewis and Clark Lake roughly every decade through repeated hydrographic surveys. These surveys are then analyzed to determine the change in water storage available in all the pools within the lake, and the Missouri and Niobrara River reaches upstream. The 2011 surveys were analyzed to produce the currently published storage volumes, reported in Section 2.2.1.

USACE previously compiled the location of the delta face in Lewis and Clark Lake from aerial imagery (USACE, 2011 and USACE, 2013) and made two estimates of future delta face locations. Figure 2.4 shows historic delta face locations and predictions made in 2013.

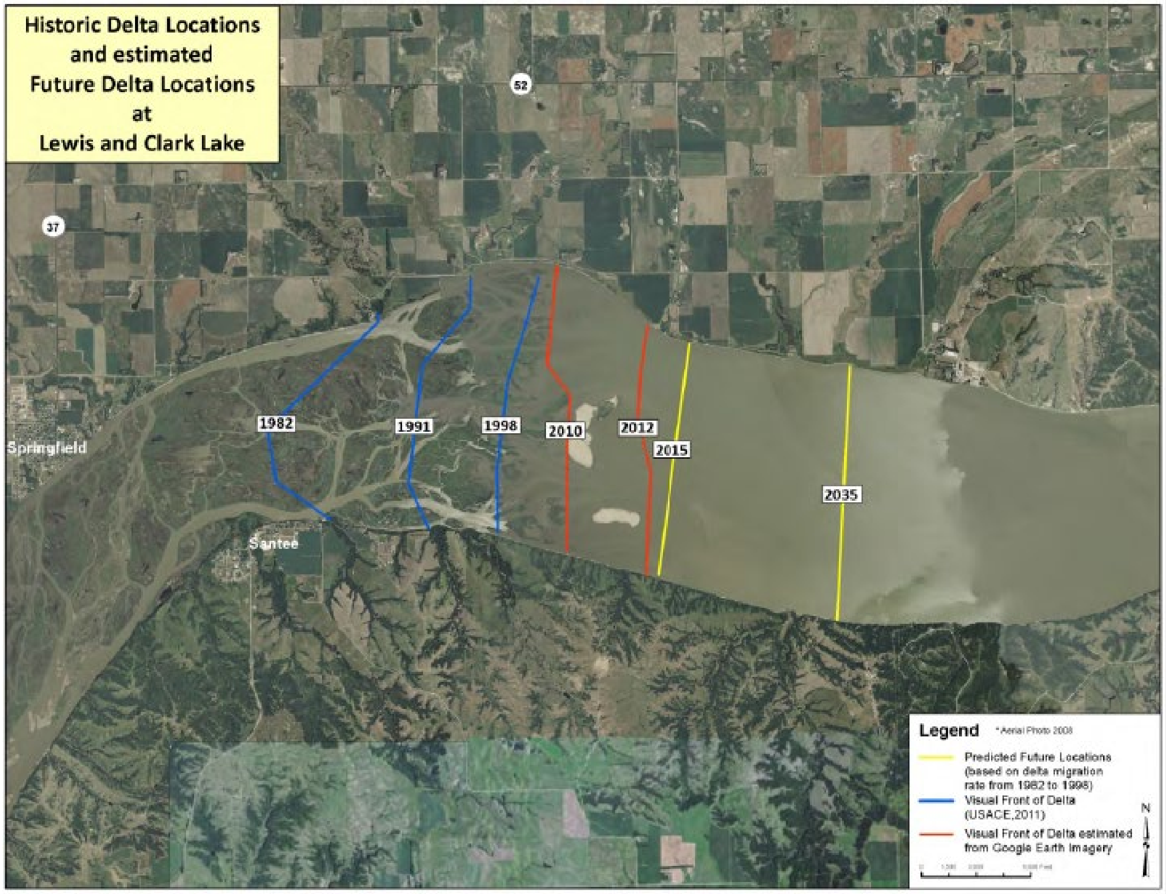

Figure 2.4 Historic and Future Lewis and Clark Lake Delta Face locations (USACE, 2013)

To better estimate the costs and benefits that will be affected in the future, a simplified volume change assessment was made by USACE to predict the future leading edge of the delta as it moves downstream. The assessment was based on the measured volume change and visible delta front location over the past 60 years of surveys and aerial imagery. Since closure of Gavins Point Dam, the area of Lewis and Clark Lake that has experienced delta deposition was shallow, generally less than 10 feet deep. As the delta progresses, sediment will be deposited in increasingly deep water, approaching 30-40 feet deep near the dam.

The rate at which the delta face moves down the lake may appear to slow, but that is a symptom of the deeper water. The assessment done here assumes the same rate of deposition in the future that, on average, the lake has experienced since closure.

Once the volume trends were projected into the future, the volume of the lake that would be filled with sediment was estimated, and maps drawn to show a projected visible face of the delta. Figures 2.5, 2.6, and 2.7 show the projected Lewis and Clark Lake visible delta front. This analysis generally predicts that by 2150 there will be very little open water surface remaining in the lake and that the vast majority of benefits will be lost.

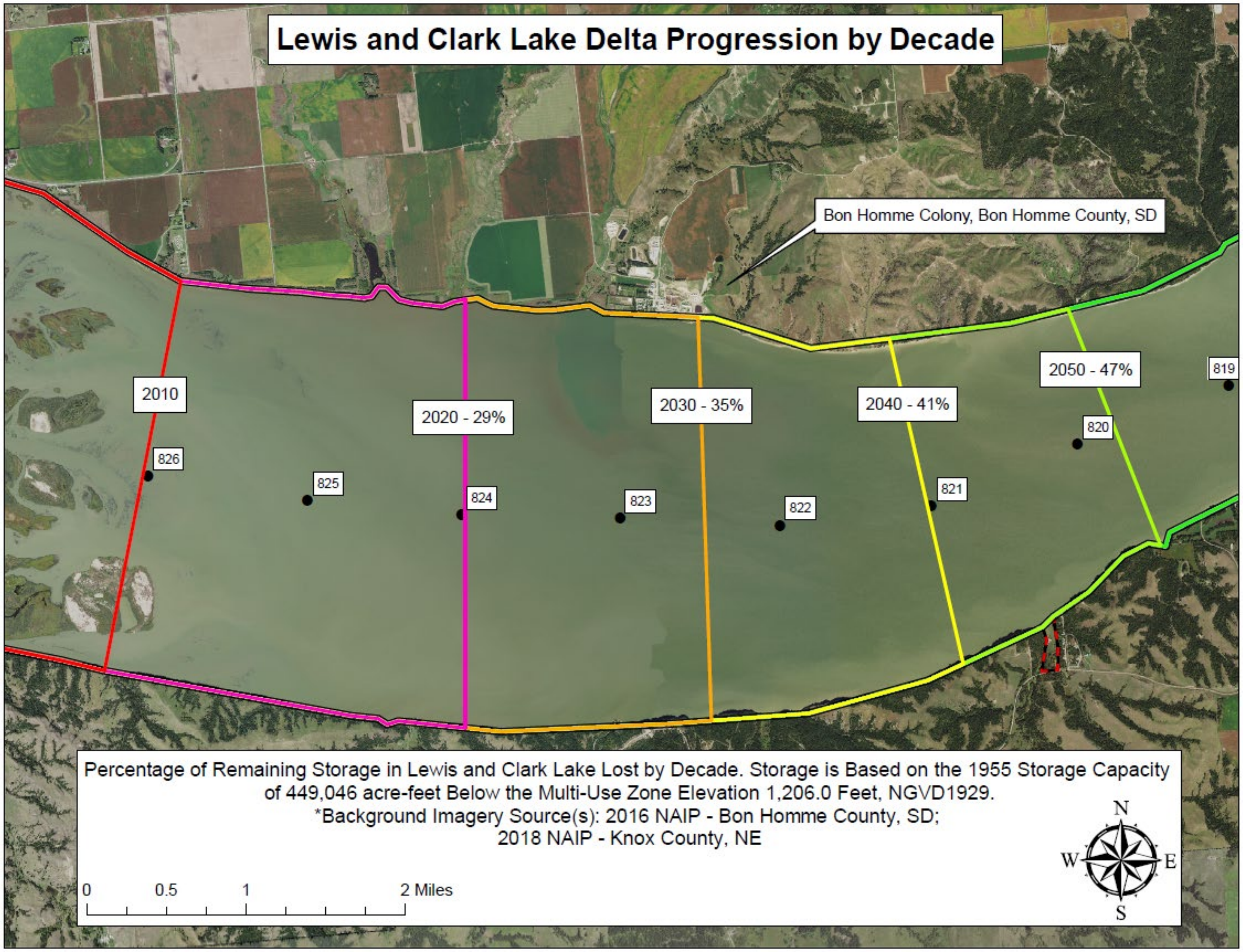

Figure 2.5 Lewis and Clark Lake Predicted Delta Face Location through Year 2050

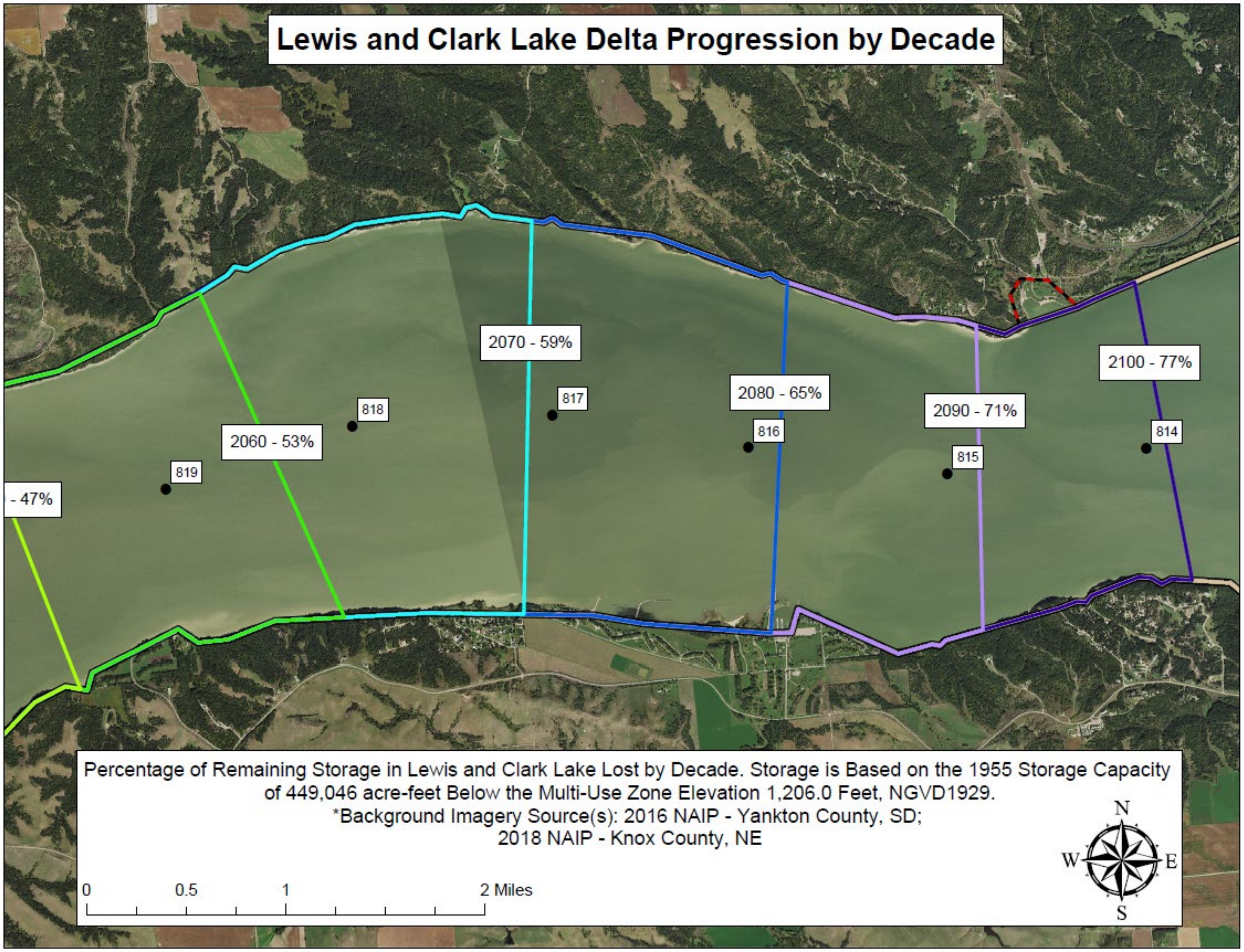

Figure 2.6 Lewis and Clark Lake Predicted Delta Face Location through Year 2100

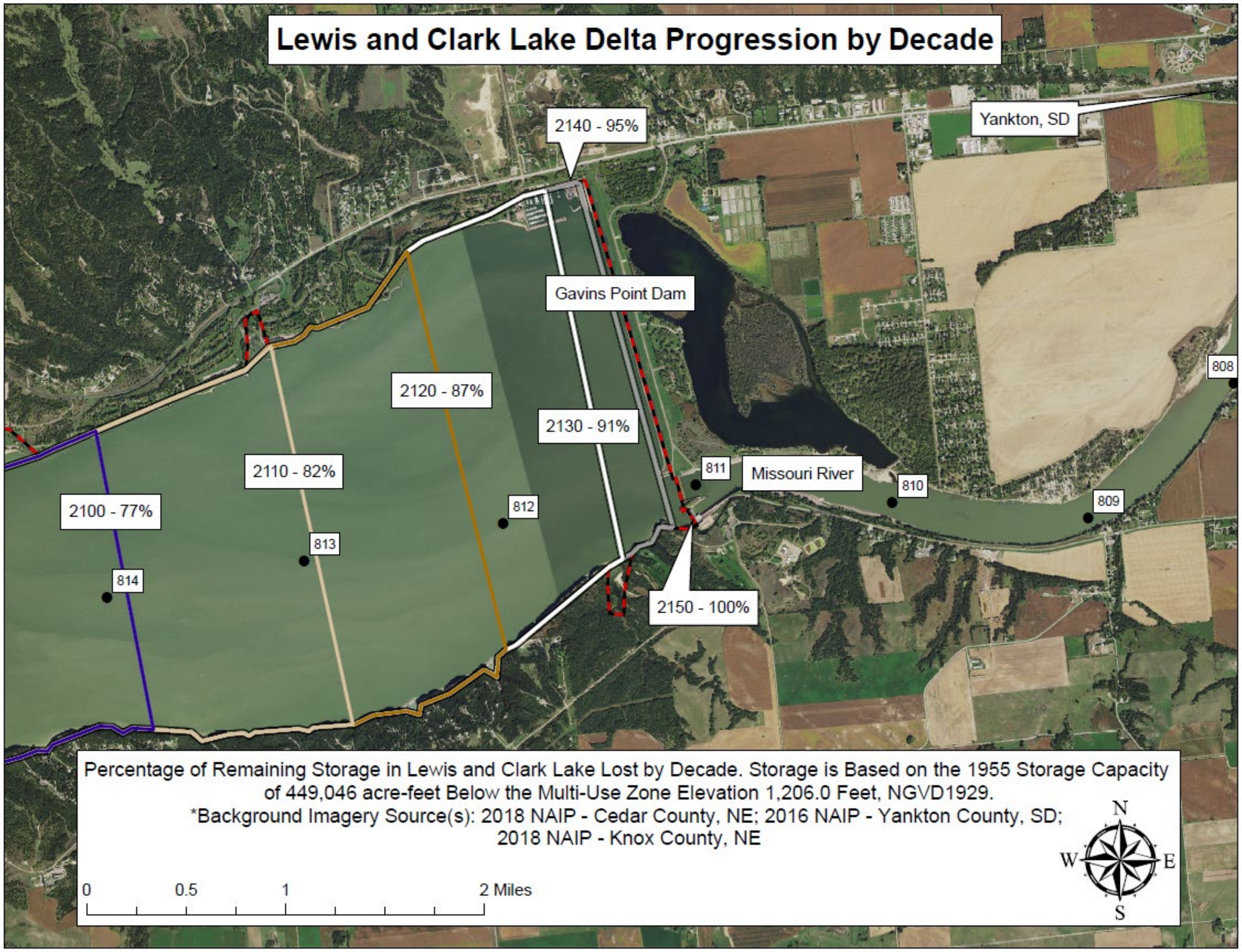

Figure 2.7 Lewis and Clark Lake Predicted Delta Face Location through Year 2150

The predicted locations reported in these figures are an estimate, and changes in sedimentation rate, Missouri River and Niobrara River flows, and system management could have significant impact on these locations.

A backwater effect is caused by the raising of the river and lake bottom due to deposition. This results in growth of the Missouri River and Niobrara River deltas in all directions. In both cases, deposition is also occurring upriver of the visible delta at the confluence of these rivers.

Similar estimates in the future location of sedimentation impacts were made for the Missouri River above the confluence with the Niobrara River, and the lower Niobrara River. In both these cases, the slope of the river channel is steeper than that in Lewis and Clark Lake. This reduces the annual distance that the impacts move when compared to Lewis and Clark Lake. Figure 2.8 projects the location of the sedimentation impacts on the Missouri River above the Niobrara River. Figure 2.9 repeats this analysis on the Lower Niobrara River.

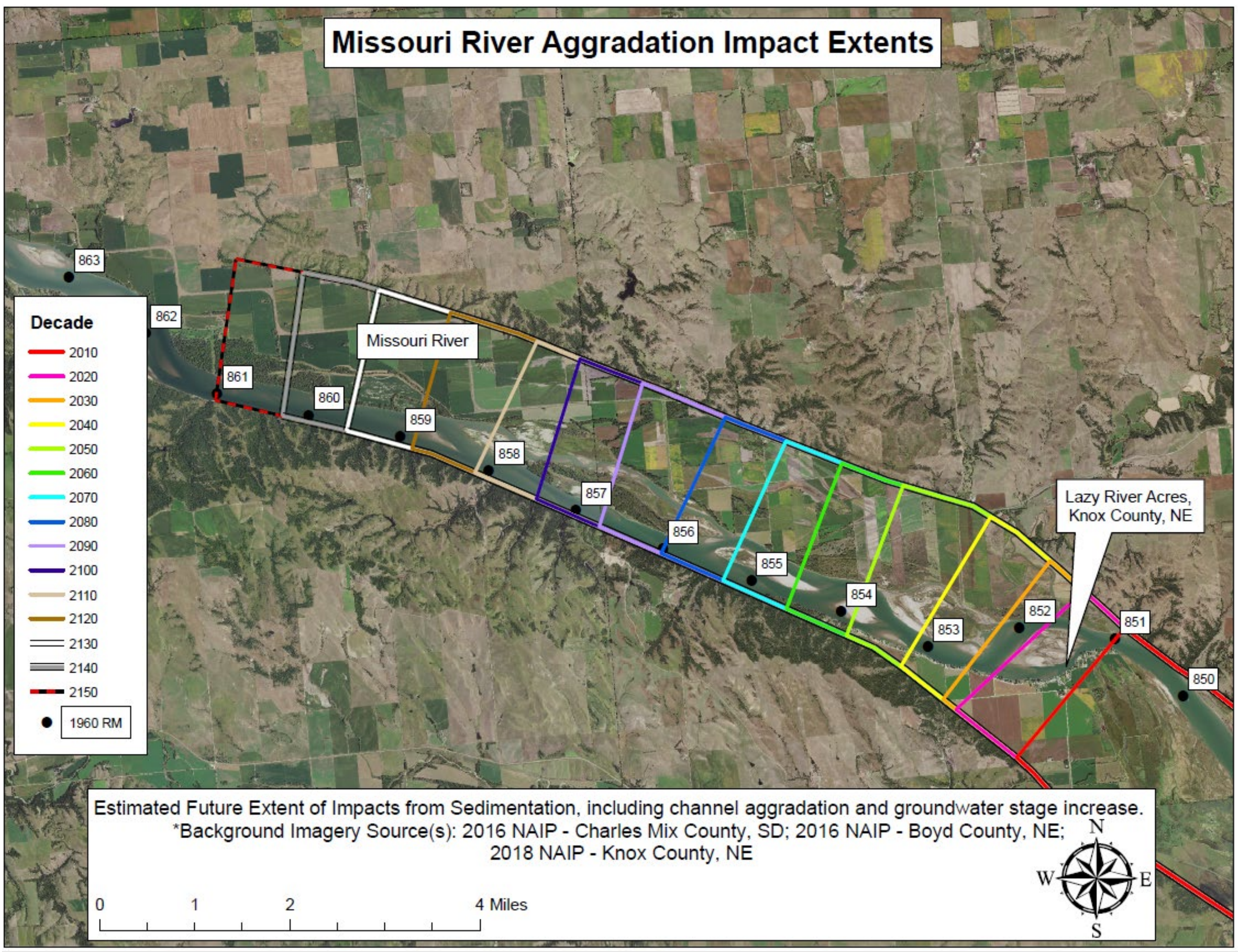

Figure 2.8 Missouri River Predicted Aggradation above the Niobrara River through Year 2150

It should be noted that these estimates inherently have a high level of uncertainty due to the resolution of the data being used. The primary goal of the assessment was to assist the economic analysis in determining when current benefits may be lost in the future and identify areas where there may be future costs associated with sedimentation. For example, based on the projected Lewis and Clark Lake delta location, the economic analysis assumes hydropower production will be impacted by sedimentation 70 years in the future (approximately year 2100 as seen in Figure 2.7). This analysis could be updated in Phase III with surveys collected by USACE in 2022, but not fully analyzed for use before the publication of this report.

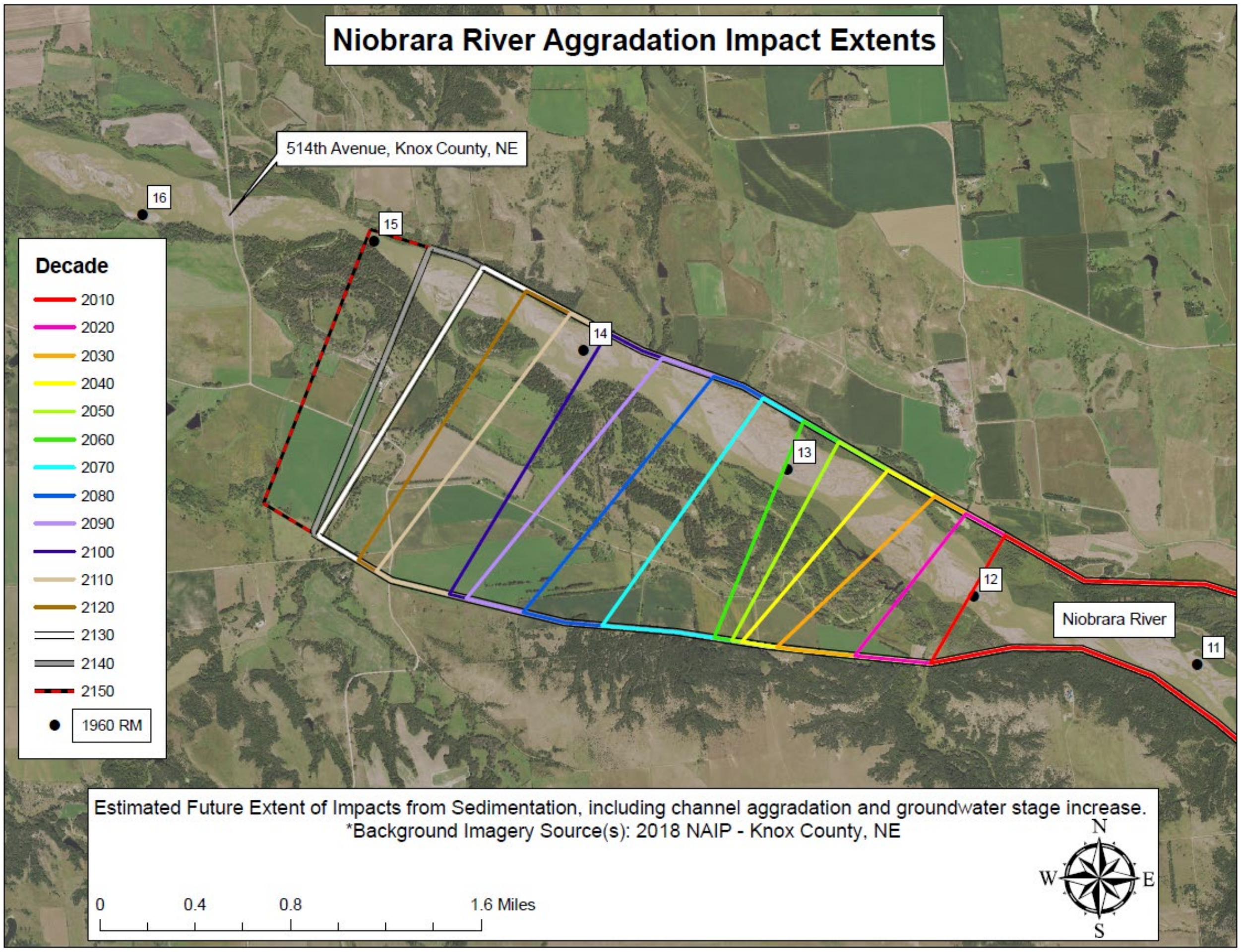

Figure 2.9 Lower Niobrara River Predicted Aggradation through Year 2150

2.5 Beneficial Uses for Sediment

"Beneficial Use" for sediment is a term that has often been associated with dredging discharge and the typical placement of the discharge into upland dewatering and storage areas. The concept of beneficial use is intended to show that developing alternative locations and application of dredged sediments can create additional economic and environmental benefits when compared to traditional upland storage. USACE has several authorizations under WRDA that have called for funding of pilot projects associated with beneficial use; however, the implementation guidance for these authorizations (e.g., Section 1122, WRDA 2016) has limited the funding of pilots as an extension of an existing dredging program. In the case of the Missouri River and Gavins Point Dam, there is no existing dredging program upon which to base a beneficial use pilot project.

With that retirement defined, sediment management at Lewis and Clark Lake can expand the definition of beneficial use far beyond that laid out in the guidance. In this case, we can consider beneficial uses of sediment independent of the method by which it is collected, transported, and deposited.

The fundamental issue at Lewis and Clark Lake is not that there is sediment in the system, as there has always been, and will always be. The issue is that due to the construction of the dam and reservoir, sediment continuity has been disrupted and the sediment is in the wrong place to maintain project benefits. Removal of the sediment from the lake and river deltas and placement in another location is necessary to maintain benefits.

2.5.1 Sediment Volume to be Managed

Estimates made through the 2011 survey of Lewis and Clark Lake put the volume of deposited sediment below the top of the exclusive flood control pool at 1210.0 feet (NGVD 1929) at around four million cubic yards annually (varying with annual inflow conditions to Lewis and Clark Lake). In addition, deposition occurring in the Missouri River above the lake and other tributaries like the Niobrara River and Ponca Creek can add an additional one million cubic yards per year or more.

If sediment in the system were managed annually to maintain the current conditions and benefits of the project, roughly five million cubic yards of sediment would need to be removed from this reach of the Missouri River. Regaining lost benefits and/or regaining reservoir storage and open lake would require more sediment removal (i.e., to return to the conditions of 1955, approximately 10 million cubic yards of sediment would have to be removed from the system for the next 60-70 years).

The traditional approach to removing any volume of sediment would be to identify locations where the sediment could be deposited and dewatered. Upland placement areas require permitting and water discharge management. In the case of Lewis and Clark Lake, sufficient area to deposit five million cubic yards at one foot-deep would require over 3,000 acres of surface area. Increasing the depth for placement could reduce the footprint needed, likely at the expense of soil tilth and usability.

2.5.2 Beneficial Use with Downstream Placement

Due to the volume of sediment to be managed and removed from the reach above Gavins Point Dam, reintroduction of these sediments to the Missouri River downstream should be considered. If full sustainability is to be eventually achieved, it is essential that downstream placement be used for a large percentage of the sediment to be managed. The Missouri River channel has degraded significantly in the reach below the dam, and the impacts the degradation has on the riverbed and banks can be seen over 20 miles below the dam.

Reintroduction of sediment below the dam could be accomplished via dredge line (low solids concentration), truckload of excavated sediment (high solids concentration), or with Missouri River flow through the spillway (low solids concentration via reservoir sluice). Each has its own challenges and requires careful coordination with the flow conditions in the river reach to avoid excessive deposition. If properly managed and timed, downstream reintroduction could result in beneficial uses that include:

- Gradual reduction or elimination of bed degradation and bank erosion in the MRNN reach between Gavins Point Dam and Ponca, NE.

- Long-term reintroduction of sediment may reduce degradation in the navigation channel below Sioux City, IA, and eventually sandbar formation and degradation around Kansas City, MO.
- Sandbar formation and maintenance to support emergent sandbar habitat for threatened and endangered species.
- Significant cost savings compared to upland placement, redistribution, or removal of sediment from the system.

2.5.3 Beneficial Use with Removal from the System

Management actions that collect sediment from the system an extremely long distance from the dam may have very high transportation costs to move the sediment for reintroduction to the Missouri River below Gavins Point Dam. In the cases where sediment may be collected by mechanical excavation or bedload collection far from the dam, finding other beneficial uses may be necessary.

When deposited sediment is removed from the system, which is generally fine to medium sand, identifying local beneficial or financially advantageous uses may define if these management methods can be justified. In other reservoir examples, sand class materials have been used for construction, manufacturing, retail, and mining applications.

For sand class materials extracted from Lewis and Clark Lake and/or its tributaries, numerous possible beneficial use outlets should be considered. They include, but are not limited to:

- Local use for highway maintenance, winter road treatment, and construction projects. Counties in NE and SD could use the sand for road work and local projects.
- Manufacture of construction materials. The manufacture of decorative and construction blocks and materials has been established at Paonia Reservoir in Colorado.
- Retail sale of cleaned, sorted, sand for homeowner use.
- Industrial and mining applications for sand. USGS 2017, identified the applicability of Missouri and Niobrara River sand for use in hydraulic fracture mining (fracking) in the upper Midwest.
- Use in large construction projects. For example, Nebraska Department of Transportation will need nearly one million cubic yards of fill material for the raising of NE Highway 12 in the local area.
- Identify agricultural lands where sediment could be deposited and combined with native topsoil to provide permanent storage while only temporarily reducing soil health and productivity. The organic material and nutrient load of sediment from the lake would determine the rate at which it could be applied. The depth of placement for this purpose is unknown at the time of publication.

The development of any of these uses for sediment collected from the lake and adjacent areas will reduce the volume that needs to be reintroduced to the Missouri or redistributed in the system; however, even with extensive development of opportunities to remove sediment from the system, it is highly unlikely that these outlets will account for more than a fraction of the volume in the near term. Long term sediment management should aim to maximize the opportunities to commercialize sediment removed from the system.

2.5.4 Beneficial Use with Redistribution within the System

If there are limitations on the volume of sediment that can be reintroduced downstream and removed from the system for commercial uses, the remaining option is to redistribute sediment within the existing footprint of the project to minimize its impact.

Sediment that is currently deposited within the pools of Lewis and Clark Lake affects the storage volume available to provide project benefits. Redistribution of sediment in these pools would have to consider the impact of flood risk reduction storage, recreation, water supply and quality, fish and wildlife, and the ongoing ability of the project to provide hydropower and re-regulate flows for downstream navigation.

With those constraints understood, there may be locations inside and outside the project footprint where sediment has already impacted benefits, and additional placement may not incur additional benefit losses. If there are areas where the storage volume in the exclusive flood control pool has been lost, there may not be significant impact to placing multiple feet of sediment on those areas for permanent storage. Within the project footprint, that placement would be subject to the EO11988 review process to mitigate additional flood risk. Upstream of the project, off-channel areas may be available for placement with different or reduced restrictions.

As an example, the conceptual plan presented in Section 4.2.2 of this report proposes to use exiting delta areas to permanently store sediment while incrementally moving toward sustainable sediment management.

2.5.5 Considerations for Scoping of Phase Three

Any sediment management plan will define how to collect, transport, and discharge sediment. In the case of Lewis and Clark Lake, where to discharge sediment and how to use sediment to create an economic benefit to justify the selected management method is unknown. Before any management plan would be executed, the discharge and beneficial use of sediment piece of the equation will need to be defined. Any method examined in Phase Three should have a detailed plan that defines the beneficial uses, commercial outlets, and long-term plan to account for the total volume of sediment to be removed from the system.

2.6 Constraints and Operational Risks due to Future Condition

At the time of publication of this report, USACE has no plans to modify the management of Gavins Point Dam and Lewis and Clark Lake. Under the current management plan, the reservoir pool is maintained in the 1204.5-1208.0 feet (NGVD 1929) of elevation range. This pool elevation varies somewhat with changes in inflow from upstream but is maintained to re-regulate the Missouri and Niobrara River flows to meet flow targets downstream. The exclusive flood control pool above 1208.0 feet (NGVD 1929) is only used as needed and evacuated as quickly as possible once flood conditions have been mitigated.

Current management to meet navigation, hydropower, flood risk reduction, and fish and wildlife project purposes in the lake proper are not impacted by sedimentation; however, water supply, recreation, irrigation, and water quality have experienced, and will continue to experience impacts from sedimentation. Due to the current location of water intakes in the lake, the impact to water supply may be the most quickly degrading benefit in the next few decades.

As deposition continues and the delta grows in all directions, currently affected benefits will be impacted with greater frequency in the future. For those benefits not yet affected, the exact time when they will become affected is difficult to project, but general future impacts are:

- **Flood Risk Reduction** – deposition of sediment in the lake is not exclusively in the exclusive flood control pool above elevation 1208.0 (NGVD 1929). About half of the total deposition below 1210.0 feet (NGVD 1929) occurs in this pool. If current management is continued, sediment will deposit more in the lower pools, and only a portion of this pool will be impacted before the lower elevation pools (multipurpose and permanent pools) are completely lost. In the future condition where these pools are completely full, sediment may impact the ability to operate the 14 gates on the dam. This could limit the ability to use the remaining exclusive flood control pool.
- **Navigation** – Lewis and Clark Lake's ability to buffer flows from the Niobrara River and provide a consistent flow to meet downstream targets may become more challenging with future storage loss in the multipurpose pool.
- **Hydropower** – as speculated in Section 2.4, eventually sand deposits at the toe of the delta will approach the intakes for the hydropower facility at Gavins Point Dam. The ingestion of abrasive sand into the hydropower tunnels and turbines will drastically shorten their life. At that time, either a major rehabilitation of the system to allow operation with sand in the supply water, or the closure and decommissioning of the powerhouse will be required. An estimate of 70 years from the current condition is used as the decision point for such an action. This timeline is highly uncertain and will be affected by hydrologic shifts or management changes at the project and basin upstream.
- **Fish and Wildlife** – the expansion of the delta will continue to move species from cold, deep-water species to warm, shallow, and turbid water species with increasing presence of waterfowl species.
- **Downstream Channel Degradation** – the Missouri River channel downstream of Gavins Point Dam has armored over the past decades and is protected by gravels in the bed for many miles. Degradation has slowed in the first 10-plus miles below the dam but will continue to extend downstream in the future. In areas where the channel bed has armored, high flows are more likely to erode the riverbanks and floodplain. This degradation could move the channel morphology to more of a single meandering channel will less floodplain connectivity.
- **Upstream Flooding** – as the Missouri and Niobrara River channels experience sediment deposition upstream of Lewis and Clark Lake, the bottom channel elevation, or invert, is increased. This results in higher river stages at equivalent discharge. USACE, 2013 provides a summary of the change in these water surface profiles since closure; it is reasonable to expect these trends to continue. In doing so, flows that previously were within the channel may begin to have flooding impacts. These flood impacts will worsen over time and may make a large portion of the floodplain unusable for any residential or commercial activity. Niobrara River flows cannot be regulated from upstream, so the increase in water surface cannot be directly mitigated.

3 LEWIS AND CLARK LAKE SOLUTIONS WORKSHOP

A three-day Solutions Workshop (June 15-17, 2021) provided the opportunity for MSAC and the project partners to meet and discuss innovative ideas with five invited subject matter experts (SMEs), key stakeholders, and USACE staff on reservoir sedimentation. The first day was an extensive site visit, the second day included the Sponsor/SME/USACE Solutions Workshop, and the third day was an open house for the public and stakeholders.

3.1 Invited Subject Matter Experts

USACE and MSAC collaboratively identified five SMEs with extensive backgrounds in a variety of reservoir sediment management methods, both domestically and internationally. These experts traveled to Lewis and Clark Lake to see the project and impacts firsthand and participate in the workshop.

3.1.1 Subject Matter Experts Experience

- **Greg Morris** – Gregory L. Morris, P.E., Ph.D., possesses key technical knowledge on reservoir sedimentation management strategies and specializes in hydrology, hydraulics, water supply, civil engineering, and environmental studies. Dr. Morris has 45 years of professional engineering experience, working internationally. He has worked and lectured in more than 30 countries over 5 continents and is known for his expertise in developing environmentally sustainable fluvial engineering strategies. Dr. Morris was the lead author of the Reservoir Sedimentation Handbook (McGraw-Hill Book Co - 1998) and one of a trio of authors of the Sustainable Sediment Management for Dams and Run-of-River Hydropower/Extending Life of Reservoirs - (World Bank Group-2016). His projects have involved dams of all sizes, ranging from small run-of-river dams to the 1,100-foot-tall Rogun dam in Tajikistan (world's highest), and has included work on projects with hydropower capacities from 4 to 4880 MW. He has developed and executed sediment sampling programs and has performed extensive modeling work in a wide range of fluvial environments. He has developed engineering solutions for sediment management projects such as off-stream reservoirs, bypass tunnels, reservoir sluicing and flushing and dredging, plus adaptive measures such as intake re-design, sediment-guided power operations, and conjunctive use to help users to adapt to higher sediment loads and loss of reservoir storage.

- **Rollin Hotchkiss** – Rollin Hotchkiss, Ph.D., P.E., D.WRE, F. ASCE, possesses key technical knowledge on reservoir sedimentation management strategies and the economics of sustainable reservoir management. Dr. Hotchkiss has nearly 30 years of experience as a civil and environmental engineering professor in Nebraska, Washington, and Utah. He is a core member of the International Sediment Initiative sponsored by UNESCO, a member of the National Reservoir Sedimentation and Sustainability Team, chair of the ASCE-EWRI Task Committee on Reservoir Sediment Management and chair of the Environmental Advisory Board of the Chief of the U.S. Army Corps of Engineers. Dr. Hotchkiss has authored or co-authored more than 150 technical papers and was the 2017 recipient of the American Society of Civil Engineers Hydraulic Structures Medal.

- **Meg Jonas** – Margaret (Meg) Jonas, P.E., retired USACE Hydraulic Engineer, possesses key technical knowledge on reservoir management strategies and USACE procedures. In over 35 years with USACE, she worked at Omaha and Baltimore Districts (hydraulic and sediment issues), the Engineer Research and Development Center (ERDC) (research hydraulic engineer), and at USACE Headquarters (senior hydraulic engineer in the Hydraulics, Hydrology & Coastal Community of Practice). She had a career interest in river engineering, stream restoration, and watershed sediment processes. She was a member of the expert Committee on River Engineering (USACE committee providing technical assistance). She was the USACE representative to the interagency Subcommittee on Sedimentation and worked to get ACWI passage of a resolution encouraging the development of reservoir sedimentation plans. She has worked nationally on projects concerning reservoir sedimentation and/or watershed sediment management, including the following: Jennings Randolph Reservoir (MD & WV), Prado Dam (CA), John Redmond Reservoir (KS), Conowingo Dam (PA), Delta Headwaters Project (MS), Susquehanna River Basin (MD, PA, NY), and the Kankakee River Basin (IL, IN). She has a BSCE (University of Virginia), an MS in Engineering Geology (George Washington University) and is a registered P.E. in Virginia. She is currently a member of the National Reservoir Sedimentation & Sustainability Team (NRSST) and the international Working Group on Reservoir Dredging (under the World Organization of Dredging Organizations).

- **Tim Welp** – Tim Welp is a Research Hydraulic Engineer at the Coastal Hydraulics Laboratory of the USACE ERDC. He has been involved in developing innovative dredging and dredged material placement equipment and methodologies for over 25 years. He is the Dredged Material Management Focus Area Lead in the USACE Dredging Operations and Environmental Research (DOER) program and editor and a prime co-author of the USACE Dredging and Dredged Material Management Engineer Manual. While his research and development activities have historically focused on application to navigation channels, the increasing awareness and need to provide more sustainable reservoir sediment management technologies has led to his participation to both better transition conventional dredging technologies as well as demonstrate and evaluate emerging dredging technologies as solutions to the reservoir sediment challenge. He was a coauthor of the recently published Western Dredging Association (WEDA) Reservoir Dredging: A Practical Overview and is currently working on the World Organization of Dredging Associations (WODA) Working Group on Reservoir Dredging. He received his Bachelor of Science degree in Mining Engineering at the University of Wisconsin - Platteville in 1984, and Master of Science degree in Ocean Engineering at Florida Institute of Technology in 1989.

- **John Shelley** – John Shelley, Ph.D., P.E., is a hydraulic/sedimentation engineer at the USACE Kansas City District. Dr. Shelley has analyzed reservoir sedimentation and sediment management at multiple reservoirs and is currently engaged in analysis of sedimentation on 17 reservoirs in the Kansas River basin. Dr. Shelley is a USACE expert on riverbed degradation and other sedimentation issues for the lower 500 miles of the Missouri River. Dr. Shelley co-instructs the USACE sedimentation modeling course and has planned and carried out specific trainings on reservoir sediment management for engineers, regulators, planners, and managers. Dr. Shelley received his Ph.D. in Civil

Engineering from the University of Kansas and a B.S. in Civil Engineering from Brigham Young University.

3.2 Summary of Workshop and Open House

A two-part site visit was conducted to provide the SMEs, MSAC members, and invited guests with the opportunity to see multiple locations where sedimentation impacts are evident. A boat tour of the delta face in Lewis and Clark Lake was organized in parallel with a driving tour of upstream sites including Niobrara, NE, the confluence of the Niobrara and Missouri Rivers, Ponca Creek at Rayder Swanson Road, and the Lazy River Acres area.

Each tour was given twice, concurrently, so all participants could complete both tours. Members of the SME group also drove over Gavins Point Dam to observe the facility and downstream channel at the conclusion of the day. Figure 3.1 shows SMEs and invited guests boarding the USACE survey boat for the tour, and Figure 3.2 shows the group observing sedimentation at Ponca Creek on the driving tour.

Figure 3.1 USACE Survey Boat used for Tours of the Delta on Lewis and Clark Lake

Figure 3.2 SME Group Observing Sediment Deposition on Ponca Creek

Following the site visits, SMEs and invited guests met for a full-day workshop to discuss the current and possible future conditions at the project and discuss sediment management strategies that could be applicable at Lewis and Clark Lake and the surrounding area.

3.3 Workshop Agenda

The agenda adopted for the workshop is included below:

Lewis and Clark Lake Sediment Management Plan Solutions Workshop

Section 22 Planning Assistance to the States Study, Phase 2
June 15-17, 2021
NFAA Easton Yankton Archery Center, 800 Archery Lane, Yankton, SD 57078

Workshop Outcomes:
The prioritization of sediment management solutions, both short-term and long-term, and a description of their general operation.
Ideas that show engineering and economic promise will be shared at the Public Open House with five-minute presentations and recommended in the Phase Two report for more thorough investigation in Phase Three.

Expected Attendees:
Facilitation Team:
Jennifer Gitt, P.E., Project Manager, USACE Omaha District
Jennifer.L.Gitt@usace.army.mil Office: 402-995-2821 Mobile: 402-880-6268
Paul Boyd, Ph.D., P.E., Engineering Lead, USACE Omaha District
Paul.M.Boyd@usace.army.mil Office: 402-995-2350 Mobile: 402-253-6752
J. Greg Johnson, Chief, Plan Formulation & PM Section Greg.Johnson@usace.army.mil
Sandy Stockholm, MSAC Executive Director msaconline@gmail.com

Invited Subject Matter Experts:
Rollin Hotchkiss, Ph.D., P.E., D.WRE, F. ASCE, Brigham Young University, Provo, UT
Gregory Morris, Ph.D., P.E., GMA Engineering, San Juan, PR
John Shelley, Ph.D., P.E., USACE Kansas City District, Kansas City, MO
Timothy Welp, USACE ERDC, Vicksburg, MS
Meg Jonas, P.E., USACE HH&C, Retired

Missouri Sediment Action Coalition:
Sandy Stockholm, Executive Director
Mark Simpson, President
Larry Wiess, Past President
Howard Paul, Past Executive Director
Nathan Johnson, Board Member
Mary Hurd, Board Member
Paul Lepisto, Board Member

Invited Participants:
Alisha Bartling, Environmental Director, Santee Sioux Nation
Tom Riley, Director, Nebraska Department of Natural Resources
Jeff Schuckman, Northeast District Fisheries Manager, Nebraska Game and Parks Commission
Tony Barada, Fisheries Division Administrator, Nebraska Game and Parks Commission
John Lott, Aquatic Section Chief, South Dakota Game, Fish and Parks
Jeff VanMeeteren, Supervisor of the SE District, South Dakota Game, Fish and Parks
Shane Bertsch, District Park Supervisor at L&C Rec Area, South Dakota Game, Fish and Parks

USACE, Omaha District:
Tom Curran, Operations Project Manager, Gavins Point Dam
Mike Nuss, Chief of Technical Support, Gavins Point Dam

Day One – Tuesday, June 15 – Site Tours
Site visits will include a driving tour highlighting sediment sources and sinks followed by a 75 min boat tour along the face of the delta in Lewis and Clark Lake.

7:00 Leave Kelly Inn – Meet in front of main entrance to carpool. Space for SMEs and USACE staff will be available in USACE vehicles. You are welcome to drive your own vehicle. Masks are recommended in carpool vehicles.
8:00-8:15 Springfield Veteran's Memorial Park overlook
8:30-8:45 Chief Standing Bear bridge overlook NE Hwy 14/SD Hwy 37
9:00-9:15 Old Niobrara town site boat ramp
9:30-10:15 Niobrara State Park bluff – 10-min walk to old bridge, restroom, and water break
Brief Stop at Ponca Creek Bridge
10:30-11:00 Lazy River Acres/Ponca Creek (Verdel Boat Landing)

11:45 LUNCH Springfield Golf Course, 41550 Boat Basin Rd, Springfield, SD 57062
Lunch for purchase has been arranged for $10 plus drink
Menu: Pork Loin sandwich, potato salad/coleslaw, baked beans, dessert
(Please notify Sandy or Jen if you have dietary restrictions for alternative menu.)
Clubhouse drinks range from $1.75 to $3 (pop, water, tea, Gatorade).
Wifi available, restrooms on first floor/ground level, clubhouse on second floor.

1:00 -2:00 TENTATIVE Randy Dockendorf with the Yankton Press & Dakotan, local newspaper, will circulate to visit with attendees at the Clubhouse.

1:00 New MSAC documentary (48 min) to be viewed at the Golf Course between lunch and boat tour cycles. (Will play multiple times to allow each tour group opportunity to view.) May also be viewed here: https://youtu.be/ixr6ir96VWA

1:00 Boat tours departing from Sand Creek Recreation Area boat ramp. 75 min boat tours with cycles of 90 min leaving at 1:00, 2:30, 4:00

Following boat tour, return to Golf Course for documentary if not yet viewed or Yankton to conclude day.

Day Two – Wednesday, June 16 - Solutions Workshop
NFAA Easton Yankton Archery Center, 800 Archery Lane, Yankton, SD 57078

8:00 – 8:15 Opening Remarks/Logistics/Goals/Introductions Facilitator: Sandy Stockholm & Jen Gitt.
8:15 – 9:30 Subject Matter Expert 15-min. presentations on reservoir solutions. Facilitator: Jen Gitt.
9:30 - 10:00 Presentation on the Guardians of the Reservoirs Challenge Ideas and Emerging Technologies. Facilitator: Paul Boyd.
Recent webinar on Challenge for independent viewing (2 hours) - Emerging Technologies in Reservoir Dredging https://www.youtube.com/watch?v=UcyHf7DNrO8
10:00 – 10:30 Break. Sign up for Jimmy John's lunch delivery if interested.
10:30 – 11:30 Initial brainstorming. Facilitator: Greg Johnson. Identifying solutions and their benefits/impacts. Categorized by:
Keep Sediment Out of Reservoir
Keep Sediment Moving Through Reservoir

Moving Sediment Out of Reservoir
11:30 – 12:00 Prioritization of solutions to refine in next session and initial screening. Dot Democracy for ideas to carry forward. Facilitator: Greg Johnson.
12:00 – 1:00 Lunch – On your own or Jimmy John's delivery to Archery Center.
1:00 – 3:00 Refinement of ideas in 5 small groups (3-4 people) to rotate through the prioritized solutions. Facilitator: Jen Gitt.
3:00 – 3:15 Break
3:15 – 4:00 Whole group hears summary of ideas and screen to ~5 ideas to present at Open House. Facilitator: Jen Gitt.
4:00 – 5:00 Presentation development for Open House. Breakout into teams to champion each solution and develop a short 5-min PowerPoint presentation based on provided template. One group may be assigned to document additional ideas not carried forward and why. Facilitator: Jen Gitt.

Day Three – Thursday, June 17 – Open House
NFAA Easton Yankton Archery Center, 800 Archery Lane, Yankton, SD 57078

8:00 – 9:00 Resulting Workshop Solutions presentations recorded for online open house through the MSAC website.
9:00 – 11:00 Public Open House – Stations presenting in 15-minute blocks: 5 min presentation, 5-10 min Q&A.
11:00 Adjourn

Open House Stations:
1) MSAC Welcome – Sign-in page, handout guide on open house, and comment collection. - Stockholm
2) Lewis and Clark Lake History. Graphics on scale of problem. - Boyd
3) Sustainable Reservoirs and Economics – 15 min video clip - Hotchkiss
4) Section 22 Study: Partners, Goals, Outcomes, Authority – Gitt/Johnson
5) – 9) Workshop Solutions 1-5 (exact number based on Day 2) - SMEs
Extra Online Content: Other reservoir management case studies.

3.4 Initial Management Ideas Brainstorming

The workshop participants watched a group of presentations in the morning of the second day, summarizing previous work and examples from the SME team, as well as an overview of the Guardians of the Reservoir Prize Challenge (see Section 4.2), followed by an initial brainstorming session facilitated by the USACE team. During this session, a wide variety of possible management solutions were submitted. All ideas were ‘posted’ and participants were encouraged to not limit their ideas by any known constraints. Figure 3.3 shows Mr. Greg Johnson, Planning Branch, USACE Omaha District leading the brainstorming session.

Figure 3.3 Brainstorming Session at the Lewis and Clark Lake Sediment Management Plan Solutions Workshop

At the conclusion of the brainstorming session, all ideas were compiled and categorized by the physical process by which they could manage sediment. Numerous scholars and experts have parsed these management actions into three categories: 1) Keep Sediment out of Reservoir, 2) Keep Sediment Moving Through Reservoir, and 3) Remove Sediment from Reservoir. All the ideas generated in the brainstorming session were assigned to one of these categories and compiled on posters.

3.5 Screening of Management Ideas

Once categorized, the management ideas were subjected to a ‘Dot Democracy’ exercise. In this exercise, each workshop participant was given an equal number of adhesive dots that were applied on posters to 'vote' for management ideas that they would like to see investigated further.

Once the results of the Dot Democracy exercise were compiled, the methods receiving the largest number of votes were identified and discussed by the participants.

The methods receiving the most votes that were carried forward for discussion were (in no particular order):

- Dredging (Hydraulic or Mechanical)
- Sluicing with or without Augmentation
- Watershed Land Management
- Low Head Dams/Sediment Traps or Collection Above the Lake
- Pipeline Around Dam

3.6 Outcomes and Open House Content

Each of the five methods carried forward was given extensive discussion within the group. All participants rotated through small groups facilitated by USACE. Pros and cons were added to the poster for each method, with the small groups encouraged to add their input on each poster. This resulted in a comprehensive look at each method.

Based on the input and discussion, four of the methods had enough pros to carry forward to the review in Section 4 of this report.

Once the four methods were identified to be carried forward, each was assigned to one of the visiting SMEs to develop a presentation for the open house the following morning. Overnight each SME developed a short presentation of the method and how it would generally be applied at Lewis and Clark Lake.

In the morning before the Open House, MSAC provided a professional videographer to record the presentations to be shared on the MSAC website. Those presentations can be viewed at http://www.msaconline.com/solutionsworkshop2021/.

Once recorded, the Open House was hosted at the NFAA Easton Yankton Archery Center from 9:00-11:00am. The event was open to the public to view the presentations and provide comments and feedback on the proposed methods. Figure 3.4 shows Dr. John Shelley presenting during the Open House.

Figure 3.4 Dr. John Shelley Presenting at the Lewis and Clark Lake Sediment Management Plan Open House, June 17th, 2021

The main themes for each method presented during the open house served as the foundation for the conceptual applications proposed in Section 4.

4 CONCEPTUAL APPLICATION OF PROPOSED SOLUTIONS

4.1 Workshop Proposed Solutions

The following management methods were identified by the SMEs at the workshop as the most likely to be able to be implemented with reasonable success. As part of this Phase Two report, a general overview of the methods is provided. General environmental impact considerations are discussed in Section 6. Any detailed engineering and cost analysis for application at Lewis and Clark Lake will be completed in Phase Three.

4.1.1 Hydraulic and Mechanical Dredging

Hydraulic Dredging and Mechanical Excavation are well understood and tested in managing sediment deposition in reservoirs. The SME team identified dredging as a method that would be straightforward to scope, plan, and cost-out for implementation; however, it is likely to be one of the most expensive methods to implement.

4.1.1.1 Management Action Background

Hydraulic dredging is a well-studied and implemented management action for deposited sediment, whether it be in river, reservoir, or coastal applications. There are numerous examples of large dredging projects across the world, but the application of the technology to manage sediment in Lewis and Clark Lake would require large equipment with very long transport distances.

During the 2021 Lewis and Clark Lake SME Workshop, all SMEs acknowledged that dredging, or more generally, mechanical removal, of sediments is a known quantity. With many examples to reference, designing the system and estimating productivity and cost are generally easier than with other reservoir sediment management actions.

While dredging or excavation are straightforward to design and execute, they are also likely the most cost prohibitive methods being considered. As noted in Coker et. al., 2009, the total sediment deposition in the Missouri and Niobrara River reaches above and including Lewis and Clark Lake approaches five million cubic yards annually. A large dredging project with extended transport distances and multiple handlings of material may result in project costs in the $10-20/per yard plus capital investment.

To determine an initial starting point for assessing the cost associated with dredging at Lewis and Clark Lake, USACE developed alternatives for dredging sediment. Each of the alternatives can be scaled to handle from a portion up to the full annual sediment inflow. These alternatives for dredging equipment were developed in conjunction with the New Orleans District Cost Engineering Branch, who have extensive experience in large river dredging projects.

The large sand fraction of the deposited sediment is ideal for the dredging methods summarized here. The absence of gravel and large material reduces abrasion on equipment and extends maintenance cycles.

To address the large volume of sediment that would need to be transported, the delivery rate was parsed into three rates across a 180-day per year operating window:

- 10,000 tons per day = 1/3 of annual sediment deposition
- 20,000 tons per day = 2/3 of annual sediment deposition

- 30,000 tons per day = full annual sediment deposition (2,755 ac-ft per year)

For purposes of this study, two alternatives are presented at a scale to handle 3.8 million cubic yards within a six-month annual operating window equating to 30,000 tons per day; 3.8 million cubic yards is an estimate of the annual inflow that is entering Lewis and Clark Lake and depositing within the maximum pool below elevation 1210.0 feet (NVGD 1929). If less sediment was to be dredged and transported annually, the size of the equipment or the annual operating duration could be adjusted.

Those two alternatives involve a single hydraulic cutterhead dredge at the collection point with booster pump for transport as discussed in section 4.1.1.3, and barge mounted mechanical excavation by a shovel and transport by belly-dump hopper barges as discussed in section 4.1.1.4.

In any dredging alternatives there would be significant onsite fabrication and assembly as well as maintenance facilities, over-wintering harbors, and constant transport of workers and supplies to the equipment.

4.1.1.2 General Dredging Project Layout

Multiple assumptions were made to standardize the plans for each alternative. They include a fixed material capture area as shown in Figure 4.1 and a common system for delivery of sediment into the Missouri River downstream of Gavins Point Dam. Figure 4.2 shows the general concept to implement at least two reintroduction locations for sediment to limit peak concentration and reduce the risk of excessive deposition in the channel downstream of Gavins Point Dam.

Figure 4.1 Deposited Sediment Collection Area for all Alternatives

Figure 4.2 Downstream Distributed Discharge Locations

4.1.1.3 Alternative #1 – Continuous Pipeline and Cutterhead Dredge

Initial Mobilization

A 30-inch dredge plant could be mobilized from New Orleans to Sioux City. Towing of all dredge plant equipment, including some dredge preparation time, would take 32 days. Here the dredge would be deconstructed and placed on trucks for mobilization to the Lewis and Clark Lake staging area. This dredge plant would require five booster pumps. An estimated 20 truckloads for the 30-inch dredge and 10 truckloads each for the boosters provides a total of 70 truckloads, excluding pipeline hauling. A labor crew of nine people, with the assistance of a 30-ton and 100-ton cranes, would construct and deconstruct the dredge plant.

Four nine-man labor crews would be used. One crew could construct or deconstruct the 30-inch dredge. Therefore, a crew working at Sioux City and one working at the Lewis and Clark Staging area could mobilize a working 30-inch dredge plant. Another two crews working concurrently could construct or deconstruct the booster pumps.

For this scenario, 5,000 linear feet (LF) of pontoon pipeline, 87,000 LF of submerged pipeline and 5,500 LF of shore pipeline would be delivered for this disposal plan. Additional required equipment includes two 600-horsepower (hp) tugboats, six 400-hp tugboats, one derrick crane, two anchor barges, three skidder barges, two fuel barges, three work barges, a crew boat and a survey boat. Additional specialized crews would construct and place dredge pipeline as necessary.

Dredging Lewis and Clark Lake

Using a density of 90 pounds per cubic foot and 30,000 tons per day yields a daily production of 24,691.36 cubic yards. Dredging for 180 days yields 4,444,444 cubic yards (2,755 acre-feet) dredge material excavated.
For this scenario we assumed the entire borrow could be excavated, discharging 0.5 miles and one mile below the dam (see figure 4.2). The pumping distances range from 85,000 LF to 92,000 LF (16.1 to 17.4 miles). One 30-inch discharge cutterhead dredge and five boosters are required to excavate the material and transport it to the disposal areas.

Annual Mobilization and Demobilization

After dredging operations are complete, the 30-inch dredge and five boosters would be towed to the harbor area and prepared for winterization. This plant would remain floating and deicers would be installed. All other dredge plants would be removed from the lake and stored on land for the winter.

One-third of all pipelines would be removed from the lake/shore and sold as scrap each year. The pontoon and shore pipelines would be stored on land, and remaining submerged pipeline not scrapped would remain in the lake. Since the dredge pipeline is a wear item it would lose wall thickness with use. Dredge pipeline should be continually inspected and evaluated as work progresses. All pontoon pipeline not scrapped should be stored on shore until next dredging season. All shore pipeline not scrapped should be removed from the dam and stored at the staging area until next year. Figure 4.3 shows a general layout of this alternative.

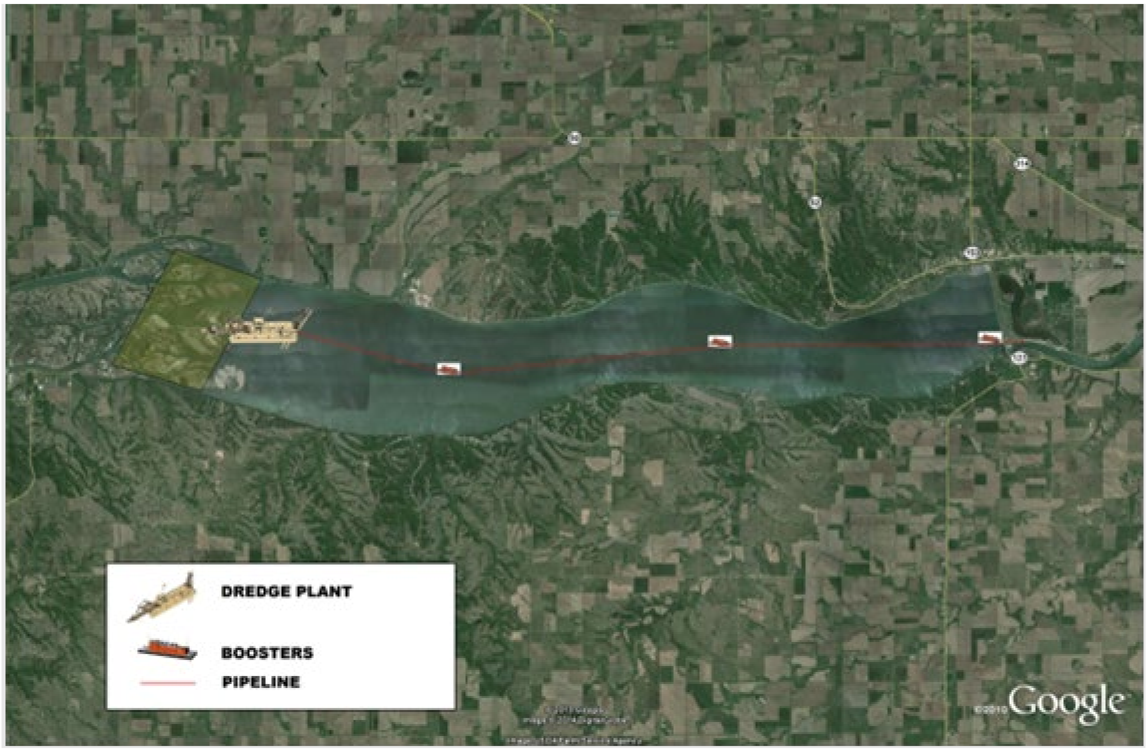

Figure 4.3 Continuous Pipeline Dredge Plant Layout

Note: Photo not to scale. Alternative described to process the full annual inflow requires five boosters.

Lake Access and Safety

A 30-inch dredge plant featuring three boosters working in the lake may be the safest scenario (see figure 4.3). Floating pipeline would be positioned behind the dredge and would require lighting and buoys to aid navigation. The remaining pipeline would be submerged, rising to the boosters when necessary. Shore pipeline would be used on the land portions over the dam and toward the discharge area. It may require slight elevation to allow for natural drainage flow patterns.

With one dredge and attendant plant there are minimal moving components navigating the lake. The dredge itself can be 250 to 300 feet-long and can swing side-to-side up to 400 feet. Extreme caution must be exercised within the vicinity of dredge operations. Fortunately, the dredge is small compared to the size of the lake.

The contractor's work area could be marked with buoys and beacons to assist boaters in navigating around equipment. The contractor must be proactive with the lake residents in education via public meetings to inform them of proper boating practices near work activities.

The pipeline and anchor wires are main concerns as they are partially submerged upon entering or leaving the water. The booster pumps are static but would have marine craft accessing them for periodic maintenance and fueling.

Turbidity would occur near the 30-inch dredge during excavation activities but would be isolated to this area only.

4.1.1.4 Alternative #2 – Mechanical Excavation and Dredging

Initial Mobilization

Mechanical excavation and dredge equipment would be mobilized from 500 miles away by truck. Two 9350 Liebherr excavators were selected as the mechanical dredge. Additional dredge plant equipment required to mobilize with the stage dredge plant is two 400-hp tugboats, one derrick crane, four fuel barges, two work barges, two 100-ton assist cranes, four 250-ton unloading cranes, four backhoes, an 80-ton barge prep crane, two crew boats and a survey boat.

The use of split-hull hopper barges was investigated, but with a construction time of eight months per barge, was considered overly time consuming. Flat-deck barges with removable walls carrying a construction time of roughly two months each were used in the estimate. Barges would be constructed onsite with the facilities built in the staging area.

Thirty-two flat-deck barges, with 1,000 CY capacities (160' X 55') each, must be constructed along with the delivery of eight 900-hp tugboats.

One each 24-inch dredge plant would be mobilized from factory for a flat fee of $500,000.

A labor crew of nine people, with the assistance of a 30-ton and 100-ton crane, would construct the dredge plant. Six each nine-person labor crews would be used. Additional specialized crews would construct and place dredge pipeline as necessary for disposal over the dam.

For this scenario, the final stage dredge would use 3,500 LF of pontoon pipeline, 2,000 LF of submerged pipeline; 5,500 LF of shore pipeline would be delivered for this disposal plan. Additional dredge plant equipment required to mobilize with the final stage dredge plant is two 400-hp tugboats, one derrick crane, one anchor barge, three skidder barges, one fuel barge, three work barges, a crew boat, and a survey boat. Additional specialized crews would construct and place dredge pipeline as necessary.

Dredging Lewis and Clark Lake

Using a density of 90 pounds per cubic foot and 30,000 tons per day yields a daily production of 24,961.36 cubic yards per day. Dredging for 180 days yields 4,444,444 cubic yards (2,755 acre-feet) dredge material excavated.

For this scenario we used a 16-mile haul to the stockpile area near the dam where the final stage 24-inch cutterhead dredge can discharge 0.5 miles and 1.0 mile below the dam. Two Liebherr 9350 excavators assisted by two 100-ton cranes would excavate material, placing it onto deck barges. Two deck barges would be paired with one 900-hp tugboat. After being ferried 16 miles, the full barges would be left by the tugboats and two empty barges would be ferried back to the excavation area. Four 250-ton cranes assisted by backhoes would unload the barges in the stockpile area for the 24-inch final stage cutterhead dredge. Two 80-ton cranes would prepare the full barges for unloading and prepare the empty barges for towing and loading. The mechanical dredge plant should excavate for approximately 4.28 months. More excavation capacity is available to allow flexibility in the varying excavation amounts possible.

The final stage dredge near the dam should excavate for 180 days. The final stage dredge plant (24-inch) comprises 3,500 LF of pontoon pipeline, 2,000 LF of submerged pipeline and 5,500 LF of shore pipeline.

The final stage dredge should excavate the entire 180 days. Assuming 30 days for mobilization, 210 total use-days was used for ownership cost calculation, applied to the cutterhead dredge plant. The mechanical dredging equipment is estimated using 180 use-days.

Annual Mobilization and Demobilization

The two Liebherr 9350 excavators, two 100-ton assist cranes, four 250-ton unloading cranes, and the cutterhead dredge would be towed to safe harbor and winterized until the next dredging season. All barges and tugboats would be dry-docked in the staging area. The plant to remain floating would have deicers installed. All other plant equipment would be removed from the lake and stored on land for the winter.

One third of all final stage dredge pipeline would be removed from the lake/shore and scrapped each year. The pontoon and shore pipeline would be stored on land and remaining submerged pipeline not scrapped would remain in the lake. All pontoon pipeline not scrapped would be stored at the staging area until the next dredging season. All shore pipeline not scrapped would be removed from the dam and stored in the staging area until the following year.

Figure 4.4 shows the work cycle of the excavators and barges for this alternative.

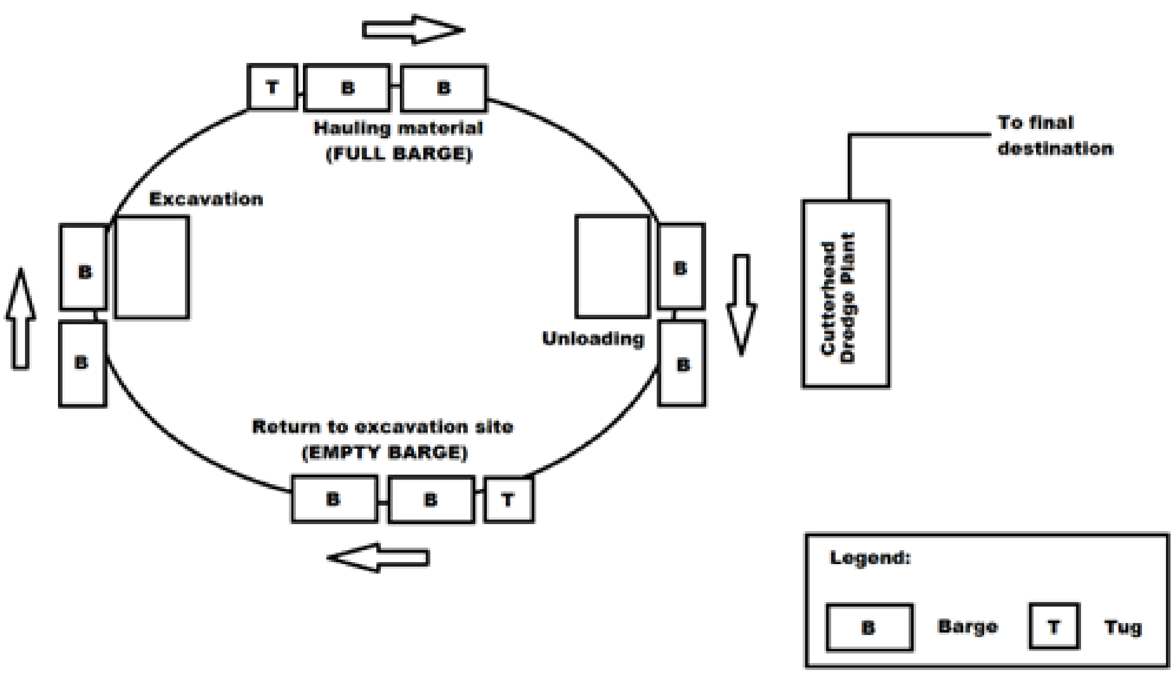

Figure 4.4 Mechanical Excavation and Dredge Work Cycle

Lake Access and Safety

A 9350 Liebherr or equivalent excavator, mounted on a spud barge, would excavate the lake bottom, placing material onto barges which would be ferried to the dam and unloaded. Here, a 24-inch cutterhead dredge would excavate the stockpile area and pump the material over the dam. This scenario has many moving parts adding to risk. With so many tows with barges, the lake may resemble an industrial area. Extreme caution must be exercised within the vicinity of dredge operations.

The contractor's work area could be marked with buoys and beacons to assist boaters in navigating around equipment. The contractor must be proactive with the lake residents in education via public meetings to inform them of proper boating practices near work activities.

The cutterhead dredge would have pipeline and anchor wires which are concerns to recreational navigation as they are partially submerged upon entering or leaving the water. The cutterhead dredge would have marine craft accessing them for periodic maintenance and fueling near the dam. The shore pipeline may require slight elevation to allow natural drainage flow patterns.

Turbidity would occur near the mechanical and cutterhead dredge excavation sites.

4.1.1.5 Considerations for Inclusion in Phase Three Analysis

1. Scope, size, production rate, and cost are easier to develop for a dredging or excavation project than any of the other management actions considered. The cost estimate developed by USACE that is associated with the proposed methods in this section was last updated in 2021 and could be updated further in Phase Three.
2. Dredging with long annual durations and semi-permanent installations require the development of infrastructure to fuel or supply power to the units and overwinter. This infrastructure and its continuous operation can be disruptive to many project benefits including recreation, irrigation, water supply, fish and wildlife, with the tradeoff being increased reservoir storage to support navigation, flood risk reduction, recreation, water supply, etc.
3. Projects of this size often require extended contract lengths to mitigate risk to the contractor. A 10-to 20-year contract duration may be required to entice contractors to bid, so assurances of long-term funding support may be vital.
4. Electrification Considerations - All alternatives are scoped using diesel fuel to power all dredges, boosters, barges, and excavators. The dredges, boosters, and excavators could be powered by electricity from either Gavins Point Dam or other local electric sources. Significant additional initial costs would be incurred to establish substations on the reservoir bank, but benefits could include long-term cost savings (five to seven percent estimated by Stan Ekren from Great Lakes Dredge), reduced environmental concerns about fuel spillage, and decreased noise.

4.1.2 Watershed Sediment Management

By reducing sediment delivery to the Missouri River and Lewis and Clark Lake through watershed improvements, the SME team agreed that the rate of delta growth could be slowed to extend the life of the lake. The team acknowledged that implementation of watershed management actions would not yield instant results and that continual monitoring and improvements would be required to eventually establish a new rate of sediment delivery. In the case of the Niobrara River, there are many reaches of the river actively delivering sediment, and the scale of the work required to make a measurable difference in delivery is unknown. With those caveats, further examination of the methodology was recommended.

4.1.2.1 Management Action Background

Watershed Improvements was one of the four management actions recommended by the SMEs invited to the June 2021 Lewis and Clark Lake Sediment Management Workshop. The long-term goal of watershed improvements is to reduce the sediment delivery to Lewis and Clark Lake, therefore slowing the rate of storage and benefit loss in the reservoir. These improvements, unless completed on a massive scale, would not be a single management activity that could approach full reservoir sustainability. However, watershed improvements may serve as an important part of a suite of management activities to move towards the reservoir sustainability goal.

USACE contacted ERDC to engage an SME in grade control, bank stabilization, and erosion reduction through the Water Operations Technical Response (WOTS) program. The site visit and subsequent report, included in this section, were provided by the program at no cost to the sponsor. Additional engagements through the WOTS program may be possible in Phase Three if analysis and design of structures to reduce sediment yield are carried forward.

The site visit and assessment were limited to select sections of the Niobrara River, the largest contributor of sediment (50-60 percent) to the Missouri River entering Lewis and Clark Lake. Additional contributions are made from river and reservoir bank erosion, Bazile and Ponca Creeks, and The Missouri River above Niobrara, NE. Additional assessments may be performed in some of these areas, but with limited resources, the Niobrara River was chosen as even moderate reductions in delivery may have significant positive impacts in reducing the rate of aggradation on the Missouri River and extending the life of Lewis and Clark Lake.

Over the past few decades, USACE, Natural Resources Conservation Service (NRCS), United States Geological Survey (USGS), and many other state and local agencies have completed studies, and in some cases, mitigation actions to reduce sediment transport and subsequent delivery in the Niobrara River.

The following assessment report summarizes the observations from the field and data analysis. The recommendations provided outline possible Phase Three work and a general summary of possible areas that should be prioritized for action.

4.1.2.2 Fluvial Geomorphology (FG) Level I-Channel Stability Analysis of the Niobrara River, NE

Introduction:

This report is a preliminary geomorphic assessment based on limited field analysis and site visits to the lower Niobrara River, downstream of Valentine, NE (Figure 4.6). The Niobrara River is in North Central, NE and originates in the Wyoming foothills (Lusk, Wyoming). The watershed is approximately 11,600 square miles and follows a mostly eastern path through the Sand Hills and the Great Plains of Nebraska and South Dakota. The river is mostly an east-west trending with the downstream reaches consisting of sandy, braided, and wide cross-sections. The upstream reaches transition into more bedrock control with narrow or absent floodplains and canyon-like features. The analysis area extends for about 93 miles and begins at the confluence of the Niobrara and Missouri Rivers and ends upstream at Valentine, NE (Figure 4.5).

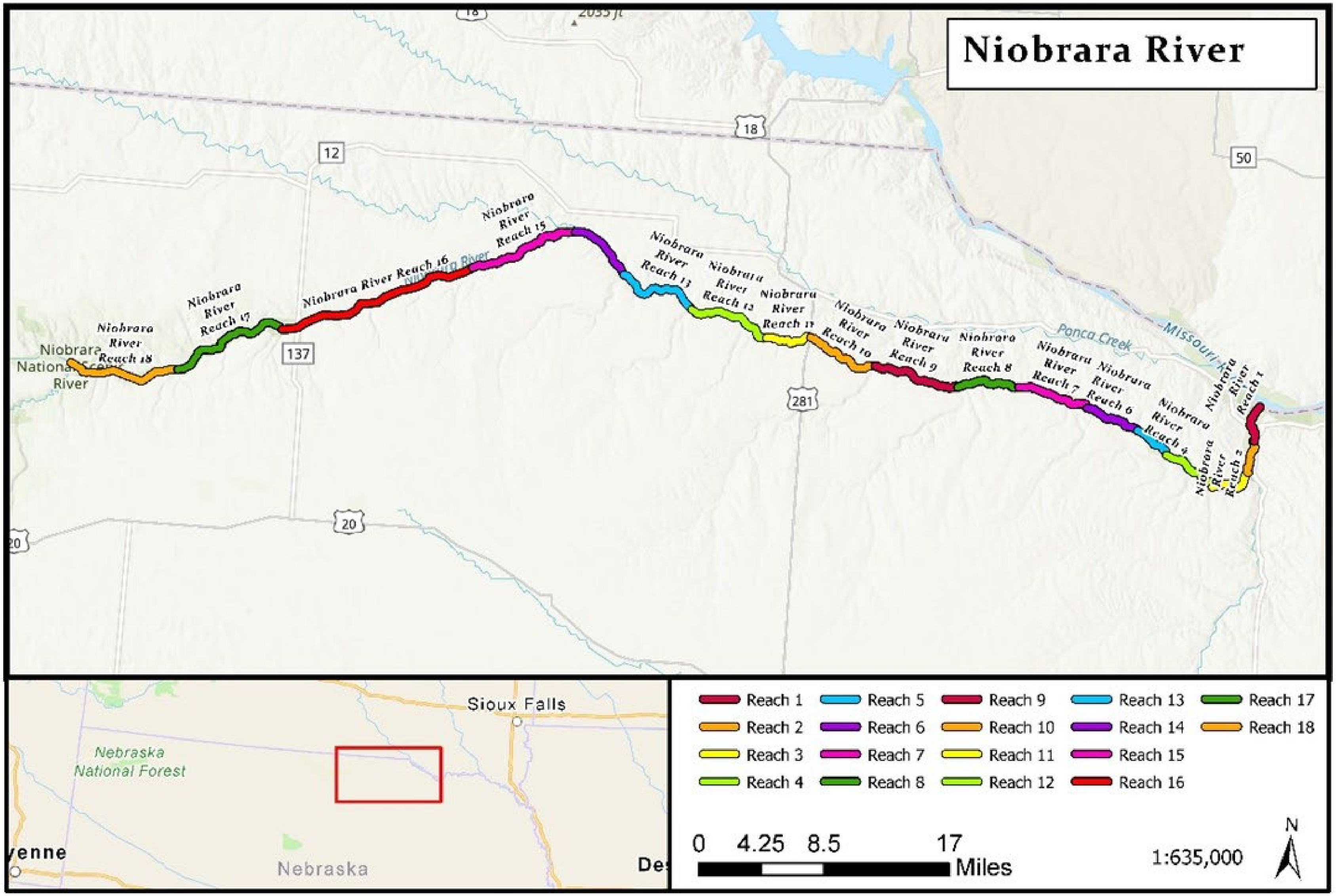

Figure 4.5 Niobrara River FG Level I Reaches

FG Study Reaches and General Assessment:

For the FG Level I-Channel Stability Assessment, the Niobrara River has been divided into 18 reaches beginning at the confluence of the Missouri River and ending just upstream of Highway 7 (Figures 4.5 and 4.6. The reaches were established based on bridge and tributary confluence locations. Historical LiDAR is compared from 2011 and 2020 (Reach 1 also has 2018 LiDAR) to interpret geomorphic trends of the river from the Spencer Dam failure in 2019. Figure 4.6 illustrates a longitudinal profile generated from the LiDAR water surface elevations between the two time periods. At this scale the local slope trends are not visible; however, you can see the larger channel slope trends and changes as shown with the break between Reach 10 and 11 at the Spencer Dam location. The dam breached on March 14, 2019, and the headcut (from losing the channel invert control elevation) has migrated upstream eroding bed and bank materials and depositing them downstream in the aggrading channel reaches.

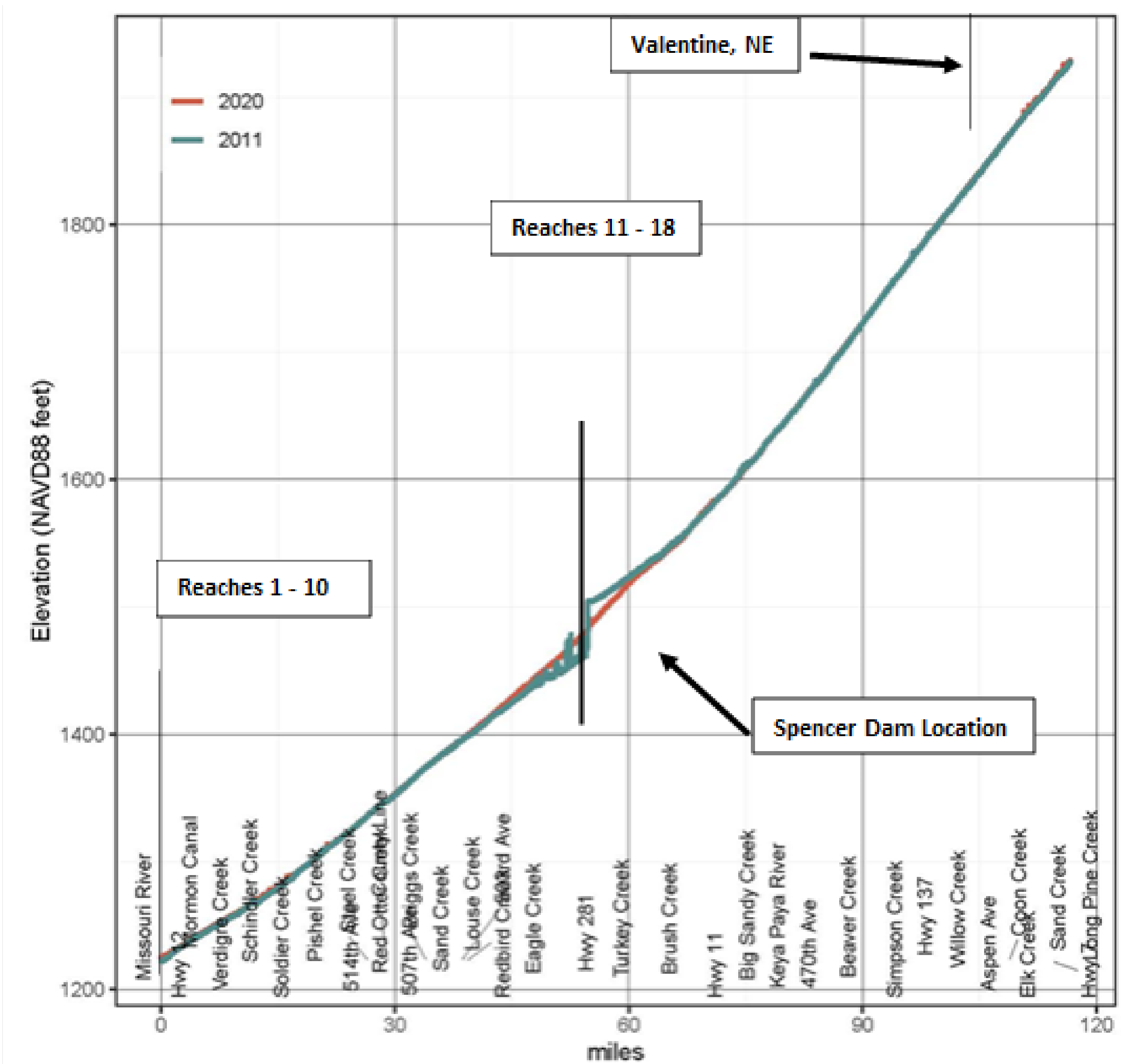

Figure 4.6 Niobrara River FG LiDAR Water Surface Profiles

The next section provides preliminary geomorphic interpretation of the system. Some locations were field visited, but others were not due to time restrictions on completing fieldwork. The Lower Niobrara River reaches were assessed by splitting the reaches downstream (reaches 1-10) and upstream (reaches 11-18) of the Spencer Dam site.

Reaches 1 – 10 Analysis:

The river is a sand bed river that forms many braided, over-widened channels within the reaches. The overall geomorphic trend is an aggrading bed, with channel erosion and widening. Vegetation is established on point bars that erode or are buried and re-establish new channels. The aggrading channel bed trend is most pervasive in reaches 1 and 2 and 9-10. In Reach 1, channel aggradation is illustrated in Figures 4.7 and 4.8. Based on these cross-sections, the channel appears to have filled approximately two to six feet.

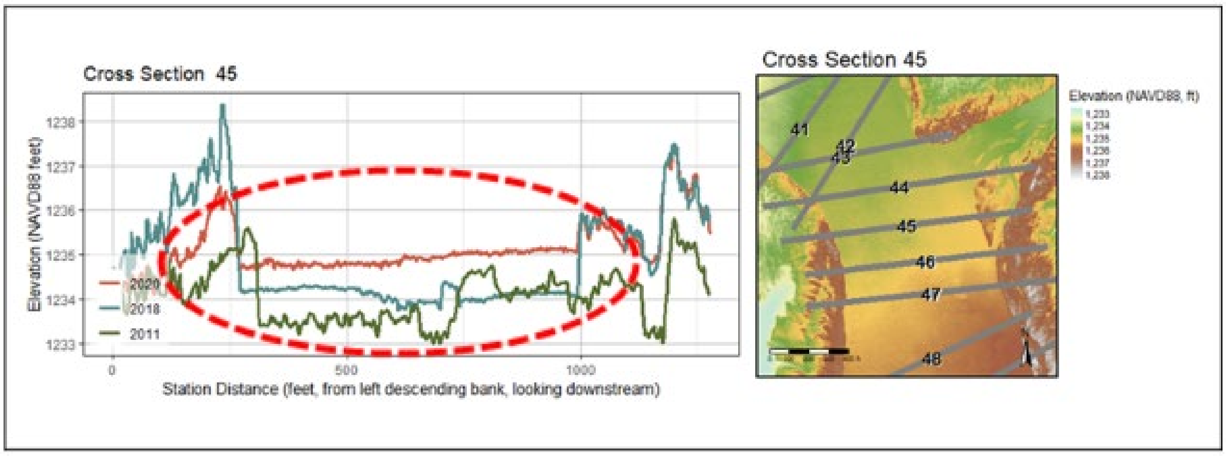

Figure 4.7 Niobrara River channel Cross-section #9 and Planview in Reach 1 Illustrating an Aggrading Channel

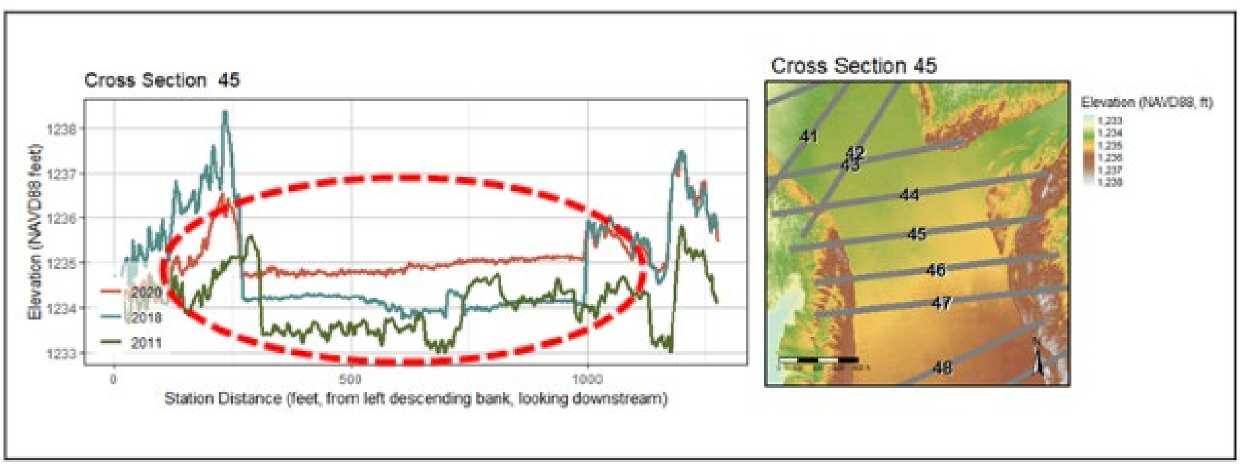

Figure 4.8 Niobrara River Channel Cross-section #45 and Planview in Reach 1 Illustrating an Aggrading Channel

Additional channel aggradation is illustrated from the upstream cross-sections of Reach 8 to the upstream beginning of Reach 10. Figure 4.9A shows the channel aggradational wedge in the profile from approximate cross-section 40 to 100. Figure 4.9B also shows bank erosion and the aggrading channel adjustment.

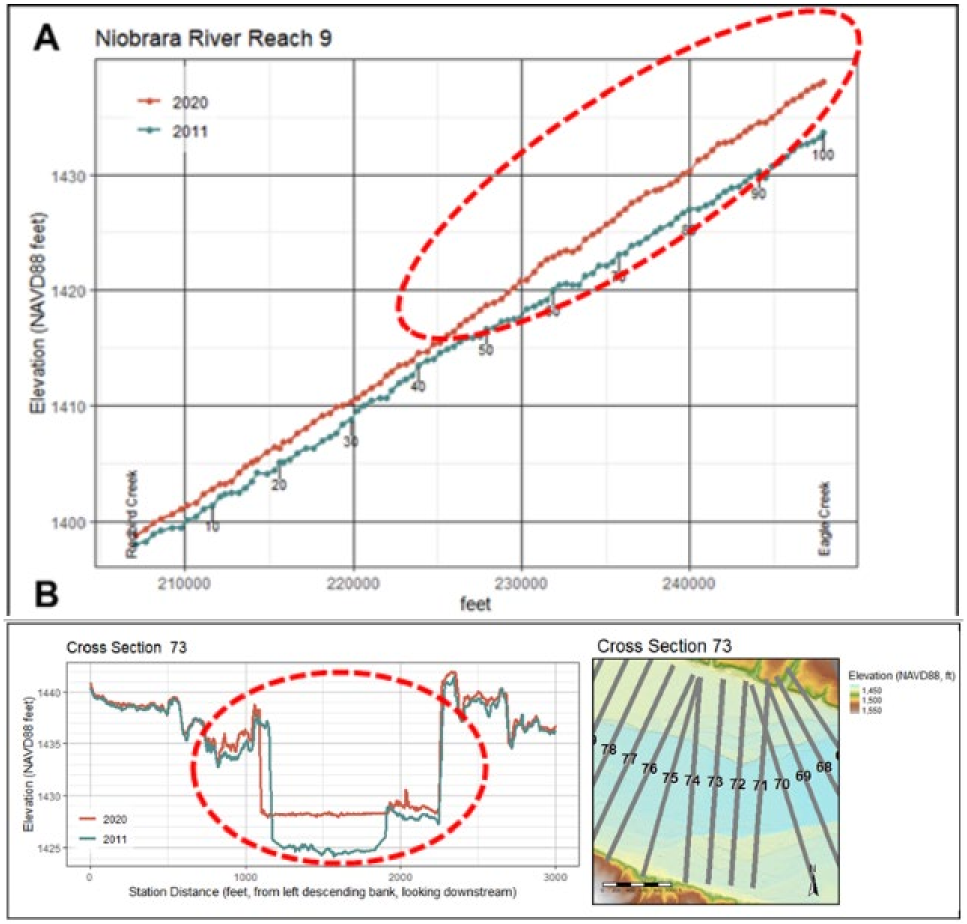

Figure 4.9 Niobrara River Channel Profile (A) and Cross-section #73 / Planview (B) in Reach 9 Illustrating Aggrading Reaches

Reaches 11 – 18:

The river is still a sand bed river that forms many braided, over-widened channels but does transition to more a single-thread, mixed sand, gravel, and bedrock channel system upstream of Reach 16. The overall geomorphic trend is a degrading bed, with channel erosion and widening. The degrading channel bed is most pervasive in Reaches 11 through 14 and in Reach 15. Figure 4.10 shows the pre-2019 Spencer Dam break profile compared to 2020 channel conditions. The channel is adjusting to a new lower channel invert elevation and is actively degrading through Reach 11 and appears to have (as of the 2020 LiDAR) migrated upstream into Reach 14. Figure 4.11 is in Reach 11 immediately upstream of the breached dam site and channel deepening (12-13 feet) and widening (200-plus feet) is occurring based on the comparisons between 2011 (pre-dam break) and 2020 (post-dam break).

This represents a little over 11 miles of channel degradation and which could be visible at the Route 11 bridge upstream (Figure 4.12). Riprap has launched in this area (many times as a result of local bridge scour).

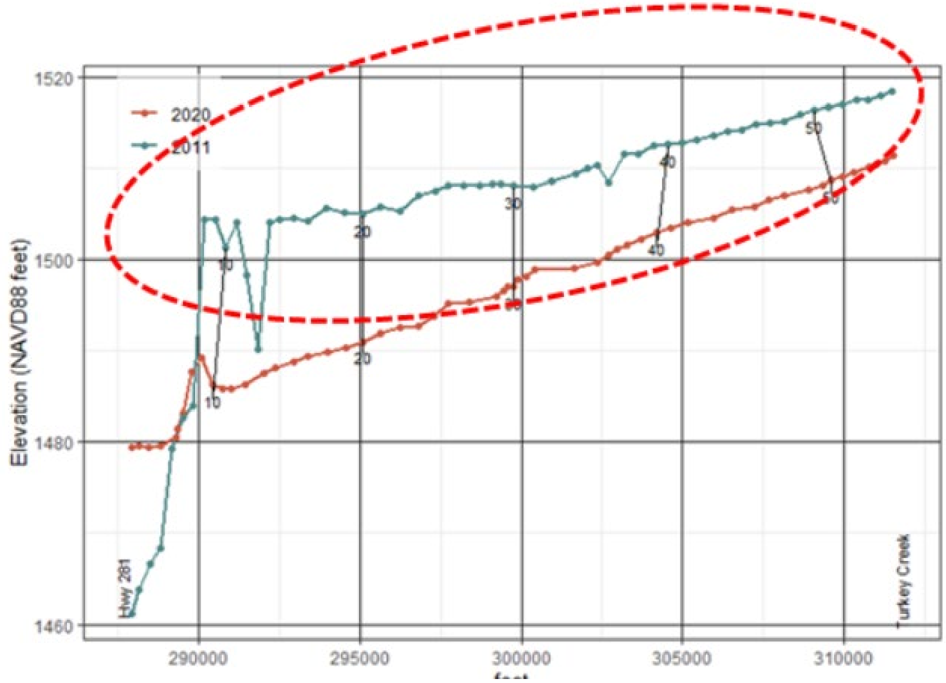

Figure 4.10 Niobrara River Channel Profile Upstream of Spencer Dam Site in Reach 11 Illustrating a Degrading Channel

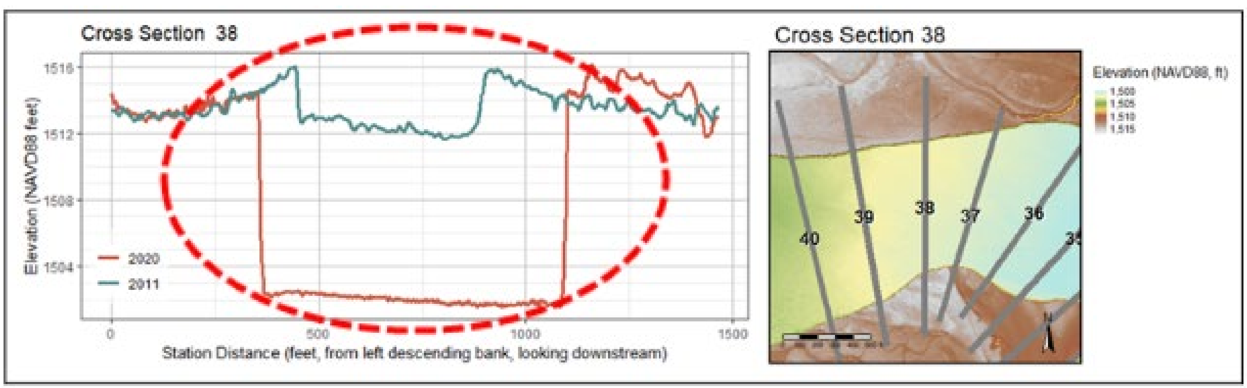

Figure 4.11 Niobrara River Channel Cross-section # 38 and Planview Upstream of Spencer Dam Site in Reach 11 Illustrating a Degrading Channel

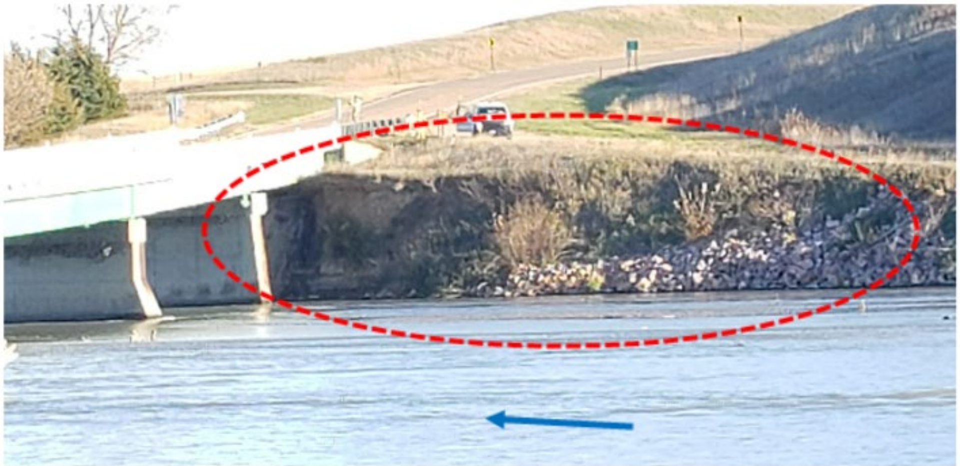

Figure 4.12 Niobrara River Route 11 Bridge in Reach 11 Showing Right Bank Riprap Launching that May be Part of the Channel Deepening and Widening

Figure 4.13 of Reach 14 is illustrating the upstream-most migration of the headcut propagating upstream from the Spencer Dam failure (as of 2020 LiDAR). The channel has deepened (~one foot) and widened (~100 feet) as the headcut has progressed upstream.

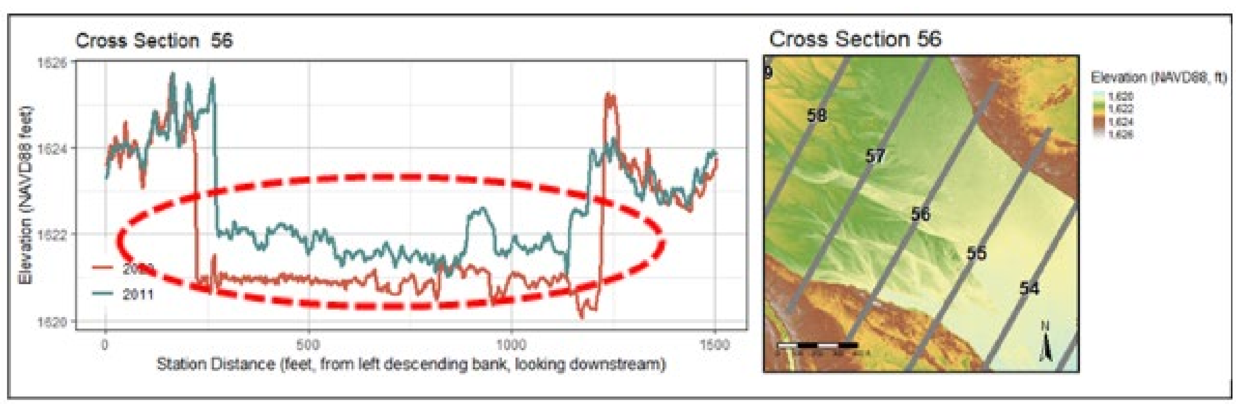

Figure 4.13 Niobrara River Channel Cross-section # 56 and Planview Upstream of Spencer Dam Site in Reach 14 Illustrating a Degrading Channel and Likely Location of Upstream Most Headcut

There was an additional headcut located in Reach 15 (Figure 4.14). In addition to the headcut, many of the reaches from 11 to 16 appeared to have significant bank erosion on alternating bank lines (Figure 4.15 and 4.16).

Figure 4.14 Niobrara River Reach 15 Channel Illustrating a Headcut in the Channel Showing Some Resistive Clay or Bedrock Materials

Figure 4.15 Niobrara River Right Bank Erosion and Sediment Supply to the Channel

Figure 4.16 Niobrara River Left and Right Bank Erosion and Sediment Supply to the Channel

Additional data from the FG Level I CSA reports and field data are being analyzed and will be further developed into a comprehensive Technical Report, expected to be published by USACE in 2024.

4.1.2.3 Considerations for Inclusion in Phase Three Analysis:

This section provides recommendations on actions and studies that should be considered for the Niobrara River. It is unknown how much sediment delivery reduction can be realized with management actions, but additional analysis in Phase Three of the study could better define the scale.

1. Identify sources, pathways and sinks on the Niobrara River mainstem. WEST Consultants, Inc., of Tempe, AZ, developed a report for USACE in 2010 that indicated 80 percent of the sediment from the Niobrara River comes from channel bank and bed erosion, with the remainder coming from overland erosion (WEST, 2010). The study also stated that while bank erosion cannot be eliminated, the most cost-effective approach to reducing sediment delivery is working downstream of the Gordon, NE area of the watershed.
2. Complete additional geomorphic analysis on the Spencer Dam area (Reach 10-11) as the dam break has caused a significant drop in the channel invert causing channel degradation upstream (deepening and widening) and aggradation (channel bed increase) downstream (Figure 4.7). Future analysis should include estimates of the impact of the sediment release post failure to the downstream Niobrara and Missouri River deltas.
3. New LiDAR is expected in 2024 in the lower Niobrara River area. Updating the FluvialGeomorph analysis could provide estimates of the eroded volume of sediment post-Spencer Dam and allow for determining the level of impact the failure will have on the long-term sediment delivery trends.
4. Based on the expanded analysis, a series of grade control structures and bank stabilization measures may be considered to protect the river system from the long-term impacts of the dam failure. Other areas identified with high erosion and delivery should be considered including Reach 15 and areas where the maximum benefit can be realized.
5. Overgrazing, especially along streambanks, leads to erosion; research shows that one steer on a creek bank for 100 days will do more damage than 100 steers on the same creek bank for one day (MSAC, 2011). Identify sources, pathways and sinks on tributary watersheds to address channel bank and gully erosion sediment sources.
6. Engage with NRCS to coordinate further study, analysis and stabilization efforts throughout the Niobrara and other contributing watershed.

4.1.3 Sluicing

The SME team cited many successful case studies of reservoir sluicing during the workshop. While all acknowledged that the conditions and infrastructure in Lewis and Clark Lake and Gavins Point Dam are not ideal for sluicing, they did recommend that sluicing be considered and augmentation of the conditions through physical modifications be analyzed to increase sluicing efficiency and reduce collateral impacts. Multiple augmentation methods, including gate lowering, tunnels, and flow management are considered.

4.1.3.1 Management Action Background

Reservoir Drawdown Sluicing was one of the four management actions recommended by the SMEs invited to the June 2021 Lewis and Clark Lake Sediment Management Workshop. Multiple sluicing scenarios were suggested by the SMEs, each based on experiences of successful sluice events at other reservoirs.

Lewis and Clark Lake does not reflect the common planform of a reservoir that would have a highly efficient drawdown sluice. In most cases with successful sluicing, those reservoirs have small storage volumes, steep gradients, and low-level outlet in the dam to facilitate full drawdown of the reservoir pool to run-of-river conditions.

At Lewis and Clark Lake, pool storage volume is large, extending over 20 miles from the dam; the channel gradient is approximately one foot per mile, and the only available outlets that do not utilize the hydropower facility are approximately 25 feet above the bottom of the reservoir. A fully drawn down pool will not result in a complete return to run-of-river conditions, with a pool multiple miles long remaining that will trap re-entrained sediment from upstream before it passes the dam spillway.

In the past two decades multiple numerical models have been developed to examine the possible efficiency of a drawdown sluice under various flow, duration, sediment composition, and augmentation conditions. The most recent of these analyses was completed in 2014 using the 2011 surveyed river and reservoir geometry (the most current until fall 2023). In the previous analysis, a HEC-RAS 1-dimensional moveable bed model was used to create a calibrated delta evolution model from 1955-2011 and examine multiple sluicing scenarios and augmentations going into the future.

The summary of those results, primarily of excerpts from the report, follows, and the full USACE Omaha District Office Report will be available by spring 2024.

4.1.3.2 Description of Conceptual Sluicing Plan

Challenges to sediment management at Lewis and Clark Lake have been well documented over the decades since dam closure in 1955; they can generally be summarized as listed in Table 4.1.

Table 4.1 Gavins Point Dam and Lewis and Clark Lake Advantages and Challenges to Sediment Management

Advantages	Challenges
Gavins Point is the downstream dam of the Missouri cascade and immediately upstream of the target reach to increase sand load.	Sixteen miles of open water between the current sediment delta and the dam.
Relatively Small Reservoir for the Missouri River.	The dam has no low-level outlets. So even when drained, the reservoir has a standing pool and multiple miles of open water between the delta and the structure.

Advantages	Challenges
Niobrara River delivers substantial sand load 20 miles upstream of the dam.	There are social and policy constraints on the releases that can be made from Gavins Point dam.
Fort Randall Dam allows managers the flexibility to specify an optimal inflowing hydrograph with unusual precision.	
The impoundment volume of the upstream Missouri cascade removes the standard refilling uncertainties associated with sediment management draw downs in other systems.	
Sediment reintroduction below Gavins Point Dam may mitigate channel degradation.	

Morris and Fan (1998) defined the classical taxonomy of passive reservoir sediment management alternatives, including: sluicing, routing, bypass, and turbidity currents. It is still very difficult to predict, model or manage turbidity currents, and bypass solutions that are not part of the original design are almost always prohibitively expensive, making sluicing and routing the two main passive options.

Sluicing events draw down the reservoir to achieve a run-of-river condition (or as close as the outlets will allow). Run-of-river conditions form a channel in the reservoir sediment accumulated from previous events. Routing alternatives draw down the reservoir during particularly sediment laden flows (e.g., the rising limb of the hydrograph) to pass sediment through the reservoir before it has a chance to deposit. USACE Omaha District evaluated the efficacy and sustainability of a suite of several sluicing alternatives, engaging the USACE Hydrologic Engineering Center (HEC) to evaluate these alternatives with a river analysis system (HEC-RAS).

4.1.3.3 Hydraulic Model and Calibration

The Lewis and Clark Lake sluicing model was originally developed in HEC-RAS 4.1 and updated to HEC-RAS 5.3 in 2018. The model is currently available and can be updated for use in Phase Three with new surveys from 2022 if carried forward for consideration.

Model calibration includes parsing the calibration into three-time blocks to match surveys and bed material samples. The primary goal was to match the cumulative total mass of deposited sediment in the system during each calibration window. Figure 4.17 shows the final calibration of cumulative volume of material deposited in each window versus the measured deposition from surveys. Tradeoffs had to be made when examining the deposition of various grain class sizes. Priority was given to matching the sand fraction in the calibration and the expense of accurately matching the mass of fines (silts and clays deposited). Most models struggle to accurately represent the very slow settling of fine grain classes, and they are a smaller fraction than sand in the Missouri River at this location.

The sand fraction is the limiting factor in transport in any sluice event in this system. While there is a little gravel size fraction material, fine to medium sand are the fractions that need to be transported for a successful sluice. Once these size fractions are being transported, all finer fractions will also be transported.

Overall, the calibration to sand size fraction, which is predominantly deposited in the reach down to RM 825, is very good. From RM 825-810 at the dam, the model underestimates the volume of fines deposited.

Quasi-Unsteady and Unsteady flow computations were evaluated for the model. Unsteady effects improved model behavior in the high priority zones (delta scour and deposition, in that order, in more recent time series) producing more scour and less deposition in the delta during the 2007-2011 and 1975-1995 events, so the calibration was retained for the simulations.

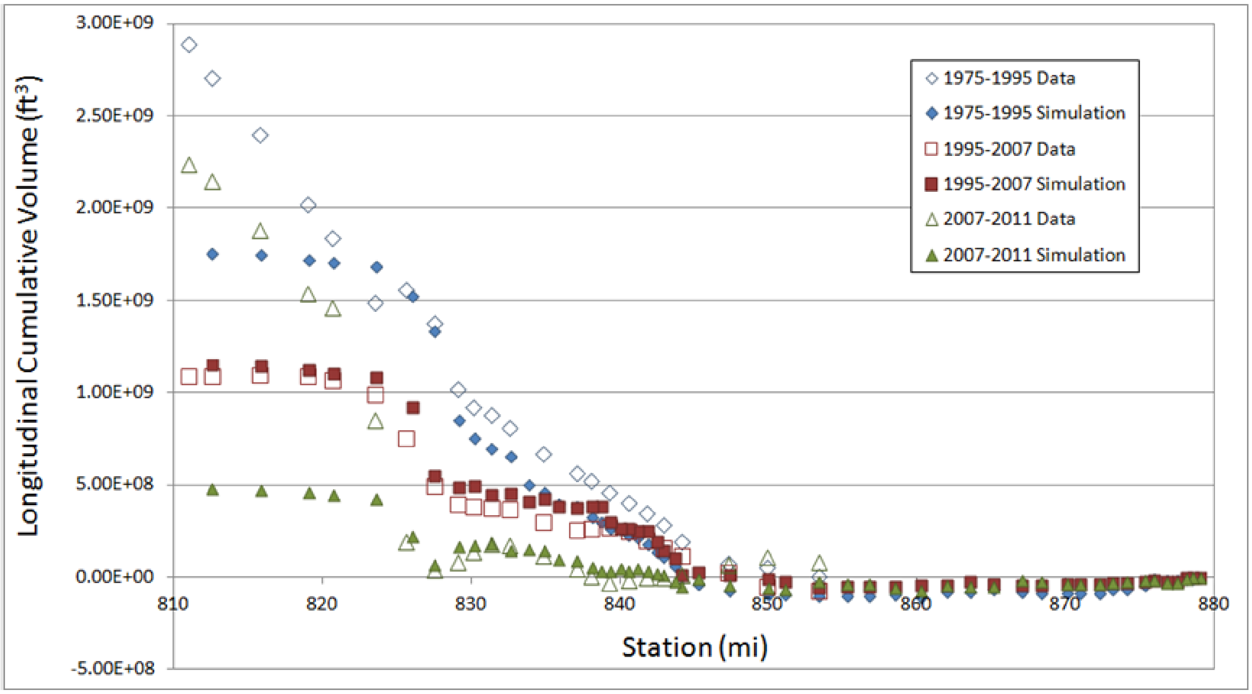

Figure 4.17 Unsteady Calibration for Lewis and Clark Lake Sluicing HEC-RAS Model

4.1.3.4 Modeling of Flow Scenarios

As part of the previous study, multiple flow scenarios were identified for models. They include a no-action future that replicates the period of record flows, multiple scenarios of drawdown sluicing with current and future conditions, and anthropogenic augmentations to sluicing including lowering of half the spillway gates, the addition of sluicing tunnels at the bottom of the reservoir, a longitudinal revetment, and dredging. Table 4.2 summarizes the flow scenarios modeled, and each is described in detail in the full report.

Table 4.2 HEC-RAS Sluicing Model Flow Scenarios

Scenario	Sluicing Flow (cfs)	Sluicing Duration (Days)	Other
II-1	None	None	No Action – 53-year projection to determine delta progression through 2064
II-2	60,000	7	Base alternative – single drawdown sluicing event
II-3	60,000	7	Scenario II-2 with 2064 geometry
II-4	60,000	7	Seven spillway gate inverts lowered to 1,170 ft
II-5	30,000	7	Half magnitude version of II-2
II-6a	60,000	7	Low Elevation Tunnels (invert 1,157 ft)
II-6b	30,000	7	Low Elevation Tunnels (invert 1,157 ft)
II-7a	180,000	~8	Repeat of Scenario I-1 from Phase I *
II-7b	88,000	~10	Repeat of Scenario I-2 from Phase I *
II-8	30,000	7, repeating	Annual sluicing event through 2064
II-9	30,000	7, repeating	Annual sluicing event with longitudinal revetment through 2064
II-10	30,000	7	Annual sluicing event with dredging 675 tons per day during sluice through 2064

**Phase I refers to a previous modeling study, not Phase 1 of the Lewis and Clark Lake Sediment Management Plan Section 22 Study.*

4.1.3.5 Modeling Results

In general, modeled scenarios that were run with the current dam infrastructure saw a transport of sediment deeper and farther into the reservoir pool but had no sand fraction transport. That was the case for both the current and estimated future geometry for the year 2064. Figure 4.18 shows the bed change for each of those scenarios.

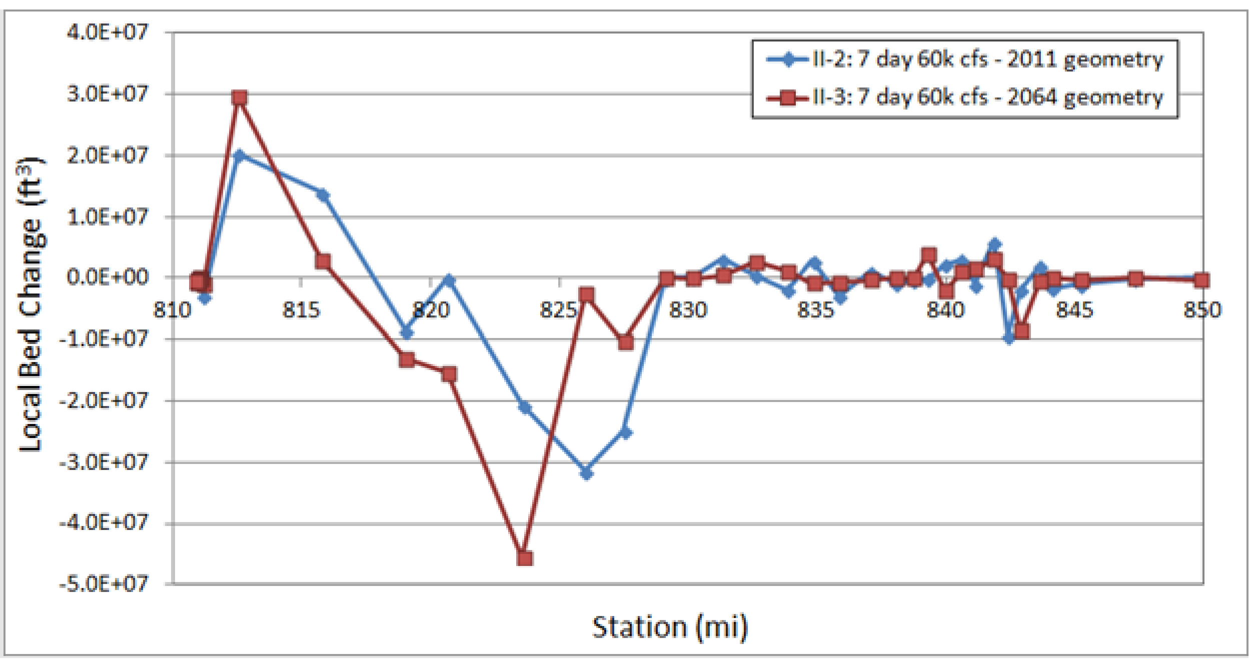

Figure 4.18 Local Bed Change at Each Cross Section for Scenario II-3 compared to II-2

Note: the same sluicing event starting with the 2065 and 2011 starting geometries, respectively.

The lowering of spillway gates in scenario II-4 still did not result in transport of the sand fraction; however, it significantly increased the transport of silt and clays scoured from the delta, resulting in an increase in reservoir storage after a flush. In this scenario, once the reservoir pool storage below the spillway gates was filled with redistributed sediment, sluice efficiency and the transport of sand would increase significantly.

The adding of sluicing tunnels to the model allowed for much more sediment to transport to the bottom of the reservoir and a large increase in the fine material transported past the dam. Figure 4.19 shows the bed change when the tunnels are added to the 60,000 cfs flushing event.

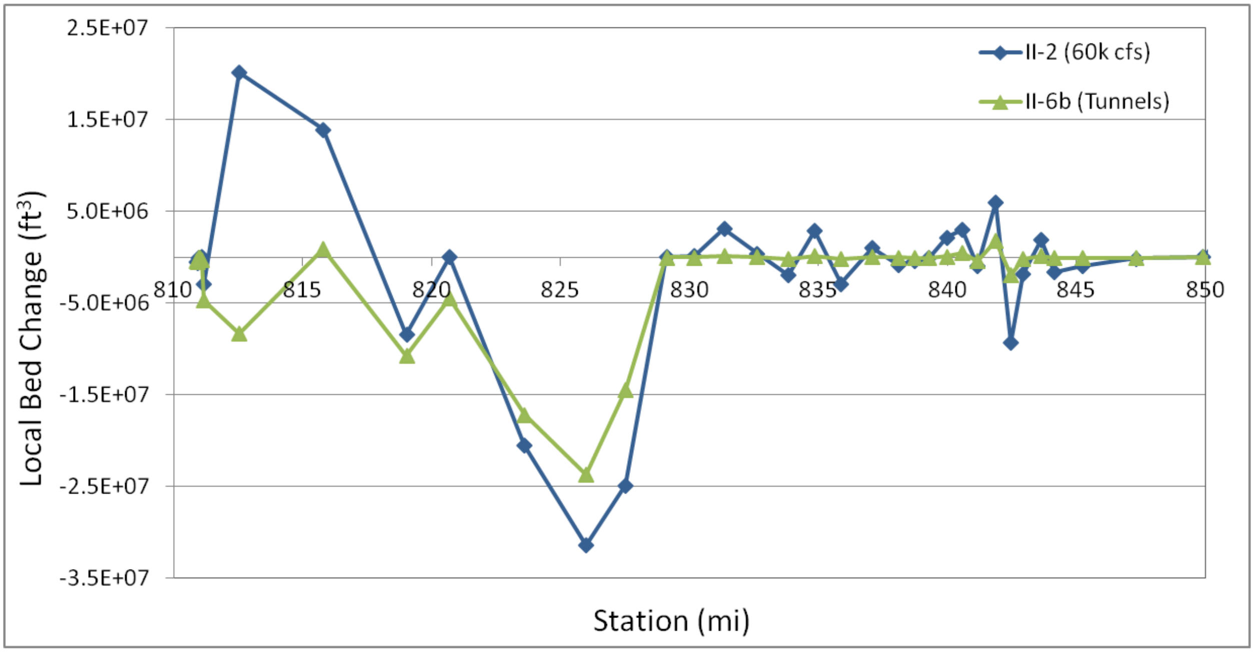

Figure 4.19 Seven day, 60,000 cfs Sluicing Event with and without Tunnels

The inclusion of the sluicing tunnels was the only scenario that showed a significant transport of sand-size material past Gavins Point Dam. Figure 4.20 shows that nearly 8,000,000 cubic feet (183 acre-feet) of sand-size, and a total of about 68,000,000 cubic feet (1,560 acre-feet) were predicted to be discharged through the tunnels. If multiple sluices were to occur, and if the delta were closer to the dam, an increase in total sediment discharge per sluice event would be expected.

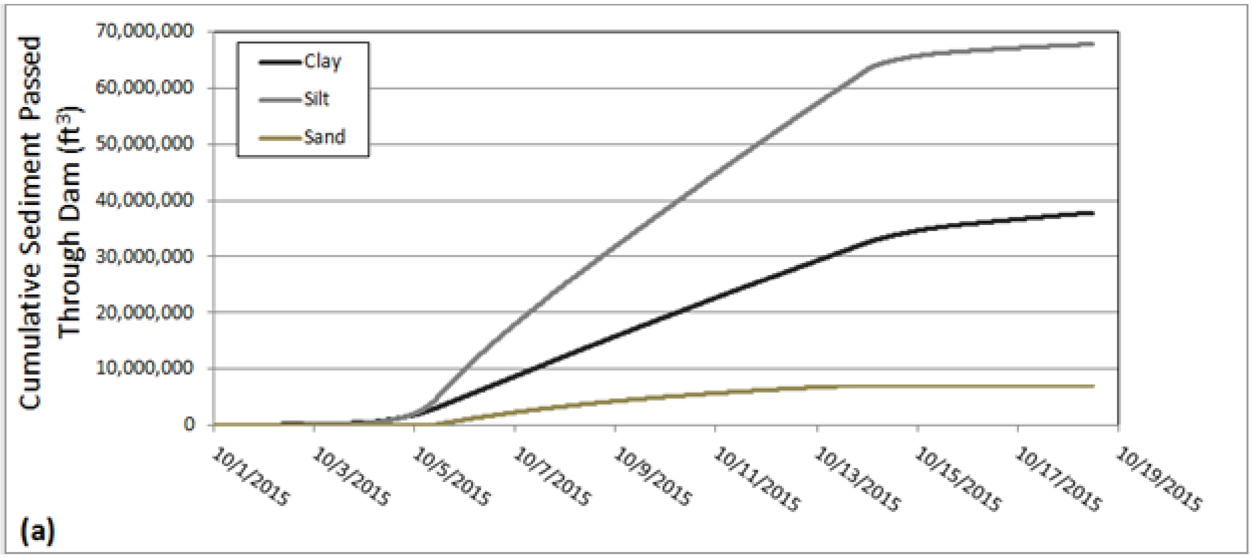

Figure 4.20 Sediment Volume by Grain Class Released from Gavins Point Dam for Scenario II-6a

Note: Tunnel with 60,000 cfs

The last relevant scenario to this study was II-8, with an annual sluice event at 30,000 cfs. This is the least extreme scenario, but also yields the least positive results. The annual sluice for the next few decades resulted in the redistribution of sediment into the bottom of the reservoir but only a very limited volume of fine material transported below the dam.

To attempt to increase the efficiency of that scenario without increasing flow, a longitudinal rock revetment was simulated in the model. The revetment is submerged at normal pool elevations, but, in a drawdown sluice condition, would direct flow onto the Nebraska bank of the reservoir to shorten the flow path and maintain higher flow velocity, and, as a result, increase sluice efficiency. Figure 4.21 shows the general location of the revetment as modeled.

Figure 4.21 Approximate Alignment of Proposed Revetment

When the sluice in the scenario with the revetment is repeated annually, eventually the sand class begins to be transported over the spillway. This is a result of revetment accelerating the rate at which sediment is transported to, and fills in, the bottom of the reservoir to the elevation of the spillway invert. In the modeled scenario, this would start to occur after approximately 50 years of flushing events.

4.1.3.6 Considerations for Inclusion in Phase Three Analysis

1. All SMEs at the workshop had experience with sluicing and considered it a method that warranted additional consideration. The current geometry of the lake, coupled with the gate and spillway intake locations make sluicing ineffective in the current state. To increase effectiveness, augmentation through flow channelization and/or physical addition of sediment during a sluice, coupled with dam modifications to provide low level outlets would be necessary.
2. The analysis summarized in this section used geometry from 2011. With new surveys collected in 2022, and the advancement of the delta during that time, the sluice efficiency of all the modeled scenarios would likely increase.
3. Not captured in this analysis are the collateral impacts of drawdown sluicing on the local area. While the reservoir pool elevation during a sluice will vary by a few feet when comparing the 30,000 cfs scenarios to the 60,000 cfs scenarios, the predicted drop in reservoir pool elevation will likely exceed 20 feet, and in the case of the scenarios with lowered spillway gates or tunnels, even lower. The model can predict what this pool elevation will be during the sluicing events, and that information should be used to assess impacts to other project benefits that will be temporarily lost.
4. Updates to the model will be necessary if it is to be used in Phase Three. The model is a complex analysis tool, that will require re-calibration to the new survey and updating to analyze any additional scenarios. The costs and time associated with these updates are significant.

4.1.4 Bedload Sediment Collection

Reducing delivery of sediment to areas where deposition occurs can actively reduce the growth of the delta. Bedload Sediment Collection was recommended by the workshop SME team as a method that should be considered to reduce sediment loading to the Missouri River and Lewis and Clark Lake.

4.1.4.1 Management Action Background

Transport of river sediment along the bed of a river can comprise a measurable and significant fraction of total sediment transport. Along the bed, sediment either moves as bedload, rolling along the bed/water interface, or as saltation load, bouncing back-and-forth between bedload and suspended load. The combination of these loads can comprise from to 0-30 percent of the total load in sand bed rivers, but is highly dependent upon sediment grain size, bed roughness, water flow, velocity, and temperature.

The Missouri River delta above Lewis and Clark Lake is supplied sediment from three major sources: the Missouri River, the Niobrara River, and the combination of other small tributaries and bank erosion in the lake. Reducing the delivery of the bedload fraction from any of these may increase the sustainability of the lake.

4.1.4.2 Description of Bedload Collection

Lipscomb, et. al., 2005, showed that under idealized conditions, a bedload sediment collector can collect more than 90 percent of the available bedload in the medium-to-large sand grain class if that material is available for collection. Collection rates drop as the material available becomes finer, due to the lower fall velocity associated with finer grain classes.

Tucker et al., 2015, referenced a sediment collector system installed with the specific goal of reducing downstream delivery of sediment to John Martin Reservoir, resulting in reduced dredging cost and impact. This system incorporated a 30-foot-wide collector capable of separating up to 100 tons per hour. Figure 4.22 shows the collector installation, and figure 4.23 the identification of components.

Figure 4.22 Sediment Collector™ Installed in Fountain Creek, CO (Tucker et al., 2015)

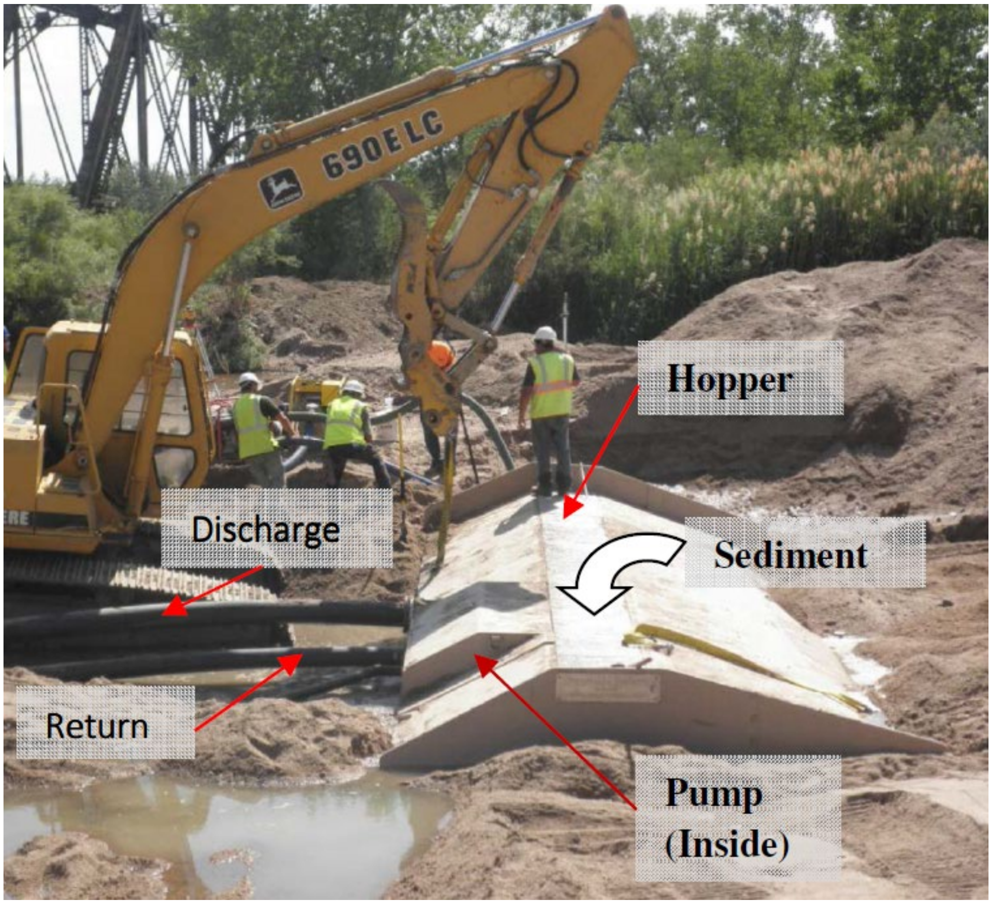

Figure 4.23 Components of the Sediment Collector™ at the Fountain Creek, CO Install (Tucker et al., 2015)

An Archimedes screw for coarser material or cyclone separation for finer sediment is used to dewater the collected material and stockpile for later use.

Any installation requires river access, storage area, a power source, highway access, and necessary resources to move the collected material to other locations.

The Sediment Collector™ and similar technologies have been repeatedly shown to be effective at collecting bedload from rivers with sand and coarser bed material. This trait would make the method effective on any of the sources of sediment to Lewis and Clark Lake; however, the method has not previously been scaled in application to the bedload of a river like the Missouri or Niobrara. The value proposition of scaling up bedload collection vs. unit costs could be examined in a pilot project.

4.1.4.3 Pilot Installation on the Niobrara River

The Niobrara River has historically contributed 50-60 percent of the total sediment load to the Missouri River reach that makes up the Lewis and Clark Lake delta (USACE, 2013). The delivery of this sediment is chronic (i.e., slow, and continuous), due to nearly unlimited sediment supply and base flow driven by springs through the basin, increasing intermittently during flood events. This condition may make it a good candidate for this type of passive collection system that can operate continuously.

In the application case for a pilot on the Niobrara River, where much of the bedload material is in the 0.2-0.4mm range (USACE, 2013), similar to Material 1 tested by Lipscomb, bedload capture efficiency varies between 54 and 74 percent with velocity and depth of flow.

In concept, the collection of bed material from the Niobrara could be scaled to capture the full width of the river channel. If 50 percent of the bedload could be captured in the Niobrara that is annually delivering 50 percent of the estimated 2,600 acre-feet (as of 2011) to Lewis and Clark Lake, an effective 25 percent reduction in delta forming sediment bedload could be extracted. With consideration that bedload can approach 20-30 percent of total load in higher flow events, this could effectively reduce load delivered to the delta by 5-15 percent.

Any reduction in sediment delivered to Lewis and Clark Lake can be expected to slow the progression of the delta face and increase the lifespan of the lake. Whether the rate of sediment delivery reduction equals the lifespan increase in currently unknown.

The USACE Environmental Lab, part of ERDC (ERDC-EL) has been examining and testing bedload collectors for the past twenty years (Mr. Tim Welp – ERDC as author on Tucker et. al., 2007). Most of the previous work done by ERDC was with small collectors (2- to 4-foot width), or in conjunction with existing installs up to 30-foot width.

Currently ERDC-EL Primary Investigator Chuck Theiling, has a 12-foot-long collector with the necessary connections, pumps, and separators that could be used for a one-to-two-week sediment collection pilot project. Figure 4.24 shows the collector and separators of this system. An install of this system would require portable power, approximately one acre of river side access, and a roadway access capable of supporting at least 26-ton rated dump trucks.

The production rate of the system is difficult to predict, but the ERDC-EL team expects that up to one to two tons per hour could be collected and separated in this pilot with Niobrara River sand. This system requires manual removal of the sediment from the separator tanks; this configuration is therefore separator limited, not collection rate limited. Increases in total sediment removed could be achieved with faster separation methods. A monitoring program during the pilot should provide more specific production and sediment capture rates, which will be necessary to estimate the footprint and cost of larger scale implementation.

Figure 4.24 ERDC-EL 12-foot Sediment Collector™ System for Pilot Project

4.1.4.4 Considerations for Inclusion in Phase Three Analysis:

1. Unlike a large dredging or sluicing project, bedload sediment collection effectiveness can be measured at a small scale through a pilot project. To effectively estimate the impact and costs of a more permanent system, a pilot project with the 12-foot collector should be considered.
2. Any pilot project should be extensively monitored for flow rate, velocity, bedload, suspended load, grain size, and extracted sediment quality to develop a reasonable estimate of the effectiveness of an installation scaled up from the pilot to capture significantly more sediment.
3. The results of the pilot project should be used to develop economic estimates of larger applications.
4. A short one-to-two-week pilot project may produce hundreds of cubic yards of collected sand. As part of the planning for a pilot, the logistics of transport should be determined, and end users identified early. A follow up of uses and transport costs should be captured for the economic analysis.

4.1.5 Summary of Alternatives Not Carried Forward from Early Screening

Many methods were considered and discussed in the initial brainstorming session at the SME workshop. These ideas were collected and categorized on the posters used for the Dot Democracy exercise. A few of the methods appeared on multiple posters, but only the diversion and pipeline method made it through the exercise. That method was then removed from further consideration in the discussion following the exercise. Those methods fell into six general categories, summarized here with the major factors that led to their removal.

1. **Niobrara River Dam/Diversion/Pipeline –** a diversion of the Niobrara River, to reduce over 50 percent of the sediment delivered to Lewis and Clark Lake was examined conceptually and a rough estimate of the length of channel, volume of excavation, cost was developed (USACE, 2002). At that time, the cost estimates drastically exceeded benefits. Recent analysis done as part of the improvements on NE Highway 12 made it clear there would be significant real estate, access, and channel stability concerns associated with a channel or pipeline along the Nebraska bank of the river and reservoir.
2. **Gavins Point Dam Removal** – The dam currently maintains an excellent safety rating and fully meets the requirement to support all eight federally authorized project purposes. While benefits are continually decreasing due to sedimentation, there remains a very significant value to the benefits provided by the project. A detailed cost estimate is not currently available. If developed in Phase Three, some alternatives might be reconsidered as viable to prevent the removal cost.
3. **New Dam Construction above the Niobrara River** – This alternative was discussed as either a replacement for Gavins Point Dam or a complimentary new dam and reservoir project. The benefit of such a project would be to develop a project with considerably less sediment inflow by not capturing Niobrara River sediment and being sited in a reach of the Missouri River that has reduced sediment delivery since the closure of Fort Randall Dam. This could allow for incremental removal of Gavins Point Dam to slowly reintroduce 70 years of deposited sediment to the Missouri River as well as the annual

delivery from the Niobrara River. At this time, the consensus of the discussion at the SME workshop is that there is not sufficient political will to address the economic, environmental, and real estate concerns with new dam construction.

4. **Operational Changes to Capitalize on Flood Flows for Reservoir Flushing** – USACE has no current plans to change the management at Gavins Point Dam because the current management plan allows for the maximization of benefits across all authorized purposes. In a future condition where benefits were not maximized, a management change would be considered if it resulted a better equilibration of benefits. For the framework of the SME Workshop, the participants were asked to consider methods that should be expected to work within the current management plan. That does not preclude methods like sluicing, but does remove permanent pool level changes, reallocation, or flushing of flood flows from consideration.
5. **Hydrosuction** – The hydrosuction management method, where a siphon over a dam can vacuum sediments from the reservoir bed and discharge downstream at a location below the intake, has been effectively applied at a number of small reservoirs. A major limitation of the method is the need to hold the siphon along the full length of the pipeline. A siphon could be maintained for a few miles, allowing for fine silt deposited near the dam to be transported; however, the vast majority of the deposited sediment is sand, at or beyond 15 miles from the dam. Maintaining a siphon at flow velocities fast enough to move sand over that distance has not been shown to be simple or reliable.
6. **Vegetation Management and Removal** – Vegetation management and removal could be used to in conjunction with a reservoir sluice to encourage erosion of deposited materials or to stabilize banks and grazing lands within the watershed to reduce yield. It is not considered sufficient in benefits on its own to be considered an effective management method.

4.2 Additional non-Workshop Solutions

In general, the sediment management methods considered at the SME workshop were ones that had a track record of success in other reservoirs. As reservoir sedimentation problems increase with the aging of thousands or reservoirs, managers and researchers are continually looking for developments in technology that will allow for faster, cheaper, and cleaner sediment management.

4.2.1 Emerging Technologies from the Guardians of the Reservoir Prize Competition

From the ‘Guardians of the Reservoir Challenge’ page at https://www.nasa.gov/guardians-reservoir-challenge:

The Bureau of Reclamation, in collaboration with the U.S. Army Corps of Engineers, is running a three-phase challenge called "Guardians of the Reservoir" to find ways for removing sedimentation that accumulates in reservoirs.

4.2.1.1 Summary of the Prize Competition Results

The Bureau of Reclamation (BoR) selected the D-Sediment team (Michael Detering, Laura Backes and Joana Kueppers from Germany) as the prize winner of the Guardians of the Reservoir Prize Competition, according to BoR’s press release of Sept. 15, 2022. The 3 D Dredger™ Team (Nicholas LaBry and Kenneth LaBry of Prometheus Innovations LLC and

Bartolomeo Mongiardina of Hydro Maintenance Service) was presented with the Versatility Award. Mazdak International Inc. of Sumas, Washington, (Baha Abulnaga and David Dibley) captured the Innovation Award. BoR partnered with USACE, NASA Tournament Lab, and HeroX on this competition, which was launched in July 2020 to develop more cost-effective sediment removal methods for reservoirs.

More than 90 submissions were received, according to an update posted at www.herox.com/GuardiansoftheReservoir/updates. The three finalists were asked to submit summaries of their emerging technologies to be included in this Phase Two report. Portions of their responses are included below.

4.2.1.2 SediMover® Technology (by D-Sediment and Hülskens Sediments)

Note: Section 4.2.1.2 was authored by the manufacturers of the Sedimover® Technology. Statements made herein may not align with those by the Omaha District, U.S. Army Corps of Engineers.

Since dams are interrupting the natural sediment continuity and therefore the created reservoir suffers from sedimentation as well as the downstream river facing erosion, the obvious and only sustainable solution to overcome both problems is to re-establish a near-nature sediment transfer. Any other option would in the long run lead to either a silted and thus lost reservoir, massive dredging, dewatering and landfill, downstream river erosion or all combined, including the associated cost.

Major endeavor to achieve sustainability in reservoir management is to develop an environmentally friendly, reliable, and cost-effective solution which considers uninterrupted reservoir operation and associated use (e.g., power generation and recreation).

For ensuring this, D-Sediment and Hülskens Sediments developed the SediMover® technology and through this, were the winner of the BoR/USACE “Guardians of the reservoir challenge” with the judges being “impressed” on our achievements. Specialties of the patent protected equipment are:

1. Sediment is being continuously sucked in (similar to dredging) and being transferred to (a) the water intake/turbines or (b) directly downstream or (c, not displayed here) sediment treatment ashore.
2. The sediment mass transport can be adjusted to the downstream rivers transport capacity or other criteria. The sediment transfer is being continuously measured for environmental compliance, optimal equipment usage, and proper online documentation. By this, we re-establish a near-nature sediment continuity.
3. The vessels are designed for autonomous operation, allowing not only unmanned operation and thus cost efficiency, but also multiple effective operation time (virtually 24/7) compared to conventional dredging (8/5).
4. The equipment is scalable with single or multiple vessels, serving any reservoir size. It can be used solitary or in combination with land management/watershed protection, sluicing, sediment treatment or conventional techniques.
5. The SediMover® does not interfere with reservoir operation, not even during installation. It does not conflict with and preserves recreational functionality and navigation.

6. The SediMover®'s modular design allows for different collection technologies and working depths, pump capacities and types, alternative or parallel transfer options, easy equipment transport and installation, simple adaptation before and during operation, simplified on-site maintenance and spare part stocking.

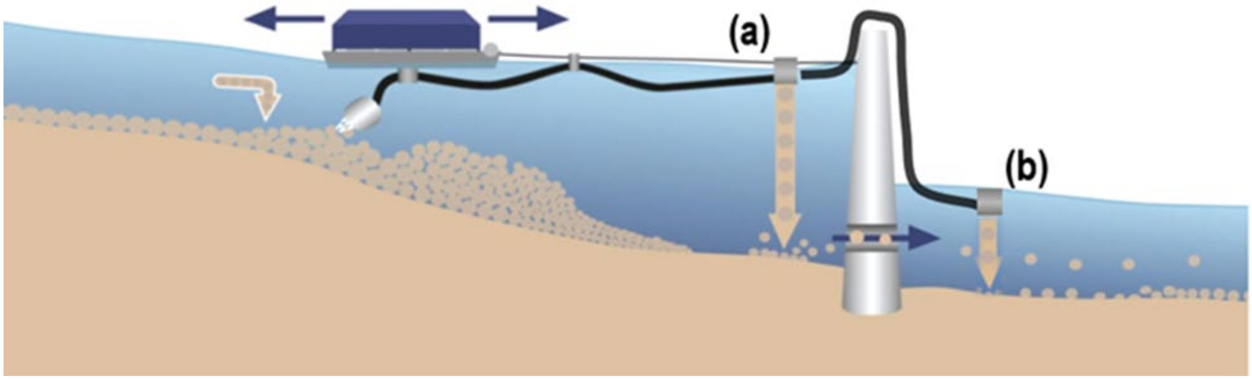

Figure 4.25 Conceptual Application of the D-Sediment and Hülskens Sediments SediMover® Technology

To put it to the point: Applying the SediMover® technology is a no-regret. The earlier you start, the more cost effective it will be. We already demonstrated the applicability in real-scale commercial projects. Exceeding this, we helped to establish public guidelines for application of the technology in cooperation with official stakeholders, including dimensioning and dealing with eventual sediment contamination.

Concerning Lewis & Clark Lake, we suggest to starting a pilot application close to the dam and then to extending range and capacity towards the delta front. By this, it is fitting perfectly into the so far discussed options at MSAC. By our technology we cannot only slow down the rate of sedimentation, but sustainably maintain the reservoir. We can do so only by this technology and in combination with other techniques.

And there is more to come: We are extending our technology to make use of "harvesting" methane emissions from sediment and are then performing practical climate protection, patent pending.

Further information is available at www.huelskens-sediments.com or in a video demonstration at https://youtu.be/5nqG4qT6e1w.

Additional points:

- One very important feature of the system is its ability to imitate a near-nature-sediment-transfer by data connection to the reservoir's outflow information, considering the actual downstream river's transfer capacity for sediment. By this, we prevent to overload the downstream river and at the same time allow an efficient and smooth sediment transfer and equipment utilization. A windfall profit is the data transparency of our system, allowing operators as well as authorities to monitor the system and the sediment transfer.
- In addition, the SediMover system has some more features, such as its ability to have it combined with classical dredging, if required. This is even increasing its utilization.

- Make use of the modular character of the system:
    - Conduct a basic layout study
    - Start with an initial (1) SediMover close to Gavins Point Dam
    - Gain experience on the situation at Lewis and Clark Lake
    - Extend the operation step-by-step to reasonable scope (discharge and transfer distance), including operational and economic optimizations.

4.2.1.3 3 D Dredger Team™ - (Prometheus Innovations LLC and Hydro Maintenance Service)

Note: Section 4.2.1.3 was authored by the manufacturers of the 3 D Dredger Technology. Statements made herein may not align with those by the Omaha District, US Army Corps of Engineers.

The 3 D Dredger™ (3DD) is a fully autonomous dredging system created by Swiss engineering firm Hydro Maintenance Service and developed in collaboration with Prometheus Innovations, LLC. The 3DD is designed to handle any sediment composition as well as larger debris using a selection of three dredging attachments. The system is designed for deployment in any environment and water body geometry, without impacting facility operation nor recreational activities. The system operates over a programmed path utilizing a real-time kinematic global navigation satellite system coupled with an inertial navigation system to monitor its position and movement around a moored pattern. The system can incorporate an on-board bathymetric mapping system to determine progress of sediment excavation. The fundamental goal behind development is to create a sediment removal solution capable of restoring both the original basin geometry as well as the downstream sediment distribution to pre-facility sediment loads without negatively impacting the environment.

System Operations and Capabilities
The system is a small footprint, modular, portable design with a triangular footprint of 26 feet per side, a height of 16 feet, and a draft of 6 feet. A 3D render of the floating platform is provided in Figure 4.26.

Figure 4.26 3D Render of the 3 D Dredger™ System's Initial Floating Platform Design

The current system can only be deployed in areas of 100 ft x 100 ft at minimum; however, as the dredging template can consist of any number of anchor positions, no upper limit to the size of the dredged area exists. Therefore, the system is capable of managing sediment in a reservoir of any size and geometric configuration.

Total Packages and Depth Capabilities

The 3DD is designed to remove sediment and debris material using one of three attachments fitted to a vertical winching system on the bottom of the central column of the floating platform deployment. …

These dredging tools are capable of operating in water depths ranging from 12 feet to 650 feet and are each designed with a specific purpose in mind. …

Overview of Application at Lewis and Clark Lake/Gavins Point Dam

The 3 D Dredger™ sediment management solution has an application for the sediment issues at the Lewis and Clark dam reservoir because it is a system that is intended for semi-permanent installation so that it can be utilized by the owner to continuously, on a short period activation, work to manage sediment inflow. The 3 D Dredger™ has a floating unit and separator price point in the range of a single conventional dredging spread mobilization and because it is a robotic, autonomous system, it does not require a crew complement other than a single observer for control oversight. The cost of the floating platform and hopper/separator system includes installation and training for the owner's staff and HM Service provides support and maintenance on demand for situations that arise that are beyond the capabilities of owner trained staff.

In a very high-level general overview, we estimate that the 3 D Dredger™ will need to be activated approximately every 90 days and operate for a 30-to-45-day period to manage the sediment inflow of 4 million yd3 per year. This assumes a fairly constant sediment inflow which is not likely so this will need to be adjusted to accommodate periods of higher and lower sediment inflow.

The 3 D Dredger™ sediment management solution seems like it would be the most cost-effective solution for the Lewis and Clark dam reservoir and can be scaled up if desired by the owner to achieve original basin geometry in a short duration effort and also manage sedimentation upstream and downstream at critical points simultaneously in a cost-effective manner. This is simply done by adding 3 D Dredger™ units. This is an option to consider but the owner should also be aware that the 3 D Dredger™ is a modular unit and portable with modular transport in five Conex containers that can be carried by truck, train or barge so that the system can be deployed easily at various locations along the stream trace where shoaling is desired to be managed.

This method of sediment management could extend the lifespan of the reservoir indefinitely while also restoring the streamflow sediment condition in the downstream environment, providing a holistic approach to basin restoration and sediment management with an incorporation of the technology into the regular general operation and maintenance of the reservoir, dam, and stream.

We are currently in negotiations with a major international shipbuilder to fabricate and construct the 3 D Dredger™ system at one of its US shipbuilding sites under license from our organization and should have an agreement in place by early 2023. This will shorten the delivery time for the system as well as potentially reduce costs.

4.2.1.4 Slurry Pulsejet & Capsule Pipeline Technology – Mazdak International

Note: Section 4.2.1.4 was authored by the manufacturers of the Slurry Pulsejet Technology. Statements made herein may not align with those by the Omaha District, US Army Corps of Engineers.

The accumulation of sediments in reservoirs often occurs at depth in excess of 50 ft. The Guardians of Reservoirs identified that existing technologies are not very efficient to dredge sediments from 50 to 200 ft. Many suction dredgers are limited to depth of 50 ft. Clamshell systems spent half the time lowering the empty bucket and swiveling the crane to stows.

Mazdak International Inc, with a team headed by Baha Abulnaga, P.E, operates a slurry research lab in Washington state. Inspired by the concept of an internal combustion liquid piston engine, a new invention called “slurry pulsejet engine” was developed. This is the first internal combustion slurry engine ever developed.

The engine is mounted on a platform and lowered to the depth of 200 ft. The entry of slurry into the cylinder is through a check valve. On the inlet side, the pressure consists of the static head of water above the layer of the sediments. For the discharge to surface the pressure increases due to the density of the slurry mixture. The engine must therefore overcome the pressure difference between upstream and downstream. This is done by feeding the cylinder with compressed air from a mother ship. The air enters through a solenoid valve. A separate line brings a gaseous fuel such as natural gas, or propane. After that compressed air forms a plenum on top of the slurry, the air solenoid valve closes, then fuel is brought in through a separate solenoid valve, and after it closes, a spark is ignited electronically. The detonation creates a pulse and expands the air and fuel mixture, pushing the slurry in the cylinder to the discharge pipe. Following this pulse, the expansion of the gases causes a low-pressure situation, the exhaust valve is opened, and the inlet check valve opens automatically allowing a new volume of slurry to enter the pulsejet engine.

For example, for slurry with specific gravity of 1.21, dredging slurry at 200 ft, the water column on the suction is at 91 psi, but the discharge pressure to raise the slurry would be at 108 psi, so the pulse differential pressure would be 17 psi. The air fuel detonation must therefore raise the pressure to 108 psi. For a site like Hoover Dam at a depth of 600 ft, the differential pressure would be 53 psi.

The engine can be built from 24“ to 84“ cylinder bore in single cylinder or multiple cylinders in parallel for various volumes of solids. It is connected to a mother ship using flexible HDPE pipes, that can be purchased to 300 psi rating.

Slurry is discharged to a sump on the mother ship and further conveyed through booster pumps and floating slurry pipeline from upstream to downstream the dam.

These sediments often entrap organics that decompose by anoxic fermentation into biomethane leading to emissions 25 folds more potent than carbon dioxide as greenhouse gases. There are enough methane emissions from water bodies, rivers, lakes and reservoirs to cover the entire needs of the Earth in electricity. As the technology for collection of methane from reservoirs evolves, the slurry pulsejet engine will be able to use the collected methane.

Mazdak International Inc is now looking for a site to conduct field tests.

Mazdak International Inc is developing separately from the competition, a new method to transport the sediments, by encapsulating them. The hydraulic capsule pipeline received a separate grant from the National Science Foundation as SBIR Phase I. It is currently applying for Phase II and has approached MSAC for a site to conduct Beta tests.

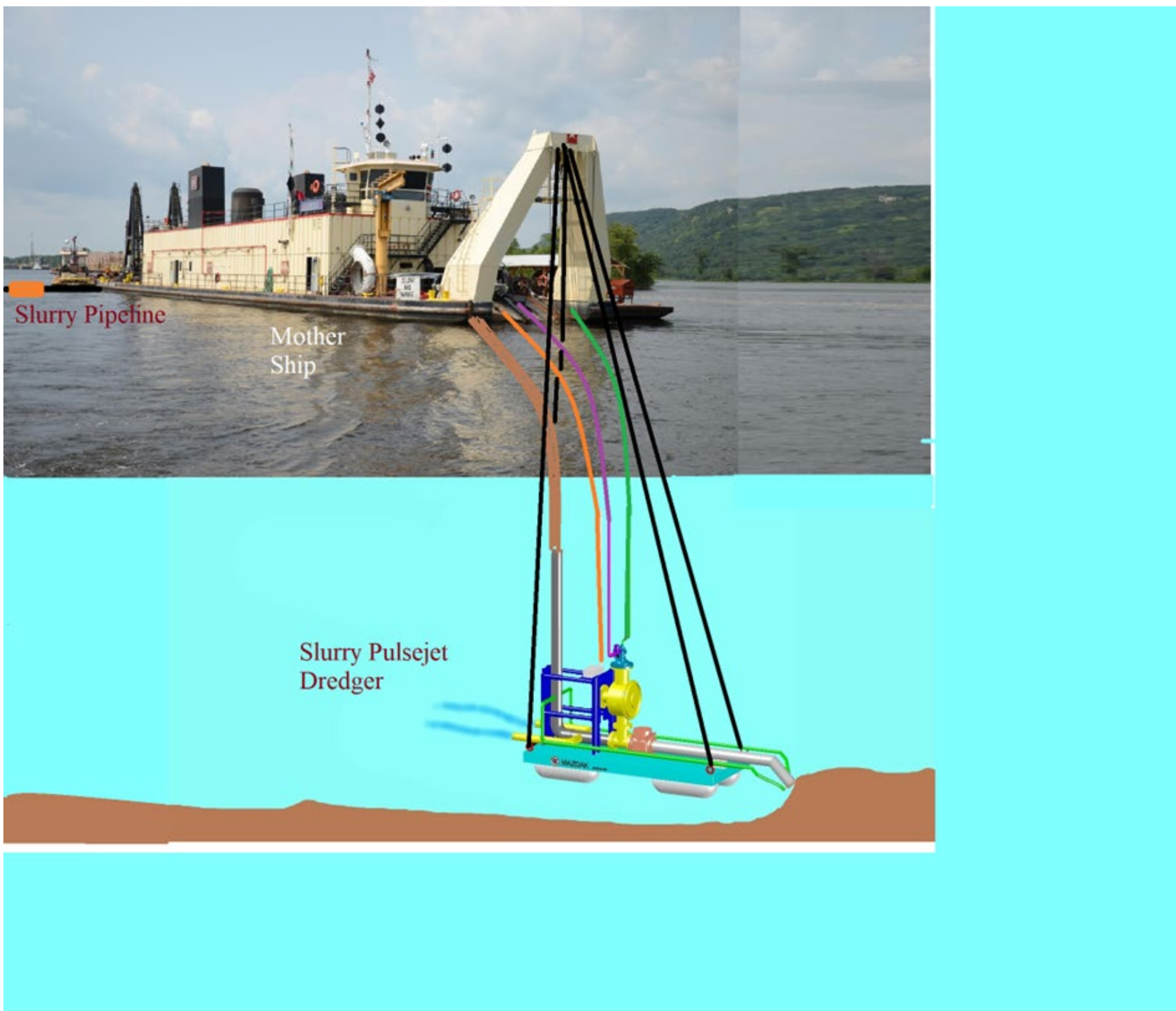

Figure 4.27 Mazdak International Slurry Pulsejet Dredger

Additional Information:

- (Delta Sediments) – The sediments from any conventional mechanical system such as clamshell, or dewater the slurry from a suction cutter dredger, or pulsejet engine and could be fed into capsules and sent by pipelines. Capsule pipelines require 40% less water than slurry pipelines. There is no abrasion in the pipeline as the sediments are fully encapsulated and in case of droughts the water can be returned upstream after the capsules are emptied of sediments. Mazdak has applied to SBIR (Small Business Innovation Research) Phase II to continue research of the Capsule Pipeline. This is not part of the GOR challenge.

- More information: https://westerndredging.org/images/proceedings/2022/1C-4.pdf and https://westerndredging.org/images/proceedings/2022/2C-5.pdf

4.2.2 Conversion of a Missouri River Dam and Reservoir to a Sustainable System

This conceptual solution was identified by the sponsor team and is summarized here for consideration of further study in Phase Three.

A paper published in 2009 by Coker et. al., discussed the development of a sustainable sediment management system for Lewis and Clark Lake using remote and autonomous material handling equipment. The summary of that paper and considerations for implementation is provided here.

4.2.2.1 Management Action Background

At the request of the sponsor, the management actions presented in a paper from the Journal of the American Water Resources Association, published August 2009, and titled “Conversion of a Missouri River Dam and Reservoir to a Sustainable System: Sediment Management” by Coker, Hotchkiss, and Johnson (Coker, et. al, 2009) are reviewed for consideration as a method to be evaluated more closely in Phase Three of this study.

4.2.2.2 Description

The management actions proposed in the paper are generally conceptual in nature from an engineering standpoint. But enough detail is included for the authors to develop a general cost profile for the actions based on known information at the time. The goal of the paper is to present a possible set of management actions that could be justified by showing benefits that exceed project costs.

The economic analysis presented in the paper was not reviewed by USACE before publication and this summary considers only the engineering and management aspects of the proposed actions.

The proposed actions are parsed into four phases:

Phase I: Lowering of the Reservoir Bed

The deposited material at the delta face in Lewis and Clark Lake, predominantly sand and silt, would be captured by a remotely operated pipeline loader. Two pipeline loaders are proposed, a sand loader for Phase I, and a second silt and fines loader for use in Phase III. The sand loader would be a tracked, amphibious vehicle that will load sand from the delta face, sandbars, and river channels up to an operating depth of 1.2 meters. The sand loader would discharge material onto off-channel delta deposits, effectively lowering the channel water surface for the river reach upstream of the pool. This material would then be shaped by an autonomous vehicle and protected from re-entrainments by Geotubes® or similar protective devices.

This phase is proposed to move twice the annual sediment inflow rate, which would approach 10-million cubic yards, with a goal of moving to a maintenance condition within a decade.

Phase II: Maintaining the Lowered Bed

Using the same equipment as phase I, the lowered bed would be maintained through continued placement of material on off-channel areas. This phase is proposed to be at an equilibrium sediment inflow rate (approximately five-million cubic yards per year), effectively holding the location of the delta face for multiple decades.

Phase III: Topping the Relocated Sand with Silt and Clay and Moving Incoming Sand Downstream

This phase has two major actions: first would be the use of the Silt and Clay loader to top the sand deposited on the off-channel delta areas that was placed in phases I and II. The silt and clay loader is expected to be a barge-mounted autonomous vessel. The goal of this process would be to continue to remove sediment from the pool, thus extending storage life, while at the same time adding some geotechnical stability and possibilities for diverse land use to the off-channel sediment storage areas.

The second action would be the construction of a sand trap in the river reach just above the reservoir pool. This structure would be built to discharge normal river flows over a concrete weir with earthen embankment wings, providing a settling location for bedload and some suspended sand fraction. Mechanical or hydromechanical removal to a pipeline and delivery to downstream discharge in the Missouri River would become a permanent part of the system.

Phase IV: Moving of All Incoming Sediments Past the Dam

Once all previous phases are completed and active removal and transport of sand from the constructed trap in Phase III is ongoing, the system as conceived would appear to offer a fully sustainable condition. In the event that the trap efficiency of the sand trap is not 100 percent, it is possible that the sand loader and silt and clay loaders may be needed intermittently to maintain sediment transport equilibrium through the reservoir project.

4.2.3 Considerations for Inclusion in Phase Three Analysis:

1. The development of multiple autonomous dredging platforms over the past decade (see sections on D-Sediment and 3D Dredger from the Guardians of the Reservoir Competition, section 4.2.1.2 and 4.2.1.3) have proven that real world applications of the conceptual equipment proposed in this paper are likely more possible now than in the past.
2. Numerous construction equipment manufacturers are developing and marketing autonomous heavy earthmoving and agricultural equipment. For development of the Pipeline Loader, Sand and Silt Loaders, and Spreading Machine, these companies, including John Deere, Caterpillar, Komatsu, Liebherr, and others should be contacted, and their experience leveraged.
3. The development of a full economic inventory and benefits analysis in Phase Two should allow for an updated economic analysis of the proposed actions once some refinement on equipment development and operating costs can be completed.

4. The removal of sediment at lower elevations within the reservoir pool and placement above the normal pool elevation would impact the storage in the flood risk reduction pool above elevation 1208.0 feet (NGVD 1929), and not allowed under existing guidance. As part of any feasibility analysis, the impacts on storage volume within the multiple pools must be considered and sites for placement outside the project boundary identified.
5. The construction of a sediment trap structure in the river reach above the pool may have significant impacts on pool storage and inundation due to backwater effects. The design of such a structure should be developed in more detail and impacts assessed.
6. The numerical model developed for the Drawdown Sluicing management action could be updated and modified to simulate the lowering of the channel invert and placement of sediment, included in Phases I, II, and III, through the modification of the model geometry. The sediment trap structure from Phase III and the Phase IV sustainable state of "Moving All Incoming Sediments Past the Dam" could then be simulated.

4.3 Time Horizon for Implementation

Lewis and Clark Lake and the Missouri/Niobrara River reach directly above it have been capturing sediment since closure in 1955. The process is a chronic one, with sediment depositing or redistributing under all flow conditions. With nearly 70 years of sediment collected in the reach, a single solution to immediately return the lake to the 1955 condition at initial closure would be extremely invasive, expensive, and could result in a significant loss of benefits for an extended period. That closure condition included shallow 'open water' upriver to just past Springfield, SD without Missouri and Niobrara River deltas. Incremental progress towards the goal of sediment equilibrium should be considered with short-term, medium-term, and long-term goals. In addition, ongoing management actions that will need to be taken across the entire timeline are identified.

4.3.1 Continuous/Ongoing Management Actions

- Remove sediment as necessary to maintain lake, irrigation, and drinking water access.
- Engage leaders from South Dakota, Nebraska, and Federal legislators to identify new authorizations and appropriations to support short-, medium-, and long-term sediment management.
- Update the Lewis and Clark Lake Sediment Management Plan with new actions and data.
    - Update economic analysis of hydropower benefits, recreation including National and Regional values, and impacts and costs due to sedimentation.

4.3.2 Short-Term Goals

No changes in water and sediment management are expected from the Operations of Gavins Point Dam in the short term. Flow will be regulated based on upstream flow and storage in the Missouri River system, as they have been in the past. In Section 5.8, near-term costs associated with sediment management are summarized. These costs, outside of the Highway 12 construction, are associated with maintenance of existing access points, and possible costs associated with flood events that cannot be well predicted.

During the short-term window of 0-10 years, sedimentation will advance in all directions from the delta. The primary area of concern will be the Lazy River Acres area on the Missouri and the Cedar-Knox Rural Water supply intakes in Lewis and Clark Lake. The following actions are suggested as short-term sediment management actions:

1. Complete Phase Three of the Lewis and Clark Lake Sediment Management Study to create a roadmap for all the following actions within 24 months of project start.
2. Develop a plan and collaborate to relocate or manage sediment at the Cedar-Knox Rural Water District (RWD), BY-Water, and City of Springfield, SD, water intakes.
3. Assess the risk of flooding at Lazy River Acres and Niobrara using new survey data along with other areas including Bazile Creek, and other recreation areas, roadways, property, and infrastructure in both states. Upcoming USACE actions include:
   - Update a future conditions analysis from 2012 in 2023-24 with predictions of future conditions through 2070.
   - Expand the analysis to examine the impacts of sediment from Lewis and Clark Lake transported to the downstream Missouri River channel.
   - Update USACE analysis of reservoir flushing/sluicing with new survey data.
4. Establish multiple pilot projects to test current and emerging technologies to manage sediment.
5. Conduct Economic Analysis of dam decommission at End of Life and update economic analysis of recreation, agricultural, and non-agricultural uses, and environmental impacts. This analysis should be updated throughout the life of the reservoir to determine when management actions become financially feasible.
6. Engage leaders from South Dakota, Nebraska, and Federal legislators to identify new authorizations and appropriations to support medium- and long-term sediment management.

4.3.3 Medium-Term Goals

For this discussion, medium-term is considered 10-20 years from the date of this report.

The following actions are suggested as medium-term sediment management actions:

1. Update the Lewis and Clark Lake Sediment Management Plan with new actions.
2. Remove sediment as necessary to maintain lake access.
3. Institute active sediment management actions to capture and transport sediment to below Gavins Point Dam from area(s) of greatest impact. Transporting up to 50 percent of the annual sediment load should be set as a goal.
4. Engage leaders from South Dakota, Nebraska, and Federal legislators to identify new authorizations and appropriations to support medium- and long-term sediment management.

4.3.4 Long-Term Goals

During this term (20-50 years from date of this report) the value of continued operation of the hydropower facility will likely be evaluated. The increasing development and use of renewable electricity supplies may change the economic analysis of hydropower. The Lake will also pass 50 percent of storage loss, and some sediment management actions that were not practical in the short- or medium-term may become viable. These actions may still not provide a complete sediment equilibrium but may be cost effective to reduce the annual sediment deposition in the lake and effectively extend the life of the remaining benefits. The condition of the lake, reservoir, and surrounding areas, both from an economic and environmental perspective is difficult to predict for the next century. Social, economic, environmental, and political priorities may change and influence the future of Lewis and Clark Lake. If the project still provides sufficient benefits, and some sediment management has been instituted in medium-term actions, the Lake may reach a new equilibrium state with the retention of a limited set of benefits.

Also, under consideration in the long-term is the condition and management changes to the other reservoirs in the upper Missouri River basin. While none are impacted by sediment as much as Lewis and Clark Lake, all will be significantly more impacted than they are currently. Directly upstream, Fort Randall Dam and Lake Francis Case could experience 30 to 40 percent total storage loss, based on the historical trends as of 2022. Upstream management changes to address sediment at that project could have a significant effect on the Lewis and Clark Lake reach. By the time long-term actions are being considered, sediment management upstream on the Missouri will become an integral part of management decisions.

1. Update the Lewis and Clark Lake Sediment Management Plan with new actions – integrating upstream sediment management.
2. Complete an updated economic analysis of hydropower benefits.
3. Remove sediment as necessary to maintain lake access.
4. Increase sediment balance goal to manage up to 100 percent of incoming sediment, establishing an annual equilibrium that will maintain the remaining benefits.
5. Engage leaders from South Dakota, Nebraska, and Federal legislators to identify new authorizations and appropriations to support long-term sediment management.

5 ECONOMIC INVENTORY AND BENEFITS

Lewis and Clark Lake is a multipurpose project that provides many benefits to the Nation and the surrounding regions of South Dakota and Nebraska. The main business lines that the project is authorized for include flood risk management, hydropower, irrigation, navigation, recreation, and water supply. For a more detailed discussion of the economic accounts, please see Appendix A.

5.1 Flood Risk Management

Lewis and Clark Lake provides downstream benefits for flood risk management, and the flood risk pool is operated between the elevations of 1206 and 1212 feet. The project is part of a system of six reservoirs along the Upper Missouri River that work together to provide reduced flood risk for the Upper and Lower Reaches of the Missouri River. Because Lewis and Clark Lake will only be operated between the 1206- and 1212-foot elevations for flooding events and not normal operations, the increased sedimentation within the lake is not expected to have a significant impact on the reservoir's ability to provide flood risk mitigation downstream.

5.2 Hydropower

The Gavins Point Dam hydropower plant generates 726 million kilowatt hours of electricity annually, which equates to $19,239,606 worth of power. Should the sedimentation behind Gavins Point Dam continue, sediment would begin to stack behind the embankment walls and eventually reach the powerhouse intake gates, rendering the dam inoperable. It is estimated this would occur in the 2080s, based on current rates of sedimentation.

5.3 Irrigation

There are currently more than 32,427 acres irrigated in South Dakota and 3,389 acres irrigated in Nebraska from the Missouri River between Fort Randall Dam and Ponca, Nebraska. The increased sedimentation of Lewis and Clark Lake will decrease the access of water to many farmers. While these permit owners could extend their intake pumps farther out from the existing shore to accommodate the shrinking channel, they could also receive water from a well. When considering alternative sources of water, USACE Engineer Regulation (ER) 1105-2-100 requires researching the least-cost alternative for other sources that meet the same needs as existing sources. The economic analysis assumes that farmers will switch from an intake on the lake to a new well. The total cost for farmers in both South Dakota and Nebraska of switching from their current intake on Lewis and Clark Lake to a new well totals $714,281.

5.4 Navigation

Because the benefits that navigation accrues come from reaches below Gavins Point Dam, there are not expected to be any effects to navigation benefits as a result of increased sedimentation of Lewis and Clark Lake.

5.5 Recreation

The estimated number of visitation days to Lewis and Clark Lake and the surrounding recreation areas totaled 1,033,079 in 2021. It is likely this number would continually decline over the next 150 years as the lake fills with sediment. Visitors would recreate at other reservoirs, either nearby ones in South Dakota, or others farther away in neighboring states. Based on a 2023 unit day value (UDV) of $32.86 as defined in ER 1105-2-100 and Economic Guidance

Memorandum 23-03, the current annual economic benefit from recreation is $33,946,974. There are two different types of recreation that occur on Lewis and Clark Lake: water-specific and general. The water-specific recreation will decline faster than the general recreation number of visits because the lake's sediment level will directly impact water-specific recreation. Water-specific activities such as boating, skiing, swimming, angling, and water-specific sightseeing will see a larger year-over-year loss of benefits compared to non-water-specific activities. It is estimated that in the year 2150 the lake will be completely full of sediment. In this year, there will no longer be any water-specific recreation, and visitation will be limited to 122,056 non-water-specific visits to the lake, which involves activities such as camping, picnicking, and sightseeing. Assuming that both types of recreation decline at a constant amount, $1,025,582 in recreation value will continue to be realized at Lewis and Clark Lake. This is a loss of $7,654,905 annually from the year 2150 onward.

5.6 Water Supply

The water supply for nearby towns and rural areas will likely be threatened by increased sedimentation on Lewis and Clark Lake. There are several water intakes on Lewis and Clark Lake that will be affected under the future without action alternative. The four main water intakes included for NED analysis are the B-Y RWD intakes, and two Cedar-Knox County intakes. These provide water for municipal, rural, and industrial uses and not a single user. To keep these projects operating, they must be modified to either utilize a different water source or reach farther into the new channel. This economic analysis estimates that new water intake systems will need to extend into the middle of the existing lake, as the lake will be reduced to riverine conditions due to increased sedimentation. Between new pipes and pumping mechanisms, it would cost a total of $411,672 to reliably supply water for B-Y RWD. The combined cost for the B-Y and Cedar Knox intakes is $693,948. These costs would occur sometime between 2090 and 2110.

5.7 Other Economic Costs

Other economic costs include the agricultural and structural buyouts that will likely occur should the sedimentation in Lewis and Clark Lake remain unchecked. One of the biggest issues with sedimentation upstream is the rising water table that causes more frequent flooding. There are 5,620 acres on the Missouri River that that would require a buyout sometime within the next 150 years. This would result in a total cost of $21,432,671, without present valuing. There are also 1,160 acres at risk from increased sedimentation on the Niobrara River. The total value of this agricultural land is $4,424,284. The combined number of acres that will likely need to be bought out under the future without action condition totals 6,780. The total (not present valued) cost for lands along the Niobrara and Missouri rivers is $25,856,955. This report assumes the cost of buyouts will be incurred equally across all 150 years of the project. For the land along the Missouri River this results in $104,805 worth of land being bought each year. For the land along the Niobrara River, this results in $21,635 worth of land being bought each year.

While there will likely be agricultural buyouts as the sedimentation behind Gavins Point Dam increases and pushes the water tables higher upstream on the Missouri River, there could also be structural buyouts. The total depreciated replacement value of the structures on the Missouri River upstream section is $54,289,762, for the Niobrara River that value is $1,827,231. For structural buyouts, only the value of the property itself is considered, while content and vehicle values associated with the structures are excluded.

5.8 Estimate of Near-Term (20 year) Sediment Impact Costs

The biggest drivers of near-term sedimentation impacts are associated with structural and agricultural buyouts, as well as a gradual loss of recreation. In the next twenty years the sedimentation is expected to increase and move slowly out into the current open lake. The agricultural and structural buyouts detailed above in Section 5.7 will likely begin to occur in at least a ten-year window. Losses to recreation are also expected to begin declining as there will be fewer acres of open lake on which to recreate. Near-term sedimentation impact costs could total nearly $20 million.

5.9 End of Reservoir Life Scenarios

There are three potential “end of life” scenarios that could occur if the lake is completely full of sediment at the end of this study period. These three options were developed by USACE Omaha District water control and systems engineers and are displayed below. These are very coarse estimates. Additional analysis should be considered for Phase Three to refine these estimates.

- **Option 1:** Gavins Point operates as a re-regulation dam with a small pool only for flood storage. It would exist mainly to support navigation operations. The dam safety program would continue as well. All other benefits of the reservoir would be lost. The cost of this would remain low, approximately in line with current USACE expenditures for dam operation and maintenance.
- **Option 2:** The structure would remain intact; however, there would be no active management of the pool. All other benefits of the reservoir would be lost. The cost of this would remain low, approximately in line with current USACE expenditures for dam operation and maintenance.
- **Option 3:** Removal of the embankment and a return to a more riverine flow for this portion of the Missouri River. This would occur over a period of at least forty or more years, so that sediment can be slowly released back into the system. This would cost between $200 million and $1 billion over the course of these forty years.

5.10 Framework for Applying Life Cycle Economics

Traditional USACE Net Present Value (NPV) methodology involves using a single interest rate that discounts future values based on the current Federal interest rate. This is the exponential discounting function and is the formula Microsoft Excel uses to calculate functions such as Present Value (PV) and Payment (PMT). This analysis presents the NPV using this classic, or exponential discounting, but also uses eight other methods for discounting future values[1]. These other discounting methods include the Ramsey, Hyperbolic, Quasi-Hyperbolic, Gamma, Weibull, Green Book, Intergenerational, and Logistic formulas for discounting. All these equations use the FY2022 Federal discount rate of 2.25 percent, except for the intergenerational discounting rate, which uses a variable interest rate.

[1] Harpman, David A. (2014). Discounting for Long-Lived Water Resource Investments. Bureau of Reclamation Technical Memorandum Number S&T-2014-X3574 and Manuals and Standards Report M&S-2014-G4129. U.S. Department of the Interior, Bureau of Reclamation. Denver, Colorado.

These nine methods of discounting are used to find the present value of the lost benefits in each year from the beginning of the study period to the end of the study period. These discounting methods are used to describe how dollars spent or saved today are valued differently than dollars spent or saved tomorrow, or at some point in the future. Some of these equations may be preferred for understanding the benefits of reservoirs from a life cycle approach, because they value dollars in the future closer to the value of a present-day dollar.

5.11 Summary of Economic Analysis

As a whole, this report and analysis find that actional projects can be commenced on the lake should they cost less than approximately $3.5 million annually, based on discount rates and methods mandated by USACE policy. Other methods that were explored in this analysis return between approximately $1 million (Ramsey) and $24 million (Gamma) for annual benefits that could be saved by keeping the reservoir as is. It is important to note, however, that the inclusion of a dam decommissioning project, while unlikely, could have an effect on these results. In terms of end-of-life for the reservoir, this report highlights three potential options the U.S. Army Corps of Engineers has when considering what tasks to perform. Further efforts and analyses could explore how these potentially add into the saved benefits the project accrues.

6 ENVIRONMENTAL CONSIDERATIONS

This section will provide a general overview of environmental considerations and impacts associated with the alternative methods evaluated in this study. As this study is not leading to a proposed project to be implemented or construction, a detailed environmental impact analysis is not warranted at this phase. The purpose of this phase is to broadly consider the environmental impacts of the array of sediment management methods to determine what detailed analysis, coordination, and information is needed in the next phase, and identify important resources to consider. If a future project is proposed to be implemented, an analysis conducted in compliance with the National Environmental Policy Act (NEPA), and other applicable environmental laws, regulations, and policies would be required. Coordination with and reviews by Federal, state, and local agencies, Tribes, and the public would be completed during the process of proposing a project for implementation.

As described in Section 2.1 and shown in Figure 2.1, the large study footprint includes multiple waterbody resources and crosses two states, Nebraska and South Dakota. The environmental considerations in this section are limited to this current study footprint.

6.1 Environmental Setting

6.1.1 Waterbodies (Streams, Rivers, Lakes) and Wetlands

The study footprint includes the following main waterbodies: Missouri River, Lewis and Clark Lake, Lake Yankton, Niobrara River, Verdigre Creek, Bazile Creek, Ponca Creek, Emanual Creek, and Choteau Creek. All but one of these waterbodies (Choteau Creek) are listed as impaired under 303(d) of the Clean Water Act (CWA), mainly due to *E. coli* restricting Primary Contact Recreation. The Missouri River downstream of Gavins Point Dam is 303(d) listed in Nebraska for Public Drinking Water Supply due to Arsenic and Sulfate. The state of South Dakota has listed Lewis & Clark Lake as a Beneficial Use Water Class: warmwater permanent fish life propagation waters.

The study footprint also includes numerous and large areas of wetlands and deepwater habitat, including palustrine emergent, scrub-shrub and forested wetlands, as well as riverine and lacustrine wetlands. Wetlands at the at Lewis & Clark Lake are primarily located in delta areas upstream. Less extensive wetland areas are associated with the mouths of several small creeks flowing into the lake, and marginal wetlands in the upper end of the lake have formed on the many bars of silts, sands, and clays deposited by the Niobrara River as it entered Lewis and Clark Lake. These wetlands are dominated by cattail and giant reed marshes. The remaining wetland areas consist predominantly of a mixture of cattails, giant reed, rushes, and reed canary grass. Purple loosestrife is a noxious aquatic plant that has infested about one-half of the delta area in varying degrees.

The waterbodies and wetlands in the study area are regulated under Sections 404 and 401 of the CWA. Additionally, the Missouri River is a navigable water regulated under Section 10 of the Rivers and Harbors Act. Section 404 requires authorization from the Secretary of the Army, acting through the Corps of Engineers, for the discharge of dredged or fill material into all waters of the United States, including wetlands. Section 401 provides states and authorized Tribes the authority to protect the water quality of federally regulated waters within their borders, in collaboration with Federal agencies. In cases where a state or Tribe does not have authority, the Environmental Protection Agency (EPA) is responsible for issuing certification.

The study area contains designated portions of the Missouri National Recreation River (MNRR), listed and protected under the Wild and Scenic Rivers Act of 1968, 16 USC 1271 (WSRA). The MNRR designation was first applied in 1978 to the 59-mile section of the Missouri River between Gavins Point Dam downstream to Ponca State Park, Nebraska. In 1991, an additional 39-mile section between Fort Randall Dam and Niobrara, Nebraska, was added to the designation. The last 20 miles of the Niobrara River and six miles of Verdigre Creek were also added in 1991. Figure 6.1 below shows the extent of the MNRR 39-Mile District and 59-Mile District. The National Park Service (NPS) is the Federal land-managing agency with wild and scenic river (WSR) management responsibilities for the MNRR and has the responsibility for implementing Section 7 of the WSRA. Under Section 7, NPS must review proposed federally initiated or federally assisted water resources projects on designated or congressional study rivers (including those upstream, downstream, and on tributaries of the designated or study segment of the river, including those projects proposed by NPS) and determine whether such projects meet the standards established by the WSRA. Federal actions may not proceed unless the NPS has determined in writing that the proposed project fully meets the requirements of the WSRA. Consistent with the WSRA, NPS may not implement or consent to implementation of a water resources project constructed or assisted by another Federal agency if such project is found to exceed the threshold of the appropriate standard. Compensating for an impact on a WSR resource by improving the condition of other resources is not sufficient to allow a project to proceed if the appropriate standard would still be violated.

Figure 6.1 MNRR Reaches within the Study Area.

6.1.2 Vegetation

Terrestrial vegetation at the project is typical of the northern Great Plains. Mixed grass prairie is common in the uplands and some tallgrass prairie vegetation is found along the eastern shore. Eastern deciduous woodland and forest are found on the floodplains along the larger tributaries, along the free-flowing reach of the Missouri River below Gavins Point Dam, and within many of the intermittent drainages along the main stem and its tributaries. Deciduous forests and woodlands are located in uplands and draw mostly on moist aspects, along the lake shore, and in bottomlands associated with the Missouri River and its tributaries. Deciduous shrublands at the project are associated with grasslands, wetlands, drainages, and stream bottoms. The region supports medium-tall to tallgrass prairie vegetation. Emergent marsh vegetation is found along shorelines, on the larger islands, in shallow bays, in the upper reaches of Lewis and Clark Lake, and at the mouths of streams where deltas have formed. Agricultural vegetation and lands include fields managed for hay, perennial crops, wildlife plantings (mostly very small scale), annual row crops, and managed pastures with agricultural indicators observable from the imagery. Numerous noxious herbaceous weeds, listed by the states of Nebraska and South Dakota, occur in the counties within the study area.

The Nebraska side of the study area includes numerous parcels of land that have USDA-NRCS Conservation Easements, particularly at the Niobrara's confluence with the Missouri River and along the stream corridors of the Niobrara River, Bazile Creek, Verdigre Creek and Ponca Creek. These easements are administered by the NRCS under Wetland Reserve Program (WRP), or other similar programs. WRP is administered by NRCS which provides technical and financial assistance to eligible landowners to restore, enhance, and protect wetlands through 30-year or perpetual easements or restoration cost-share agreements. The goal of the program is to restore wetland functions and values to natural conditions to the extent practicable, while maximizing wildlife habitat values (see http://www.nrcs.usda.gov/programs//wrp/). Additionally, the U.S. Fish and Wildlife Service (USFWS) has conservation easements within the study area, but cover much less area than NRCS easements. Figure 6.2 below provides an overview of these easement locations (see https://nrcs.maps.arcgis.com/apps/webappviewer/index.html).

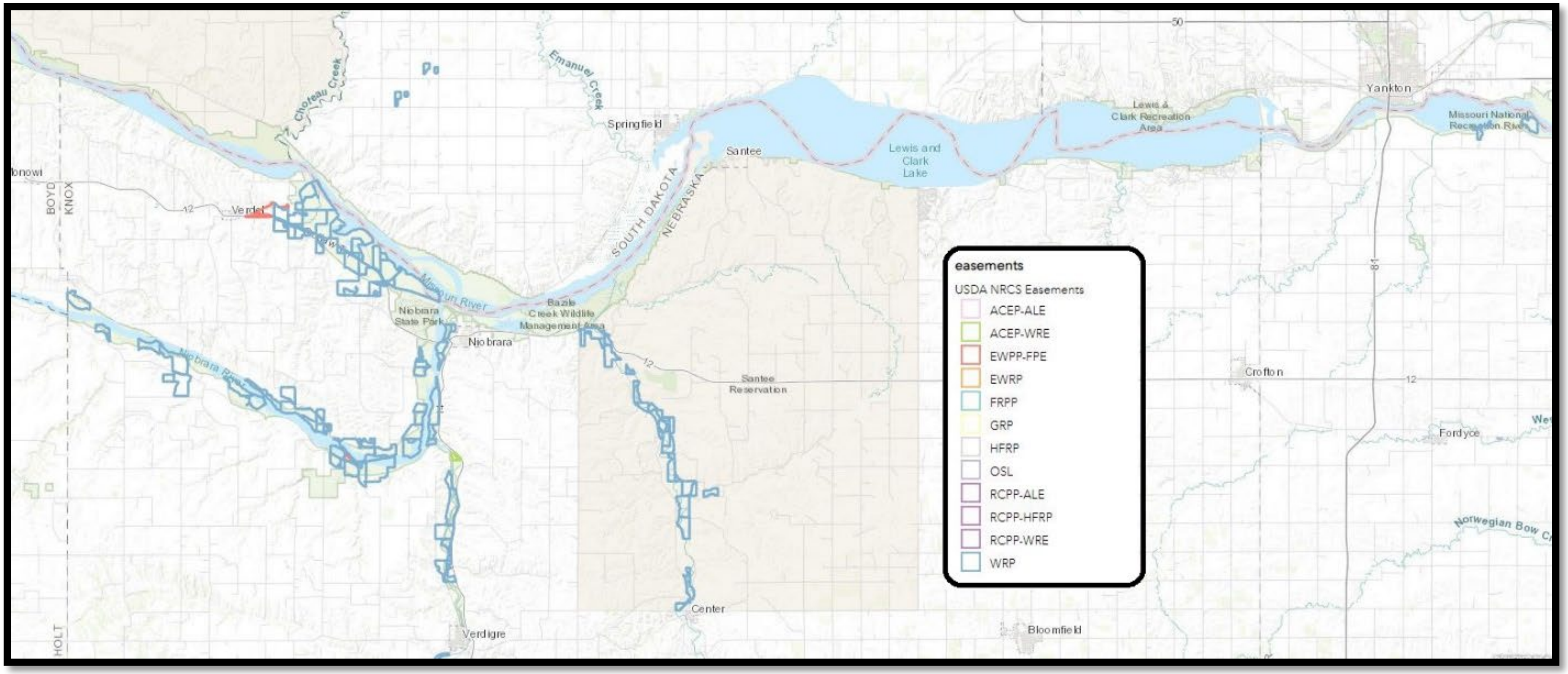

Figure 6.2 NRCS Conservation Easements within the Study Area

6.1.3 Species of Special Consideration

Federally threatened and endangered species are protected under the Endangered Species Act (ESA). The USFWS Information for Planning and Consultation (IPaC) online project planning tool was used to determine which federally listed species, critical habitats, and migratory birds may occur in the study area. The South Dakota Natural Heritage Program (NHP) and the Nebraska NHP were used for information on state-listed species and other special status species at the project. The IPaC website listed 12 federally listed species under the ESA and one designated critical habitat that potentially occur in the study area. These species and critical habitat are listed in Table 6.1 and discussed below, including one species that has been proposed for listing and one candidate species.

Table 6.1 Federally Listed Species and Critical Habitat Potentially Occurring in Study Area

Common Name	Scientific Name	ESA Listing	Critical habitat at the Project?	Expected Occurrence
Northern long-eared bat	*Myotis septentrionalis*	Threatened	No	Migrant; forested habitats, man-made structures and mines
Piping plover	*Charadrius melodus*	Threatened	Yes	Migrant, nesting; sparsely vegetated sandbars, sand and gravel mines, and reservoir shorelines
Rufa red knot	*Calidris canutus rufa*	Threatened	No	Migrant; inland saline lakes
Whooping crane	*Grus americana*	Endangered	No	Migrant; marshy wetlands and vegetated streams
Pallid sturgeon	*Scaphirhynchus albus*	Endangered	No	Missouri River, Niobrara River, Lewis and Clark Lake
Topeka shiner	*Notropis topeka*	Endangered	No	Unlikely; slow-moving small to midsize prairie streams with sand, gravel, or rubble bottoms.
Higgins eye (pearlymussel)	*Lampsilis higginsii*	Endangered	No	Possible; Missouri River
Scaleshell mussel	*Leptodea leptodon*	Endangered	No	Unlikely; Missouri River
American burying beetle	*Nicrophorus americanus*	Threatened	No	Unlikely; dependent on carrion availability
Monarch butterfly	*Danaus plexippus*	Candidate	No	Open habitats including fields, meadows, marshes, and along roadsides
Tricolored Bat	*Perimyotis subflavus*	Proposed Endangered	No	Migrant; forested habitats, man-made structures and mines
Western prairie fringed orchid	*Platanthera praeclara*	Threatened	No	Tall-grass prairie and wet meadows

Designated critical habitat for the threatened piping plover is located throughout the study area. Figure 6.1 below shows the extents of the critical habitat.

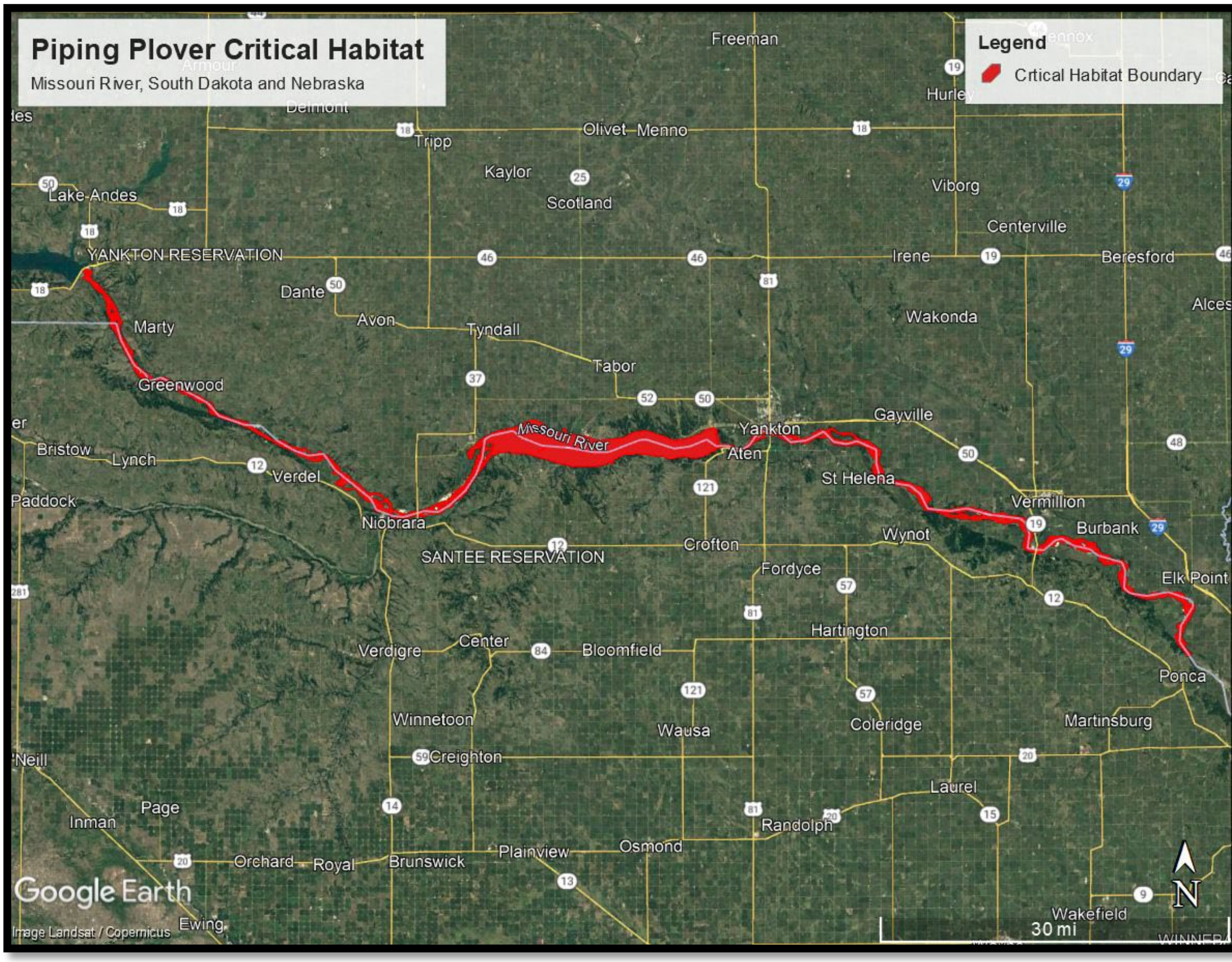

Figure 6.1. Piping Plover Critical Habitat within the Study Area.

Table 6.2 shows the state listed species for Nebraska and South Dakota for the general study area. These tables include whether the species is expected to occur, although further analysis would be required in a future study. Note that all federally listed species are also state-listed under the Nebraska Nongame and Endangered Species Conservation Act.

Table 6.2 Nebraska and South Dakota State-listed Species

Common Name	Scientific Name	Nebraska Status*	South Dakota Status*	Expected Occurrence in Study Area
Birds				
Interior least tern	*Sterna antillarum*	SE	SE	Migrant, nesting
Piping plover	*Charadrius melodus*	ST	ST	Migrant, nesting
Whooping crane	*Grus americana*	SE	SE	Migrant
Mammals				
Northern long-eared bat	*Myotis septentrionalis*	ST	n/a	Migrant
Fish				
Lake sturgeon	*Acipenser fulvescens*	ST	n/a	Possible
Pallid sturgeon	*Scaphirhynchus albus*	SE	SE	Main channel, upper reservoir
Sturgeon chub	*Macrhybopsis gelida*	SE	SE	Reservoir, delta areas of tributaries
Blacknose shiner	*Notropis heterolepis*	n/a	SE	Rare
Northern redbelly dace	*Chrosomus eos*	n/a	ST	Possible
Shovelnose sturgeon	*Scaphirhynchus platorynchus*	n/a	FT	Possible
Sicklefin chub	*Macrhybopsis meeki*	n/a	ST	Unlikely
Mollusks				
Scaleshell	*Leptodea leptodon*	SE	n/a	Unlikely
Reptiles				
False map turtle	*Graptemys pseudogeographica*	n/a	ST	Possible
Eastern hognose snake	*Heterodon platirhinos*	n/a	ST	Possible
Insects				
American burying beetle	*Nicrophorus americanus*	SE	n/a	Unlikely
Plants				
Western prairie fringed orchid	*Platanthera praeclara*	ST	n/a	Shrubland, grassland, and wetland habitat

** S = State, E = Endangered, T = Threatened, n/a = not listed as State threatened or endangered*

6.1.4 Other Fish & Wildlife

When Lewis and Clark Lake was created by the closing of Gavins Point Dam, the aquatic ecology of this section of the Missouri River was changed from lotic (living in actively moving water) environment to predominantly lentic (living in still water) conditions. The fish species now present in the lake reflect both of these ecological conditions.

A large variety of bird species either reside at or seasonally migrate through the area. Wetlands in the upper reaches of the lake contribute to the breeding environment for wood duck (*Aix sponsa*), blue-winged teal (*Anas discors*), mallard (*A. platyrhynchos*), and northern pintail (*A. acuta*). Lewis and Clark Lake is located along the Central Flyway for the North American continent. Many varieties of birds use this migratory route and rely on the diversity of habitats available in the study area. Bird species found at Lewis and Clark Lake are species associated with wetlands, shorelines, marshes, mudflats, eastern woodlands, the woodland/meadow ecotone (boundary zone), and open grasslands.

Certain birds are protected under the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act. According to IPaC, the study area contains at least 27 USFWS Birds of Conservation Concern (BCC), including the bald eagle and golden eagle. The study area provides wintering habitat for the bald eagle (*Haliaeetus leucocephalus*) near the open tailwaters downstream from the dam where an ample food supply of fish is readily available.

6.1.5 Aquatic Invasive Species

Aquatic invasive species (AIS) are non-native plants, animals, and other organisms that live primarily in aquatic habitats (i.e., covered with water all or part of the year). Aquatic invasive plants include algae, floating plants, submersed plants, and emergent plants. Aquatic invasive animals include insects, fish, reptiles, mollusks, crustaceans, and amphibians. AIS found in Lewis and Clark Lake are: European reed (*Phragmities australis*), curly pondweed (*Potamogeton crispus*), Eurasian watermilfoil (*Myriophyllum spicatum*), Asian clam (*Corbicula fluminea*), zebra mussel (*Dreissena polymorpha*), rusty crayfish (*Faxonius rusticus*), brittle naiad (*Najas minor*). Several species, including bighead carp (*Hypophthalmichthys nobilis*), silver carp (*H. molitrix*), and rusty crayfish (*Orconectes rusticus*) have not been confirmed in Lewis and Clark Lake but are known to occur below Gavins Point Dam in the Missouri River and in Lake Yankton (USACE, 2020).

6.1.6 Cultural Resources

Cultural resources are historic properties as defined by the National Historic Preservation Act of 1966 (NHPA), cultural items as defined by the Native American Graves Protection and Repatriation Act of 1990 (NAGPRA), archaeological resources as defined by the Archaeological Resources Protection Act of 1979 (ARPA), sacred sites as defined by Executive Order 13007, and collections and associated records as defined by 36 CFR 79. Cultural resources are associated with human use of an area. They may include archaeological sites, historic properties, or ethnographic locations associated with past and present use of an area. A cultural resource can be physical remains, intangible traditional use areas, or an entire landscape, encompassing past cultures or present, modern-day cultures. Physical remains of cultural resources are usually referred to as archaeological sites or historic properties.

The 2004 Programmatic Agreement for the Operation and Management of the Missouri Reservoir Mainstem System for Compliance with the National Historic Preservation Act, as amended (PA) was created to address the cultural and historic resource impacts involved with the ongoing operation and maintenance of the Missouri River system of mainstem dams. Under the PA, USACE established a program to preserve, protect, identify, evaluate, and nominate historic properties under their jurisdiction or control (including traditional cultural properties (TCPs) and historic properties to which Tribes attach religious and cultural significance) in consultation with others and to fully consider the preservation of historic properties not under their jurisdiction or control but affected by Federal agency undertakings.

USACE recognizes that sacred and cultural resources, many of which are historic properties, are critically important to the affected Tribes listed in the PA. Avoidance of adverse effects to these resources and the preservation of remaining sacred and cultural places is a high priority for USACE, regardless of the eligibility of the resource to the National Register of Historic Places (NRHP).

A large percentage of cultural resource sites at the Gavins Point Dam/Lewis and Clark Lake Project that are listed on the NRHP, potentially eligible for the NRHP, or unevaluated, have been and continue to be impacted by erosion and human activities. The normal operation of the mainstem reservoirs affects the potential NRHP status of these sites, primarily through erosion. The slumping of cut-bank soils destroys site integrity and exposes artefactual remains to the elements and depredation. Actions taken by USACE to stabilize cultural resource sites being destroyed by shoreline erosion include riprap stabilization, fencing, signage, traffic management, soil mats, vegetative plantings, barricades, offshore structures, and armoring the shorelines adjacent to the sites.

6.2 Summary of Environmental Impacts

This section will broadly consider the environmental impacts of the different array of methods described in Section 4 to determine what detailed information, analysis, agency, Tribal and public coordination is needed in the next phase. If a future project is proposed to be implemented, an environmental assessment or environmental impact statement, in compliance with NEPA would be completed.

6.2.1 Environmental Impact Considerations Applicable to All Applications/Methods

This section takes the environmental setting discussed in section 6.1 and generally addresses what potential environmental impacts could occur if these methods were to be further studied and implemented and describes anticipated coordination needs. The additional subsections below go into brief detail on some differences between each method’s environmental impacts. However, with limited information on each method, environmental impacts cannot be fully evaluated in this phase of the study.

All methods considered in Section 4 involve discharges in waterbodies, which would require Section 404 evaluations and 401 water quality certifications. Across the alternatives the larger the impact on waterbodies and wetlands, the more detailed of an analysis would be required to determine the extent of impacts, alternative measures to minimize those impacts, and resource mitigation. Conditions to minimize impacts to water resources would be required. Coordination with the state water quality authorities, EPA, and Tribes would be required for 401 water quality certifications. Conditions and best management practices to maintain and protect water quality would be required. Impacts affecting other habitat types will also require consideration through a functional analysis, and mitigation would be required where impacts cannot be avoided or minimized.

All methods would involve impacts within suitable habitat for several of the federally and state listed threatened and endangered species, compiled in Tables 6.1 and 6.2. Of the federally listed species, the two that may be most impacted by these methods are the piping plover and pallid sturgeon, which occur throughout the Missouri River, Lewis and Clark Lake, and Niobrara River. Additionally, the entire stretch of the Missouri River within this study area is federally listed critical habitat for the piping plover (see Figure 6.3). Coordination with the USFWS, Nebraska Game and Parks Commission (NGPC), and South Dakota Game, Fish and Parks (SDGFP) would be required to determine the extent of each method's impacts to listed species and conservation measures, including avoidance of work in certain locations and sensitive timeframes for the listed species. Section 7(a)(2) of the ESA requires Federal agencies to ensure their actions are not likely to jeopardize the continued existence of listed species or result in the destruction or adverse modification of designated critical habitat.

All methods would occur within or in close proximity to the MNRR (see Figure 6.1), requiring coordination with the NPS and a WSRA Section 7(a) determination. Section 7 of the WSRA prohibits Federal agencies from assisting a water resources project that would have a "direct and adverse effect" on the "outstandingly remarkable values" (ORVs) and free flow for which a river was established. A 'positive' Section 7(a) determination from NPS, including coordination with USFWS, determining that the proposed activity would not have a "direct and adverse effect" on the ORVs and free flow of the MNRR, must be obtained for a project to move forward.

All methods would involve impacts within suitable habitat for multiple species of fish and wildlife, including migratory birds, requiring additional analysis and coordination among the resource's agencies (USFWS, NPS, NGPC, SDGFP). Coordination with these agencies would also be required to analyze, minimize, and mitigate impacts to migratory birds, fish and other wildlife. Conservation measures for reducing entrainment of fish and other aquatic life would be recommended. Conservation measures for avoiding and minimizing impacts in migratory bird habitats or avoiding sensitive foraging or breeding timeframes would be recommended.

The methods that would involve activities occurring within the Niobrara River and the delta may require coordination and permission with NRCS, depending upon the locations/siting, due to the presence of numerous WRP easements in the area (see Figure 6.1.2). Permanent impacts to WRP easement areas should be avoided to the extent practicable.

All methods will require identification and coordination of approved disposal sites for the dredged material, with some proposing in-water disposal and others involving currently unknown locations or uses of the dredged material. Testing of the dredged material may be required, to determine presence and effects of contaminants.

All methods would involve at least temporary impacts to project benefits that the measures are ultimately expected to incur benefits for, such as recreation, irrigation, water supply, fish and wildlife, navigation, and flood risk reduction. A thorough evaluation of expected temporary and permanent impacts and benefits to these associated resources will be needed.

All methods would require evaluation for impacts to cultural resources, and coordination with the State Historic Preservation Office (SHPO) and Tribes under Section 106 NHPA. In compliance with Environmental Justice Executive Orders, all methods would need to be evaluated to ensure no disproportionate impacts to disadvantaged communities would occur. All methods would require proper evaluation and measures to minimize the spread of invasive species. More broadly, all methods would require analysis, coordination and compliance under numerous Federal, state, and local laws, regulations, and Executive Orders.

The three methods discussed in Section 4.2 are emerging technologies with limited information. Details and previous case study examples of these technologies' construction, operation and performance would be needed for a thorough environmental impact analysis.

6.2.2 Hydraulic and Mechanical Dredging

As discussed in Section 4.1.1, this method would involve a large dredging operation, with onsite fabrication and assembly, annual disassembly, piping for dredging, pontoon, and discharge, as well as maintenance facilities, overwintering harbors, and constant transport of workers and supplies to the equipment. The discharge of dredge material would include at least two reintroduction locations in the Missouri River downstream for the dredged sediment to limit peak concentration and reduce the risk of excessive deposition in the channel.

Dredging with long annual durations and semi-permanent installations and operation can be disruptive to many project benefits including recreation, irrigation, water supply, fish and wildlife, with the tradeoff being increased reservoir storage to support navigation, flood risk reduction, recreation, and water supply. The dredges, boosters, and excavators could be powered by electricity from either Gavins Point Dam or other local electric source, reducing environmental concerns about fuel spillage, and decrease noise.

6.2.3 Watershed Sediment Management

As discussed in Section 4.1.2, this method focuses on reducing sediment delivery to the Missouri River and Lewis and Clark Lake through watershed improvements, specifically within the Niobrara River. These watershed improvements could be a combination of grade control, bank stabilization, and erosion reduction measures, as well as conservation measures including grazing management, conservation tillage, crop rotation, contour farming, water and sediment retention structures and other conservation practices as defined by NRCS.

Environmental impacts associated with these watershed improvements will be dependent upon the scale, amount, location, and duration. Most measures would be located outside of the Missouri River and Lewis and Clark Lake, reducing direct impacts to those resources; however, direct impacts would occur on the Missouri River tributaries, wetlands, uplands, and their associated resources. The in-water conservation measures may be disruptive to project benefits such as fish and wildlife.

6.2.4 Sluicing

As discussed in Section 4.1.3, the method of sluicing involves a drawdown of the reservoir to achieve a 'run of river' condition, passing the accumulated sediment downstream through the dam spillway and forming a channel within the reservoir sediment accumulated from previous events. The methods considered above involve several augmentations to increase efficiency including lowering of half the spillway gates, the addition of sluicing tunnels at the bottom of the reservoir, a longitudinal revetment, and dredging. These augmentations would involve new construction, including modification of existing USACE infrastructure and additional environmental impact analysis. The predicted drop in reservoir pool elevation during sluicing will likely exceed 20 feet, and in the case of the scenarios with lowered spillway gates or tunnels, even lower.

Environmental impacts associated with these sluicing measures and associated augmentations will be dependent upon the scale, amount, and duration. The more augmentations added, the more potential impacts to project benefits may occur, including within the reservoir, upstream and downstream of the dam. The associated drop in reservoir pool during sluicing may impact several project benefits, including recreation, irrigation, water supply, fish and wildlife, with a long-term tradeoff being increased reservoir storage to support navigation, flood risk reduction, recreation, and water supply.

6.2.5 Bedload Sediment Collection

Section 4.1.4 discusses this method as it could be applied as a pilot project in the Niobrara River. This method would involve installation of sediment collector system installed to capture the full width of the river channel, with the specific goal of reducing downstream delivery of sediment. The installation would require one acre of riverside access, temporary dewatering, storage area, a power source, highway access, and necessary resources (e.g., dump trucks) to move the collected material to other locations. The pilot project would be in place for about two weeks.

Although a pilot study with a short duration may have fewer impacts than the other measures being considered, this measure still would require coordination and approvals from multiple agencies, due to the potential impacts to ESA species, the MNRR, wetlands and waters of the U.S., and dependent upon the location, WRP easements.

6.2.6 SediMover Technology – D-Sediment

Section 4.2.2 discusses this method as it could be applied as a pilot project near the Gavins Point Dam and move upstream towards the delta. This method involves vessels designed for autonomous operation, continuously sucking sediment (similar to dredging) and transferring it to (a) the water intake/turbines or (b) directly downstream or (c) (not displayed here) sediment treatment ashore.

Outside of a temporary pilot program, this autonomous method with long annual durations and semi-permanent installations and operation can be disruptive to many project benefits including recreation, irrigation, water supply, fish and wildlife, with the tradeoff being increased reservoir storage to support navigation, flood risk reduction, recreation, and water supply. The equipment's footprint during operation could be contained during recreation season or other sensitive periods, reducing environmental concerns.

6.2.7 3D Dredger- Prometheus Innovations, LLC

As Section 4.2.3 discusses, this method involves a robotic floating platform with a hopper/separator system designed to handle any sediment composition as well as larger debris using a selection of three dredging attachments.

The robotic dredging with long annual durations and semi-permanent installations and operation can be disruptive to many project benefits including recreation, irrigation, water supply, fish and wildlife, with the tradeoff being increased reservoir storage to support navigation, flood risk reduction, recreation, and water supply. The dredger footprint during operation could be contained during recreation season or other sensitive periods, reducing environmental concerns.

6.2.8 Slurry Pulsejet & Capsule Pipeline Technology – Mazdak International

As Section 4.2.4 discusses, this method involves a new invention called the “slurry pulsejet engine,” inspired by the concept of an internal combustion liquid piston engine. The engine is mounted on a platform, connected to a mother ship, and lowered to the depth of 200 feet. The entry of slurry into the cylinder is through a check valve. Slurry is discharged to a sump on the mother ship and further conveyed through booster pumps and floating slurry pipeline to downstream of the dam.

This technology with long annual durations and semi-permanent installations and operation can be disruptive to many project benefits including recreation, irrigation, water supply, fish and wildlife, with the tradeoff being increased reservoir storage to support navigation, flood risk reduction, recreation, and water supply. The footprint during operation may be contained during recreation season or other sensitive periods, reducing environmental concerns. The downstream slurry discharge would have impacts associated with in water disposal.

7 CONCLUSIONS AND CHARGE QUESTIONS FOR PHASE THREE SCOPING

7.1 Conclusions

Since closure in 1955, Lewis and Clark Lake behind Gavins Point Dam has been trapping sediment. The trapping efficiency has been near 100 percent for that entire time due to the size of the reservoir, incoming sediment size, flow conditions, and management. Without any changes, this condition will continue, until a time when sediment would approach the hydropower intake structure. That condition is many decades away, but as it approaches, trapping efficiency will decrease, and management options may become more limited. Aggradation and the expansion of the Niobrara River delta will continue upstream, and channel degradation and bank erosion will extend farther downstream from the dam.

Along with the reduction in water storage associated with sedimentation will be the continued loss of benefits that the project provides. To support the economic analysis in this report, estimates were developed as to when additional benefit losses may be observed. Major thresholds include impacts to hydropower in the 70-plus year range and possible loss of nearly all project benefits by the year 2100 under the current conditions and management.

To create a sustainable system and preserve as many project benefits as is economically viable, a large volume of sediment will need to be transported and/or removed. This will require a comprehensive sediment management plan that is likely a combination of sediment redistribution within the reservoir, beneficial use, and downstream reintroduction.

A workshop with subject matter experts in reservoir sedimentation and management was held in June 2021 to solicit feedback on management actions that should be considered for Lewis and Clark Lake as the starting point for a comprehensive sediment management plan. That workshop brought together experts, management agencies, the sponsors, and invited guests to see the project and go through brainstorming and screening exercises to identify sediment management opportunities. The workshop identified dredging, sluicing, watershed management, and bedload sediment collection as methods to be considered and were shared at a public meeting to conclude the workshop.

These methods were then applied conceptually to Lewis and Clark Lake as discussed in Section 4, as well as a few other emerging technologies. The list of methods is not exhaustive and new technological developments may present additional methods for consideration in the future.

In summarizing the economic benefits of Lewis and Clark Lake, the benefit analysis suggests between $1.5 and $24.2 million in benefits will be saved through the implementation of a project that keeps the current surface area of the lake clean from sediment. The economic analysis is based on generalized results in an attempt to create a broad image of the potential lost benefits that may be associated with further sedimentation. This analysis depends on several assumptions that have been generalized to paint the best possible economic picture of the benefits associated with the lake.

A brief environmental assessment was developed for each method proposed in Section 6. Environmental impacts are a significant consideration for all the proposed methods, as the use of the reservoir, native species, and water quality will all be impacted and need to be mitigated.

The analysis done in this Phase Two report is intended to identify the general categories of sediment management methods that could be successful, provide a life-cycle economic analysis to determine what methods may be considered viable, and give the background needed to refine the future analysis in Phase Three to develop a sediment management plan with proposed actions and expected outcomes.

7.2 Charge Questions for Phase Three Scoping

USACE and the sponsor team led by MSAC will develop a scope for Phase Three at the conclusion of this Phase Two report effort. The specific tasks and level of effort required to complete those tasks will be identified. Using the analysis completed in Phase Two, the following questions should be addressed in scoping:

1. What sediment management methods for Lewis and Clark Lake and the surrounding areas need developed to a full implementation plan? This should include full engineering, economic, and environmental analyses.
2. What are the specific beneficial uses, placement, or discharge locations of the sediment, associated with these management methods?
3. Are there ways to monetize the sediment resource to help sustain sediment management?
4. Are there sediment and water quality issues that would eliminate any method from implementation?
5. What pilot projects can be implemented in the near term to provide critical information on sediment management methods, costs, and technology?
6. What are the local, regional, and national level impacts of any sediment transport, placement, and discharge from Lewis and Clark Lake?
7. Who are the partners that need to be involved in addressing the impacts of sediment transport, placement, and discharge?
8. Is there additional economic analysis beyond that associated with the management methods that needs to be done?
9. In addition to the Federal government, who are the funding partners to execute sediment management actions?

8 REFERENCES

Coker, E. Howard, Rollin H. Hotchkiss, and Dennis A. Johnson, 2009. Conversion of a Missouri River Dam and Reservoir to a Sustainable System: Sediment Management. *Journal of the American Water Resources Association* (JAWRA) 45(4):815-827. DOI: 10.1111/j.1752-1688.2009.00324.x

Lipscomb, C. M., A. Darrow, and C.I. Thornton, 2005 "Removal Efficiency Testing of Streamside Systems Bedload Monitoring Collector," Colorado State University Engineering Research Center Report.

Morris, Gregory L. and Fan, Jiahua. 1998. "Reservoir Sedimentation Handbook", McGraw-Hill Book Co., New York.

Sweeney, M.R., Cowman, T., 2018, Sediment sources of the Lewis and Clark Lake delta, Missouri River. Geological Society of America Abstracts with Programs, v. 50, no. 4, doi: 10.1130/abs/2018NC-312239

Tucker, Randall., T. Welp, and R. Thomas, 2015. "Innovative Sediment Management Methods to Reduce Dredging". Proceedings of the 3rd Joint Federal Interdisciplinary Conference of Hydrologic Modeling and Sedimentation, April 2015.

USACE, 2002. Niobrara and Missouri Rivers, South Dakota and Nebraska – Sediment Strategies. Section 095(B) Analysis Reconnaissance Report. Omaha District, November 2001.

USACE, 2011. "Office Report – Lewis and Clark Lake, History of Delta Growth. Reconnaissance Assessment". Omaha District, River and Reservoir Engineering Section.

USACE, 2013. M.R.B. Sediment Memorandum 29. "Sedimentation Conditions at Lewis and Clark Lake, October 2013". Omaha District, Sedimentation and Channel Stabilization Section.

USACE, 2023. (In Publication). "Sediment Transport and Flow Analysis through Lewis and Clark Lake Using the HEC-RAS Reservoir Model through 2012". US Army Corps of Engineers, Omaha District Office Report. September 2023

USGS, 2017. Zelt, Ronald B., Christopher M. Hobza, Bethany L. Burton, Nathaniel J. Schaepe, and Nadine M. Piatak. "Suitability of river delta sediment as proppant, Missouri and Niobrara Rivers, Nebraska and South Dakota, 2015". US Geological Survey, SIR 2017-5105. https://pubs.er.usgs.gov/publication/sir20175105

WEST, 2010. Regional Sediment Management Demonstration Project Niobrara River Basin, Nebraska and South Dakota – Phase II Supplement. WEST Consultants, Inc. for Omaha District USACE. November 2010.