



**US Army Corps  
of Engineers**  
Omaha District

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# **Niobrara and Missouri Rivers, South Dakota and Nebraska**

## **Sediment Strategies**

**Section 905(B) (WRDA 86) Analysis**

**Reconnaissance Report**

**NOVEMBER 2001**

Niobrara and Missouri Rivers, South Dakota and Nebraska

Sediment Strategies

Section 905(B) (WRDA 86) Analysis  
Reconnaissance Report

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RECONNAISSANCE REPORT  
NIOBRARA AND MISSOURI RIVERS, SOUTH DAKOTA AND NEBRASKA  
SEDIMENT STRATEGIES

Version 6 Nov 2001

SECTION I – INTRODUCTION

STUDY AUTHORITY

This study is authorized by Section 447 of the Water Resources Development Act of 1999.

STUDY PURPOSE

The purpose of the reconnaissance study is to identify specific problems associated with sedimentation and determine if a plan exists with Federal and non-Federal interest to serve as the basis for initiating a feasibility study.

LOCATION OF PROJECT/CONGRESSIONAL DISTRICT

The study area is along the lower Niobrara River in Nebraska and the Missouri River from its confluence with the Niobrara River to Gavins Point Dam in South Dakota and Nebraska as shown on Plate 1. Thune, SD-AL; Bereuter, NE-1

DISCUSSION OF RECENT STUDIES AND REPORTS

“Proposed Gavins Point Pool Raise – Sedimentation and Ground Water Assessment” 1985. The report documents the results of the technical studies dealing with the impact of raising the dam’s operating pool on sediment deposits and ground water levels. No conclusions were presented.

“Springfield Water Supply Study” 1985. This study focuses on impacts of sediment and water intakes for the town of Springfield. The study concludes that the best alternative for Springfield is to join the Bon Homme-Yankton Rural Water System (RWS). No report was published and this study was merged into the Eastern Dakota Study presented below.

“Master Plan for Gavins Point Dam/Lewis and Clark Lake (DM MG-123)” 1988. This master plan includes a comprehensive description of the project, a discussion of influencing factors, descriptions of existing and proposed development, and identification of special problems. Conclusions are that sedimentation and the rising water table will increase over time and the delta will continue to expand and force the closing of recreation areas. As the sedimentation process continues the recreation focus will change from large draft boats to smaller craft and wildlife habitat will increase.

“Eastern South Dakota and Upper Big Sioux River, South Dakota and Iowa” 1989. This report records the results of a study of the water resource needs of the eastern half of South Dakota. The portion pertaining to Lewis and Clark Lake concerns the Springfield water intake. As stated above,

the best alternative for the city was to join the RWS.

“Summary Report of Feasibility Studies: Missouri River, South Dakota, Nebraska, North Dakota, and Montana” 1989. This report evaluates a wide range of water resource problems and opportunities related to the upper Missouri River and the six main stem dams and reservoirs. It concludes that additional hydropower at Lewis and Clark Lake could be generated without raising the pool level and that aggradation has caused problems in some areas.

“Sedimentation Near the Confluence of the Missouri and Niobrara Rivers, 1954 to 1999” September 1992. This study is a compilation of existing data related to the sedimentologic and geomorphologic characteristics of the Niobrara and Missouri Rivers in the vicinity of their confluence. No new data were collected during the study. The report provides a database that can be utilized to address concerns related to continued sediment deposition at the mouth of the Niobrara River.

“Lewis and Clark Lake, Lake Sakakawea Sedimentation Study, Reconnaissance Report” December 1994. This study identifies the impacts of sediment deposition on Lewis and Clark Lake and upstream areas, examines potential solutions to the impacts of the deposition, and determines the Federal and local interest in these solutions.

“Missouri River, Fort Randall Dam to Gavins point Dam and Ponca Creek Aggradation Assessment” June 1998. This study documents past aggradation and predicts future aggraded conditions between the two dams. This information can be used for real estate acquisition, scheduling of repairs and realignments for roads, and for habitat evaluation and recreational development.

### SEDIMENT DIMENSIONS IN THIS RIVER REACH

Gavins Point Project loses about 2,625 acre-feet of volume due to sedimentation below elevation 1210 each year. How much sediment is this?

- If a football field measures 100x55 yards then its area would be 49,500 square feet. The amount of sediment entering Gavins Point Project per year would cover the field to a height of 2,300 feet.
- Mount Marty College Campus in Yankton is estimated to be about 46 acres or 2,000,000 square feet. The amount of sediment entering Gavins Point Project per year would cover the campus with 57 feet of sediment each year.

All reservoirs, regardless of size, that are constructed on alluvial rivers will eventually fill with sediment, unless some sort of sediment management/removal/bypass is implemented. Implementing best management practices within basin and sub-basins (NRCS activities) can reduce the rate of sedimentation, but can not eliminate it. At present time the impact of sediment on the overall Missouri River main stem operations is minimal. However, site-specific locations, usually associated with headwater areas, have developed sediment-related problems that have imposed operational constraints on the system. Absent remedial action, these constraints will worsen in the

future. At some point in time all the Missouri River main stem projects will cease to provide the authorized purposes. At present time there are no plans in place to address operations once the projects fill with sediment. Due to the Federal investment and potential liability, post reservoir plans/policy should be developed for all Federal reservoirs. This will allow offices responsible for the operations and maintenance of the project to make the proper investments at the proper time in order to achieve the desired final state.

## SECTION II - EXISTING SEDIMENT CONDITIONS

Sediment rangelines have been surveyed in this area since the early to mid 1950's. Between 1955 and 1995, sediment deposition occurred at all rangelines from Gavins Point Dam (RM 811.05) to approximately 10 miles (RM 853.5) upstream of the Missouri/Niobrara confluence on the Missouri River and about 9 miles upstream on the Niobrara River.

Sediment entering Lewis and Clark Lake is generated from major tributaries, minor tributaries, small drainages, bed scour below Fort Randall Dam, and bank erosion along the Missouri River and Lewis and Clark Lake. Studies indicate that the Niobrara River is the source of most of the sediment, about 55%. Approximately 35% is split evenly between the Missouri River upstream of Ponca Creek, Ponca Creek, Bazile Creek, and erosion and drainages around Lewis and Clark Lake. The remaining, probably less than 10% comes from other sources (i.e. Choteau Creek, Emanuel Creek, and minor drainages).

Two main areas of deposition are occurring at the deltas on Lewis and Clark Lake and at the mouth of the Niobrara River. Most of the sediment depositing at both deltas is sand with a D50 of around the fine to medium grain size (about .25mm to .3mm).

Water surface profiles reveal that the greatest increase in water surface, for a given discharge, has occurred near the confluence of the Niobrara and Missouri Rivers. The water surface for a 30,000 cfs discharge increased about 7 feet from 1955 to 1991 near the confluence. Upstream from the confluence the increased water surface level diminishes with distance. Roughly 15 miles upstream of the confluence the water surface has not change appreciably and farther upstream the water surface has decreased. Downstream of the confluence to Lewis and Clark Lake the increase has been approximately 3 to 5 feet.

If all the sediment generated above Springfield would deposit in the lake then backwater effects would only extend to around the Running Water/Niobrara area. However, the formation of the Niobrara delta has caused another area to be effected by backwater. This area extends from the confluence upstream along the Missouri and Niobrara Rivers. Higher river stages have caused some historic farmland to be completely inundated by water, turned into wetlands or into marginal farmland with higher groundwater and more frequent flooding. These water-related events have propagated upstream of the deltas on the Missouri and Niobrara Rivers and have even moved upstream on smaller tributaries (e.g. Bazile Creek and Ponca Creeks). Not only has the sedimentation affected farmlands but also infrastructure. Highway 12 has needed to be raised, secondary roads have been abandoned or raised and bridges have been replaced.

Another event that occurs more readily in a delta area is an avulsion. This is when a channel will suddenly change its course. The Niobrara River around 1995 shifted most of its flow over to the Mormon Canal. A couple of times in the late 1990's the Niobrara went out of its east bank and rejoined the Missouri about 1/2 to 3/4 of a mile downstream of the present mouth. These events were not enough to permanently change the course of the Niobrara River but a major hydraulic event may change the location of its channel.

The Missouri River has two main channels and some smaller channels flowing into Lewis and Clark Lake. However, an event could cause one of those main channels to be greatly reduced and possibly cut off completely.

Table 1 gives a good estimate of the sediment flowing into Gavins Point Project and tries to express the amount of energy it will take to remove that sediment. Removing the yearly inflow will not make matters better above the lake but will increase the longevity of the lake.

Table 1  
Gavins Point Project Sediment Deposition/Removal Estimates

Between 1955 and 1995 Gavins Point Project has lost 105,032 acre-feet of capacity. The capacity loss is approximately 2,625 acre-feet /year which at 90 pounds per cubic-foot equates to about <b>5,150,000 tons/year.</b>				
<b>Trucks</b>				
AcFt/yr	CuFt/yr	Cuyds/yr	Truck @ 10cuyds	Trucks/day
2,625	114,345,000	4,235,000	432,500	1,160
<b>Trains</b>				
AcFt/yr	CuFt/yr	Cuyds/yr	Train Car @ 55cuyds	Train Cars/day
2,625	114,345,000	4,235,000	77,000	210
<b>Barge</b>				
AcFt/yr	CuFt/yr	Cuyds/yr	Barge@1,000cuyds	Barges/day
2,625	114,345,000	4,235,000	4,235	12

## SECTION III – PROJECTED DELTA DEVELOPMENT

### GAVINS POINT PROJECT – PREDICTION ON FUTURE DELTA LOCATIONS

The object of this assessment is to roughly predict the future location of the delta as it moves through Lewis and Clark Lake. Historic cross-section data and historical aerial photographs were used to complete this task.

The movement of the delta for this assessment is based on the historic capacity loss at and below elevation 1205 msl. Elevation 1205 is slightly less than the 2 feet below the average pool elevation and 0.5 feet above the base of the flood control pool. The forty-year average deposition rate, at and below elevation 1205 is approximately 2049 acre-feet per year.

Historic aerial photos reveal that by 1982 most of the sediment entering Lewis and Clark Lake deposited along the South Dakota side (Figure 1). By 1991, more sediment was depositing on the Nebraska side of the lake, but still deposits along the South Dakota side had progressed farther into the lake (Figure 2). An aerial photo taken in 1998 shows that deposits along the Nebraska side had deposited slightly farther into the lake than the South Dakota side (Figure 3). These photos show the depositional pattern into the lake and indicate that most of the deposits will occur around the main inflow channel.

An area-capacity program run using 1995 survey data revealed that river segment number 8 (RM 827.5-829.1) contained 4,166 acre-feet per mile of volume. The **visual** delta front was near RM 827.5 in 1995. Therefore, it is assumed that when a river segment has between 4,000 to 6,000 acre-feet per mile of volume the visual delta will be located at the downstream end of that segment.

The visual delta front is defined, in this report, as the portion of the delta above the water line (reservoir pool elevations are reasonably constant, generally fluctuating only a couple of feet). Newly formed sand bars will be located right at the front with vegetated sand bars a short distance upstream. The breakpoint between the topset slope and foreset slope of the delta is underwater and located closer to the dam than the visual delta front. Therefore, very little boating activity would occur for some distance in front of the visual delta.

Also, for this assessment the map will show the delta's face to be about equal distance from the dam through time. However, the reservoir is much wider than the river channel and this will cause the delta to grow in one area for a time before shifting to a new location. Therefore, at any moment in time one section of the delta may be much closer to the dam than other sections.

By 1998 the visual delta front had progressed to the Snatch Creek Area. By 2015 the delta should be past the Sand Island Area and by 2050 it should be in the Bon Homme Mennonite Colony/ Devils Nest Area. By 2135, this investigation predicts the visual delta front should be passing the Gavins Point Recreation Area (Figure 4). Since the lake bottom is very shallow in front of the visual delta front, boating activity will be limited.

# Gavins Point Headwaters 1982



Photo take on June 10, 1982. The pool elevation was 1205.5.

**Figure 1**

# Gavins Point Headwaters 1991



Photo taken on September 20, 1991. The elevation was 1207.6.

**Figure 2**

## Gavins Point Headwaters 1998

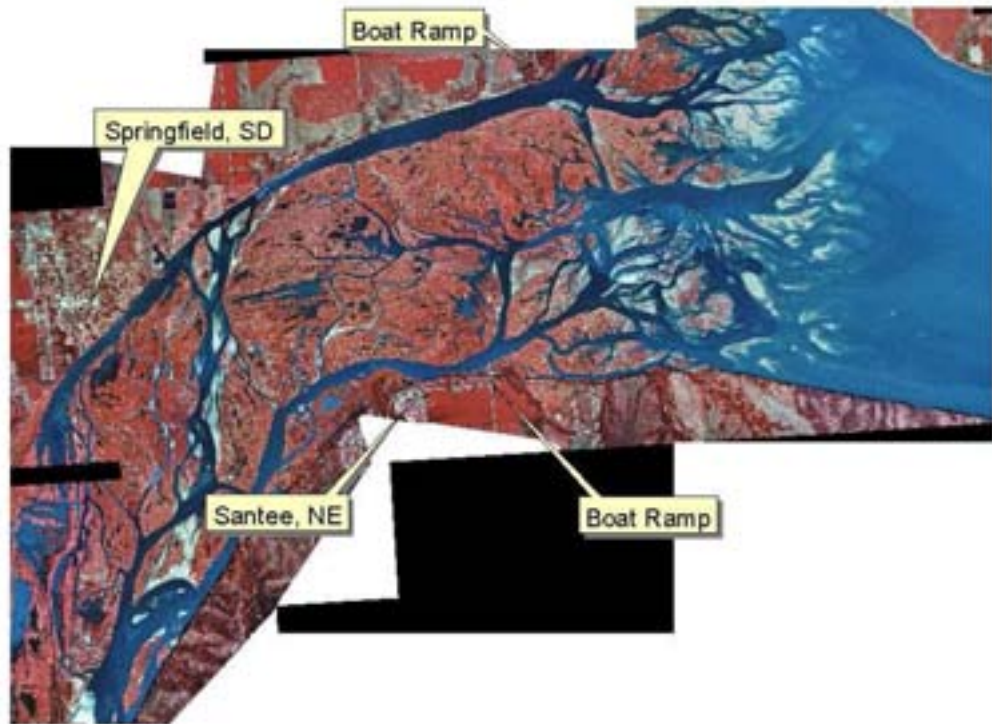


Photo was taken on June 10, 1998. The pool elevation was 1206.2.

### **Figure 3**



### IDENTIFY WHEN LAKE COMPLETELY FILLS

In 1955 the capacity of the Gavins Point reservoir was approximately 575,000 acre-feet at and below elevation 1210. In 1995, that capacity was reduced to 470,000 acre-feet. The rate of capacity lost over the 40 years (1955-95) has been 2,625 acre-feet. If this rate continues it would take another 179 years from 1995 or roughly the year 2175 to lose all or most of the capacity below elevation 1210 feet m.s.l. However, as indicated by the above discussion, most of the existing uses of the lake (boating, water supply, etc.) will be lost before the lake completely fills.

## SECTION IV - INITIAL SCREENING

A conference call was held on February 13, 2001 with local interests and the two project offices to discuss the draft plan of study. Based on conversations during the call, the Corps agreed to revise the plan of study to more clearly reflect the local interests. The Corps later received a letter from Yankton community representatives outlining their support for certain study alternatives.

Two study objectives were identified to evaluate the alternatives. The study objectives are defined as 1) extend the life of the lake and 2) reduce flooding upstream of the delta. Each alternative was analyzed in terms of meeting the objectives and whether further study was warranted. The analysis follows below.

Dredging. This alternative consists of dredging the Missouri River from two miles below Bazile Creek to upstream of Ponca Creek as shown on Plate 2. It involves the removal of sediment from the waterway and its disposal at some appropriate site. Hydraulic models will be used to simulate a dredge channel and to compute dredge quantities for the Missouri River.

This alternative extends the life of the lake and may decrease flooding but it has significant environmental issues. The local groups support this alternative. Because the alternative meets both study objects and is supported locally, further study is warranted.

Canal. This alternative consists of transporting silt from the Niobrara River and Bazile Creek through a canal along the Nebraska side to an outlet below Santee as shown on Plate 3. About 60 to 75 percent of the sediment produced by the drainage area upstream from Springfield/Santee is from the Niobrara River and Bazile Creek. This work effort will determine if it is possible to deliver the sediment from these two waterways to a certain location in Lewis and Clark Lake below Santee, NE, via a canal. Material is presently transported into Lewis and Clark Lake but the area where most of the sediment settles out changes from year to year.

This alternative does not extend the life of the lake and may increase upstream flooding in certain areas. The local interests do not support this alternative. Because this alternative does not meet either study objective and has no local support, it will be eliminated from further consideration.

Niobrara River Diversion. This alternative involves relocating the mouth of the Niobrara River to a point downstream of Gavins Point Dam as shown on Plate 4. The Niobrara River is the largest single contributor of sediment to Lewis and Clark Lake. The analysis will be qualitative with the focus on developing a preliminary cost estimate. A brief discussion of economic and environmental concerns will be included.

This alternative meets both objectives but has significant environmental issues. Further study is warranted on a limited basis.

Planned Lakes and Recreation Area Access. This alternative consists of creating small lakes within Lewis and Clark Lake as shown on Plate 5. As the delta moves farther into the reservoir, sediment

will close off lake access areas. In theory, areas containing smaller lakes could be established in the middle and upper reservoir near the access roads. These lakes could be used for duck habitat, fishing and camping. In the lower part of the reservoir, larger and deeper lakes could be established for boating and swimming activities. Construction of these lakes requires dredging and moving the sediment into managed areas within the present reservoir. Levees must be built to keep sediment from entering these lakes.

This alternative partially meets extending the life of the lake objective and does not meet the upstream flooding objective. The local group feels that they have time to study this at a later date and does not support further study at this time. Because this alternative does not meet both study objectives and has no local support, it will be evaluated on a limited basis.

Review of Coker's Proposal. Dr. Coker has gathered a considerable amount of information on the transportation of sediments through various means to a point downstream of Gavins Point Dam as shown on Plate 6. The information contains technical and cost data. As part of this study, the Corps would review Dr. Coker's data in the areas of technical adequacy, economic viability, downstream impacts and endangered species issues.

This item meets the objective of extending the life of the lake. It will probably not meet the upstream flooding objective but could be altered to address flooding issues. The local group supports this item. Because this item may meet both objectives and has local support, it will be studied further.

## SECTION V – ASSESSMENT OF THE COKER PROPOSAL

### PIPELINE TRANSPORT

Dr. E. Howard Coker of the University of South Dakota has investigated the possibility of pumping a sediment slurry from the reservoir to below the dam. R. E. Randall of Texas A&M University collaborated with Dr. Coker on that investigation. The District evaluated the dredge/pipeline concept, reviewing assumptions and adjusting the rate of sediment removal/transport, to reflect the most recent information. For the most part, we found the assumptions and calculations from Dr. Coker to be reasonable, and therefore we did not delve into rigorous cross-checking of those values. If an actual design were to be pursued, these assumptions and calculations would need a greater degree of scrutiny.

Sediment Inflow. Coker based his system on an average annual sediment accumulation of 2800 acre-feet (AF) in the reservoir. This is a reasonable estimate of the rate that the reservoir is losing storage volume. The volume of the sediment particles in the saturated deposit comprises approximately 55 percent of the total sediment volume. If a pipeline system was designed to remove the average annual inflow of sediment, it would have to transport

$$2800 \times 55\% = 1540 \text{ AF of solid material per year.}$$

Coker's calculations show that two 24-inch dredges could move this amount of material during the 8 months of pipeline transportation. A 12-inch diameter pipeline would be able to carry this material, provided the slurry has a concentration of 35 percent. The District would increase this volume by ten percent, to account for downtimes or other events that would deliver less than designed. Thus, the targeted amount of sediment (that is, the combined volume of the sediment particles) is  $1540 \times 1.1 = 1694$  AF (rounded up to 1700 AF) per year. The result is that the pipe diameter would need to be increased to 14 inches.

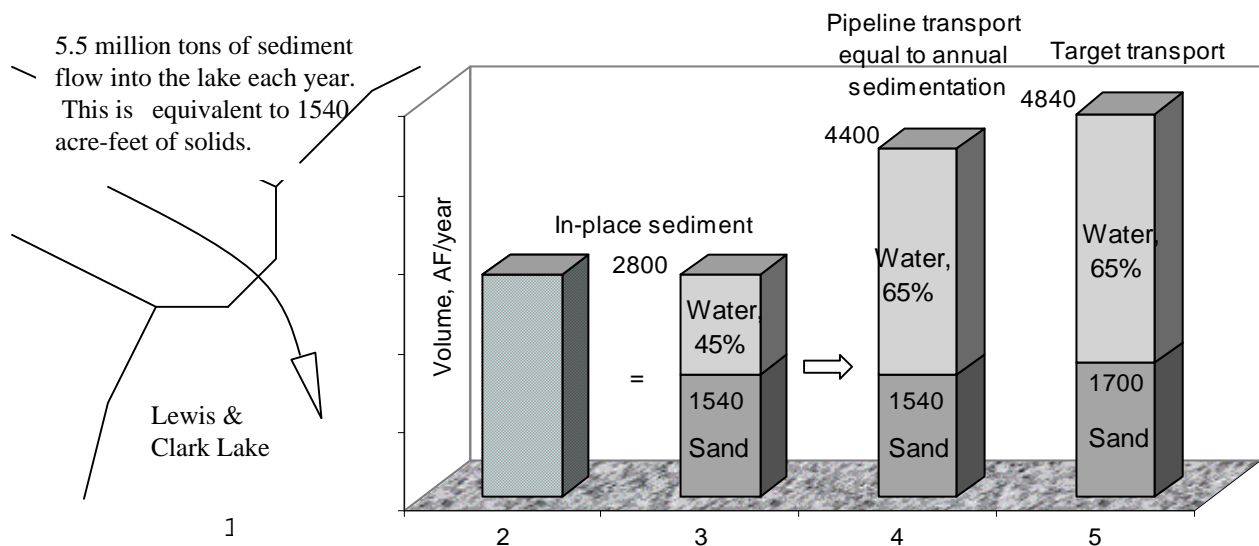
These sediment inflow and transport quantities are presented in graphical form in Figure 5. The following notes describe the five depictions of sediment deposition/transport in the figure.

1. The 1540 AF of annual solid sediment flow (i.e., 5.5 million tons) into the lake is for all the tributaries, as well as the Missouri River itself. The Coker study is based on this quantity, which was developed from measurements taken between 1955 and 1985. The district analysis of the Coker proposal used this same estimate of annual sediment inflow. More recent measurements in 1995 produced an estimate of 5.15 million tons per year, as shown in Table 1.
2. Reduction in reservoir capacity consists of the volume of sediment particles (mostly sand), along with the water that fills the voids between the sand grains. The water movement out of the settled sediment (when the pool is lowered) is not rapid enough for effective use in reservoir operation. The water saturating the sand essentially is locked in place. The reservoirs annual capacity thus is 1540 AF solids plus 1260 AF water, totaling

2800 AF. The difference between this volume and the 2625 AF shown in Table 1 is due to the different measurement periods, as discussed above in Note 1.

3. The second column shows the proportion of water and solids in the saturated consolidated sediment.
4. Annual transport of 4400 AF (for a 35% slurry) is derived for the basic proposal of two dredges moving material into a 14-inch pipe, as described below. The volume and slurry concentration for other designs would have higher volumes, and /or lower concentrations.
5. The target volume of annual sediment transport is 110 percent of the annual inflow.

Figure 5



Design Factors.

- Design Life: 50 years
- Slurry requirements outlined by Dr. Coker appear reasonable. Our reconnaissance-level review finds that the basic assumptions are appropriate, provided that a slurry concentration of 35% can be achieved.
- Pumping time: The Coker system would pump the sediment slurry 75% of the year. The District fine tuned this based on a Navigation support period between 22 March and 15 November (winter releases would not be able to move the sediment downstream). The District thus changed Coker’s 274-day pipeline operation to a 239-day operation.
- Pipeline alignment: Dr. Coker suggested that the pipeline might run up to 34 miles long. The District’s review concurred that 34 miles is a good, conservative estimate. The pipeline

probably will be south of the river, but its actual alignment will be defined by geology, topography and real estate considerations. Thus, it might be placed close to the shoreline, or parts of it might be along road rights-of way miles from the shore. We estimated that a good place to locate the dredge would be a few miles upstream of the delta's upstream-to-downstream midpoint. A reasonable discharge point is a mile downstream of the dam.

- Preferred concentration: 35%, flowing at 9.84 feet per second.

Water Flow During Winter. The Coker proposal provides for running the pipeline year-round, even though sediment would not be transported during the winter. This would be an effective way to avoid system freeze-up, but other measures such as thoroughly draining the system might be just as effective. The District calculated how much water would have to bypass the turbines in order to keep the pipeline operating under Coker's winter option. The loss of hydropower in this process was added to the cost of each alternative, even though the design may be able to do without that winter operation.

Dredge Production and Pipeline Flow Rates. Available information indicates that a 24-inch dredge should move around 1000 cubic yards per hour, and an 18-inch dredge should move about 500 c.y./hour. Under the Coker proposal, two 24-inch dredges would discharge material into a settling or buffer pond. A pump would draw the slurry from the pond into the pipeline, at an optimum concentration. Dr. Coker's analysis did not go into detail on exactly how the transfer facilities will work between the dredge and pipeline. The District's evaluation did not discover any working examples of the transfer methods proposed for this system. Also, the discharge rates of the dredge and pipeline are different enough to suggest that feasibility of a transfer system is not assured (i.e., equipment may not be available to funnel the effluent of two 24-inch dredges into a 14-inch pipe, while keeping velocities near 10 feet per second).

Alternatives. The modified Coker proposal (two 24-inch dredges and a 14-inch pipeline) was analyzed along with 2 other layouts requiring transition facilities between dredge and pipeline. These would use two 18-inch dredges, and a pipeline of either an 18-inch pipe, or two 12-inch pipes. The list of alternatives included two systems that would connect the dredges directly to the pipeline. One system would match the two (24-inch) dredges proposed by Coker, and the other would use only one dredge.

Costs. Two factors make all the pipeline systems very costly. First, since the heavy slurry would have to be moved over a long distance, the systems would require many booster pumps. It is estimated that a pump would be needed every two miles. The second factor is that the sand in the slurry will cause critical wear in only a year or two. Thus, each system would need to replace all pumps every year. Consequently, the annual cost of the systems is high relative to the initial capital cost. For the 14-inch pipeline using two 24-inch dredges (Alternative 1), capital costs would be \$20.5 million, and the annual cost thereafter would be \$29.1 million.

Cost Comparison. The highest-cost alternative in the "transition facilities" group did not have enough additional benefit to warrant its higher cost. Therefore, that layout (18-inch pipeline, with two 18-inch dredges) was dropped from consideration. Similarly, the direct system of dual 24-inch

dredge/pipeline would cost significantly more than the single 24-inch system, and it was therefore dismissed.

Alternatives Analysis. The cost comparison outlined above left three practicable configurations.

- 1 Two dredges (24-inch), transition pond, 14-inch pipeline
- 2B Two dredges (18-inch), transition pond, dual 12-inch pipeline
- 3 One 24-inch dredge, connected directly to a 24-inch pipeline

In addition to cost and the rate of sediment removal, some systems have the capability of limited operation when a critical component fails. For a single dredge and a single pipeline, however, if a single pump fails, the whole system goes down. The following table shows how these three alternatives compare to each other.

	<u>Alt. 1</u>	<u>Alt. 2B</u>	<u>Alt. 3</u>
Cost relative to Alternative 1	100%	152%	202%
Sediment removal relative to target	103%	150%	210%
Partial dredge operation possible	+	+	-
Partial pipeline operation possible	-	+	-
Dredge to pipeline	high degree of uncertainty	direct	direct

Technical Feasibility. The alternatives analysis eliminated two configurations due primarily to cost considerations. As noted in the above table, we do not have documentation on the feasibility of transferring a concentrated slurry of sand to a pipeline. The original concept (roughly equivalent to Alternative 1) hinges directly on the technical merit of a practical transfer facility.

Instream Sediment Transport. The dam caused two major changes to the river's natural sediment transport balance. The proposed sediment bypass project is designed to remedy the first problem, replenishing the sediment that the dam has diverted from the downstream channel. The second major factor is the truncation of high flows that formerly had carried large volumes of sediment downstream. Over the last 20 years, the river at Sioux City has transported between 8 million and 31 million tons of sediment per year. The average annual sediment transport in that river reach is 14.5 million tons. The target amount of sediment to pipe past the dam is 5.4 million tons per year. The difference between the maximum (31M) and average (14.5M) rates of sediment transport is an indication of the river's capacity to entrain additional material. That is, the river theoretically could carry at least 16.5 M tons more sediment than its average, which would cover the 6.1 M tons of additional material. However, that extra transport capacity is tied to the frequency and duration of higher flows, such that the added capacity of 6.1 M tons may not be assured. Furthermore, the new

sediment discharged from the pipeline could tend to accumulate until larger flows would occur (probably several years). This current reconnaissance-level analysis merely looked at the statistics for the river at Sioux City, without running any mathematical models for sediment transport. This cursory analysis concluded that the river channel downstream of Gavins Point Dam likely has the capacity to transport the additional sediment, over the long run. Short term localized sediment accumulation would be expected, and that could cause problems such as lowland flooding, channel instability, and difficult boat passage. Any future consideration of the sediment bypass proposal should include a thorough evaluation of the sediment transport issue.

Hydraulics. The District found Dr. Coker's hydraulic assumptions and calculations apparently are reasonable. Similarly, pipeline wear should be controllable with the right materials, as Dr. Coker suggested. If this project moves into a feasibility level of study, all hydraulic and product durability issues will have to be verified.

Impact On Power Generation. In the process of moving a slurry through the pipeline, water will be diverted from eventual passage through the power turbines. Thus, the sediment bypass project will be at the expense of some power generation. The extent of this power reduction was estimated for all the alternatives, for both the slurry and the possible winter-only water transport. The cost of the lost revenue is small compared to overall dredge/pipeline/pump systems. The 14-inch pipeline represents an annual hydropower loss of up to 160 MWhrs, at an estimated cost of \$6400.

## SECTION VI - PLAN FORMULATION

### DREDGING

This alternative consists of dredging the Missouri River from 2 miles below Bazile Creek to upstream of Ponca Creek Dredging.

Purpose and Strategy. The objective of this alternative is to explore the possibility of returning water surface elevations on the Missouri River, in the vicinity of the Niobrara River confluence, to near 1975 water surface levels by dredging. No new data was obtained for this study. Historic cross-section data are available from 1955 to 1995.

HEC-2 models were developed and calibrated in 1998 for predicting future water surface elevations between Fort Randall and Gavins Point Dams. Channel geometry in these models were modified to simulate a dredging activity that returned water surface profiles to near 1975 conditions. In addition, the channel improvement option was used to estimate dredge quantities.

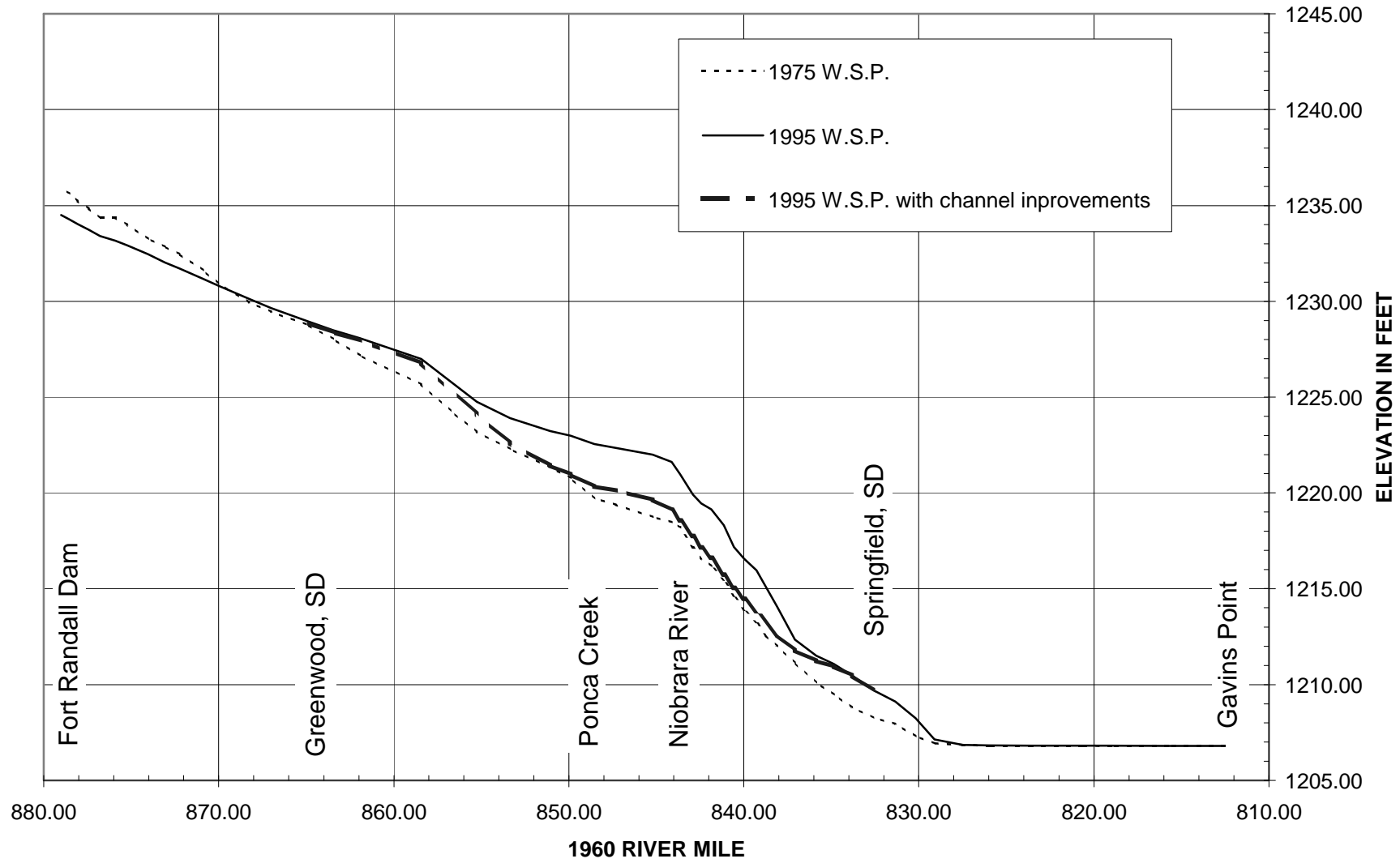
Channel Dimensions. The dredging operation was set to begin at 1960 river mile (RM) 834.8, about 2.5 miles below Bazile Creek and continue to RM 851.1, about 2 miles upstream of Ponca Creek (see Plate 2). This will lower water surfaces near Running Water, SD and Niobrara, NE and should improve conditions related to high water on the Missouri River Tributaries (Bazile Creek, Niobrara River and Ponca Creek). Channel dimensions started with a bottom width of 400' at elevation 1192.0 with 1V:4H side slopes and a channel slope of 0.0001828. At RM 843.6 the bottom width was reduce to 300' and the channel slope was changed to 0.0001262. The slope change was to mimic the natural channel. Historically the Niobrara River caused a slight change in slope.

Dredging Scenario and Results. The dredging operation is set in 1995 (last survey year). The cost is estimated using today's dollars (2001) to remove the amount of sediment that had accumulated by 1995. A cost per cubic yard of sediment was developed and will be applied to sediment volume predicted by the HEC-2 modeling

The channel dredge dimensions allowed the water surface elevations for a 30,000 cfs discharge to return to slightly above 1975 elevations from near Bazile Creek to Ponca Creek (Figure 6). However, due to the deposition pattern across the Missouri River from high bank to high bank (floodplain) the dredged channel will only bring back a 75,000 cfs (100-yr event) flow to about the mid to late 1980's water surface elevations (Figure 7).

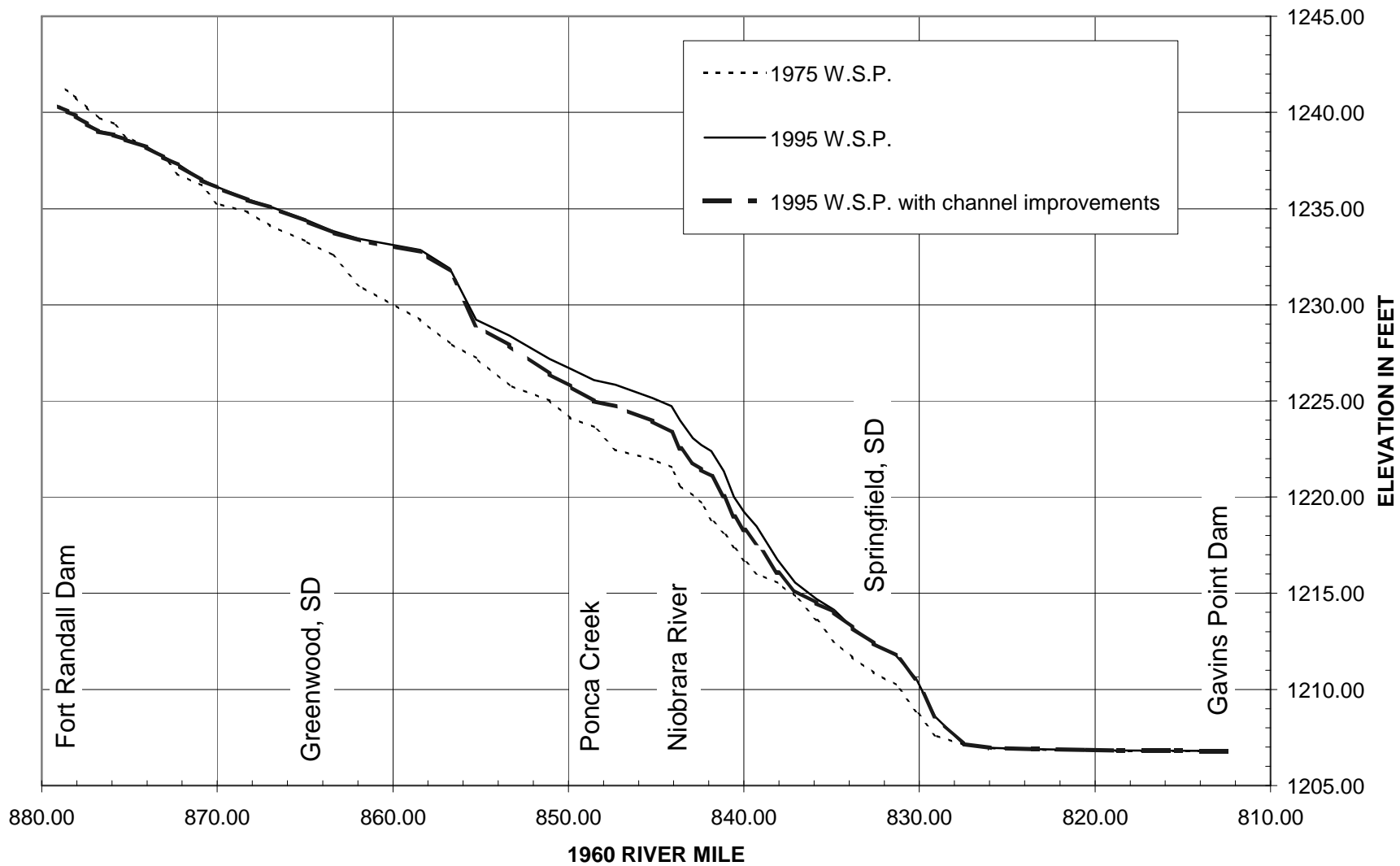
Dredged Quantities and Historic Deposition. The dredge cut would remove about 11 million cubic yards of sediment (in 1995). The cost to remove the sediment via dredging and place the sediment into 110 containment areas located on the flood plain adjacent to the river, would be about 29.8 million dollars. Dredging the sediment is estimated at \$2.43 per cubic yard or 26.7 million dollars and 3.1 million dollars would be needed to build the containment dikes. This estimate assumed 5 dredges working 24 hours per day, 6 days/week for a year. It does not account for clearing and grubbing, other mechanical excavation, hauling of soil or real estate, all of which adds costs.

**Fort Randall to Gavins Point Dam  
WATER SURFACE PROFILE FROM HEC2 MODELING at 30,000 CFS**



**Figure 6**

**Fort Randall to Gavins Point Dam  
WATER SURFACE PROFILE FROM HEC2 MODELING at 75,000 CFS**



**Figure 7**

An estimate to haul the sediment via trucks 35 miles to near Gavins Point Dam increased the cost almost 4 times to 114.5 million dollars. This estimate is only for dredging and hauling and does not account for clearing & grubbing, real estate or other contingencies. Also, there are a number of logistic, environment and social economic issues to be resolved before this alternative could be implemented

Between 1975 and 1995 more than 24.4 million cubic yards of sediment was deposited in the study reach and 11 million cubic yards needed to be removed (45 percent) to bring the water surface back to slightly higher than 1975 levels. Historically, sediment has deposited at a rate of slightly more than 1.3 million cubic yards per year in this area adding up to 7.8 million cubic yards over 6 years. Assuming the same dredge to deposition ratio, forty-five percent of 7.8 million cubic yards would be 3.5 million cubic yards. Therefore, it is estimated that another 3.5 million cubic yards of sediment on top of the 11 million cubic yards or a total of 14.5 million cubic yards would need to be removed in 2001 to return the water surface near 1975 levels. This would add another 8.5 million dollars to the dredging costs raising the total to 38.3 million dollars.

Operation and Maintenance of Project. The dredged channel will act as a sediment trap. Sediment will begin to deposit in the dredged channel immediately and benefits would begin to be reduced. In the absence of large floods, nearly all the inflowing sediment will deposit in the dredge channel. Due to money constraints, a model was not run to see how long it would take to refill the new channel, but depending on the precipitation pattern the channel would probably be refilled in 5 to 10 years. During this time, the rate of sediment entering Lewis and Clark Lake would be reduced.

This means that within 10 years another 20 to 40 million dollars would be needed to dredge the channel again.

#### RELOCATE MOUTH OF NIOBRARA RIVER

This alternative consists of cutting a channel through the bluff to reenter the river downstream of its present mouth. The objective of this alternative is to investigate the possibility of diverting the mouth of the Niobrara River to below Gavins Point Dam. Depending on the hydrology for a particular year the Niobrara River Diversion would divert 60 to 75 percent of the sediment originating upstream of Springfield/Santee from entering Lewis and Clark Lake. Not only would the diversion deposit the Niobrara River sediment below Gavins Point Dam, but would capture sediment from Bazile Creek and a few smaller tributaries.

The bypass would start at approximately river mile 3.0 on the Niobrara River and flow eastward about 44 miles to meet the Missouri River at river mile 804.0, about six miles below Gavins Point Dam.

A stable stream channel was calculated using the Hydraulic Design for Channels (SAM) Model. By utilizing previous survey, flow and grain size data a geometric section was formed that typifies the stream channel, floodplain, and transitional upland fringe. The proposed channel alignment has a 75-foot drop in elevation with an energy slope of 0.000322. SAM calculated that a stable channel

with a bottom width 400 feet would have a depth of 1.7 feet and a velocity of 1.64 ft/s.

Utilizing the information given from SAM and incorporating cross-sections from digital elevation models, the Channel Modification option in HEC-RAS estimated the volume cut. Due to the elevation changes between the valley floors and the drainage divides approximately 11,400,000,000 yd<sup>3</sup> of material would need to be excavated to move the mouth of the Niobrara River. This amount of excavation material does not account for additional cuts required to stabilize tributaries. Also, the geometric section assumes a flood plain width of 2,000 feet with a 10:1 side slope, which may not be adequate to pass flood flows. The cost estimate for this alternative is \$11,000,000,000.

## SECTION VII – PLANNED LAKE EXAMPLE

Growth of the main stem delta has affected the recreation areas in the vicinity of Springfield, SD and Santee, NE. Sand transported by the Missouri River deposits as it enters Lewis and Clark Lake causing shallows and emergent areas on which cattails and reed grass have grown. This action is continuous and the delta grows mostly in the downstream direction.

Since the width of the Missouri River channel is much smaller than the width of the lake, the channel will swing back and forth across the headwaters. Evidence supports that the original main channel, which flowed along the South Dakota side, has been replaced by a main channel along the Nebraska side. Cross section data reveals that while the old main channel's width is decreasing and the thalweg is shallower the new main channel is getting deeper and wider. Also, the historic river crossing section (river meandering from the Nebraska side to the South Dakota side) near river mile 832.5 has become shallower and narrower.

It is nearly impossible to predict channel migration in a delta environment, however it appears that the north channel may be cut off in the future. If that occurs it would be possible to create small recreation lakes in or near the old channel. The initial cost of building these lakes may be high, but its also possible they will have a low maintenance cost. Consultants (Ducks Unlimited, Fish and Wildlife, etc.) with experience in building and maintaining small lakes for a specific purpose should have input. Roads leading down to the valley floor already exist at Springfield, Sand Creek Area, Snatch Creek area and to an unnamed boat ramp near river mile 826.0.

Between Snatch Creek and the unnamed boat ramp in section 13 there is about a 1 square mile area that could be used as a Pilot project for a planned lake/lakes. The site is on the opposite side of the lake where most of the sediment is now depositing, but near the delta front so there is plenty of sediment available to move. Road access is good in this area.

## SECTION VIII - ENVIRONMENTAL CONDITIONS

### AFFECTED ENVIRONMENT

Topography. The study area on the Missouri River is situated between the glaciated and unglaciated portions of the Missouri Plateau in the Great Plains Province of the interior Plains. The river's course marks the terminus of the southern advance of the Mankato substage of Wisconsin glaciation period in the region. The adjacent areas along the river are characterized by gently sloping bluffs to the north and steep dissected bluffs rising sharply from the floodplain on the south (NPS 1997).

Climate. The study area has cold winters and hot summers with occasional cool spells. The average winter temperature is 23 degrees Fahrenheit (F) and the average summer temperature is 74 degrees F. The annual precipitation is 23 inches; approximately 80 percent usually falls in April through September. The growing season for most crops falls within this period. The average seasonal snowfall is about 29 inches and the average relative humidity in mid-afternoon is about 55 percent. Humidity is higher at night, and the average at dawn is about 80 percent. The sun shines 70 percent of the time in summer and 55 percent in winter. The prevailing wind is from the northwest. Average windspeed is highest in spring at approximately 14 miles per hour. Tornadoes and severe thunderstorms occasionally occur (NRCS, 1997).

Air Quality. The clean air act was amended in 1977 to preserve, protect, and enhance quality of the air in national parks, wilderness, and other nationally significant areas. Under the act, the national recreational rivers were designated as a class ii clean air area. Air quality in the study area is generally good. The study area is an attainment area for the National Ambient Air Quality Standards (NPS 1997).

Water Quality. Water quality in the study area is generally good. Niobrara River water has been monitored and some chemical and physical aspects of Missouri River water have been studied intermittently since before closure of the mainstem dams. The water quality factor on the Missouri most affected by dam construction was turbidity. The water became less turbid, or much clearer, after the dams reduced natural sediment transport in the river. High turbidity did not affect the primary energy source of the river, the erosion caused by main channel meandering, or the runoff from tributaries. The clean water from the dams leads to downcutting, narrowing of the river channel, rapid erosion on the new banks, loss of sandbars, and reduction of nutrients important in fish and wildlife habitat (NPD, 1997).

Because of regulation, water quality has also changed considerably. Riverflows tend to be clear rather than turbid much of the time, which reduces stream cover used by native river fishes. Inflows from the Niobrara River still create a turbid plume, which hugs the right bank of the main channel downstream to Lewis and Clark Lake. Ponds and backwaters to the river vary greatly in turbidity, depending upon bottom characteristics, exposure to wind, and exposure to other disturbances. On balance, there is probably more quiet or slow-flowing turbid water than clear water from Niobrara to

Springfield (USACE 1994).

Noise. Noise levels in the study area are varied, with relative tranquility in some areas, typical sounds in more developed areas near towns, and seasonal sounds of motorboats in other areas. The opportunity to experience a quiet, natural environment is part of the relatively primitive recreational experience that is valued on the recreational river (NPS 1997)

Soils/prime farmland. The bottomland soils in the study area consist of Sarpy-Blake-Albaton; Fluvaquent-Albaton-Solomon; Aowa-Shell-Hobbs; Aowa-Shell-Kezan; and Inavale-Barney-Orwet soil associations. These associations range from deep to very deep; nearly level and very gently sloping; excessively drained to very poorly drained; silty, sandy, loamy, and clayey soils, (NRCS 1997, SCS 1985).

The Floodplain soils include Forney-Haynie-Sarpy, Ethan-Clamo-Davis, and Fluvaquent-Sarpy. These associations range from deep to moderately deep; moderately steep to and gently sloping; excessively to very poorly drained; silty, sandy, and loamy soils (SCS 1986, SCS 1979).

Upland soils consist of Crofton-Boyd-Ethan, Eltree-Yankton-Alcester, Moody-Bazile-Trent, Crofton-Nora-Alcester, Redstoe-Gavins, and Labu-Lynch-Sansarc soil associations. These associations range from Very deep to shallow; very steep to nearly level; excessively drained to moderately drained; silty, clayey, loamy, and sandy soils (NRCS 1997; SCS 1986; SCS 1985; SCS 1979).

Most of these areas support native vegetation and provide wildlife habitat. The bedrock Pierre shale in the Niobrara area is prone to landslides (NPS 1997).

The study area is primarily a rural area where agriculture plays a major role in the overall economy of the area. Primary products include cattle, hogs, corn, wheat, soybeans, and milo. The land is classified as cropland or pasture/rangeland, which include a range of cover types, such as row crops, alfalfa fields, mixed-grass prairie, wet-mesic prairie, and tallgrass prairie, and both grazed and hayed areas (NPS 1997).

The approximate acreage that meets the soil requirements for prime farmland in each county are as follows: Knox - 32%, Cedar - 42%, Bon Homme - 76%, and Yankton - 84. A recent trend in land use in some parts of the study area has been the loss of prime farmland to industrial and urban uses. The loss of prime farmland to other uses puts pressure on marginal lands, which generally are more erodible, droughty, and less productive and cannot be easily cultivated (NRCS 1997; SCS 1985, 1986, and 1979).

Aquatic resources. The Missouri River from Fort Randall Dam to Springfield flows more or less unobstructed by Lewis and Clark Backwaters. The exact location between riverine and lacustrine is academic because flows depend on the elevation of the reservoir. Furthermore, some downstream current movement nearly always takes place through Lewis and Clark Lake due to its relatively small storage volume (USACE 1994).

Because of the wide variety of hydraulic conditions in the study area, the habitat potential is good. Pool depths vary up to 24 feet; however, the mean depth is usually less than 6 feet. The channel varies from 1,000 to 4,500 feet wide. There are numerous islands, side channels, and adjacent wetlands contiguous to the river from Verdel downstream. The channel bed lacks soft-and hard-bottom types because it is mostly composed of shifting sand. Some gravel and cobble deposits are found along a 4-mile long shoreline extending about 7 miles below Fort Randall Dam in Boyd County, Nebraska. Silty sediments are found along the shoreline below Niobrara and within numerous ponds and backwaters from Verdel downstream to Springfield. Bank habitat along the channel is poor due to instability problems above Verdel; however, below Verdel the banks are more stable and lined with emergent or overhanging vegetation (USACE 1994).

Fish habitat on the Missouri River between Fort Randall Dam and the headwaters of Lewis and Clark Lake is more similar to the natural river conditions than reaches downstream. Native fish in this free-flowing Missouri River segment are relatively productive and dominated by cool and warmwater species, including the catfish, sturgeon, sauger, suckers, and a naturally reproducing population of paddlefish. This reach is one of the recovery priority areas for the pallid sturgeon (NPS 1997).

Native fish have declined in the study area because of migration blockage, loss of habitat, change in habitat, decreased turbidity, and competition from new species, all primarily due to the river regulation effects of the Missouri River mainstem dam system. These regulatory practices have resulted in an altered annual cycle of river flows (hydrograph) that causes lower than normal river elevations during critical spring and summer months for fish migration and breeding. Mainstem and tributary reservoirs are used to store the usual high spring runoff that is released in the summer and fall at rates that are less than the spring runoff rates. This is a reversal of the natural hydrograph, and life cycles of plants, nesting birds, aquatic insects, and fish are adversely affected. Also, water releases resulting from power peaking operations during critical spring and summer months cause fish eggs and larvae to dry out as the water level fluctuates as much as 4.5 feet daily. This reach is one of the recovery priority areas for the pallid sturgeon (NPS 1997).

Prior to regulation, the Missouri River channel bed was generally inhospitable for most macroinvertebrates, including mussels. Populations were confined to backwaters or old oxbows. Because of the sedimentation in the channel in the vicinity of the Niobrara River, a bivalve fauna has developed (USACE 1994).

The Niobrara River is a warm-water, turbid stream which enters the Missouri River near the town of Niobrara. The lower reaches are especially valuable as a spawning and nursery area for stream fishes (USACE 1994).

In the main body of the lake, plankton production is considered to range from poor to good, depending upon the flushing rate. Generally, plankton production is higher than in the upstream reservoirs and much higher than the river. In deeper parts of the lake, there is good production of mayfly (*Hexagenia*) nymphs, which are consumed by many fish. Their abundance has been

estimated to range from 41 to 160 individuals per square mile, reaching levels comparable to natural lakes (USACE 1994).

Vegetation and Timber. The study area includes tallgrass and mixed grasslands. Where agriculture is not practiced, some remnants of native prairie can be found on the floodplain, dominated by vegetation such as prairie cordgrass, Canada wildrye, and switchgrasses in wet areas adjacent to the rivers. This is especially true along the steep north-facing bluffs in Nebraska where farming is impractical due to the topography. Similar native prairie areas are common along the corridor in South Dakota as well. The woody draws, cottonwood forests floodplains, and remnant prairie patches are among the best examples that can be found on the free-flowing reach of the Missouri River (NPS 1997).

Woody vegetation is relatively rare except in drainage areas and on the floodplain. Native trees such as eastern red cedar, bur oak, and green ash grow in drainages and form wooded draws (NPS 1997). Bottom-land areas along the major streams, such as the Niobrara River, Verdigris Creek, and Bazile Creek, support a variety of species. Eastern cottonwood, boxelder, green ash, bur oak, American elm, black willow, peachleaf willow, and sandbar willow are the predominant species. Other species include black walnut, eastern redcedar, mulberry, hackberry, Russian-olive, American basswood, common chokecherry, American plum, smooth sumac, gooseberry, common pricklyash, western snowberry, indigobush, and red raspberry.

The sandbar-marsh plant community is found along the broader eastern portion of the Niobrara River. The marshes have a wide variety of aquatic plants and animals (NPS 1997).

Leafy spurge, spotted knapweed, and Canada thistle are widely distributed within the area and are designated as noxious weeds by the states of Nebraska and South Dakota. Purple loosestrife is spreading rapidly and threatening wildlife habitat (forage and cover) on the Missouri and Niobrara Rivers. It also forms dense stands on several hundred acres of wetlands on the bottomlands and islands of the Missouri River below the Niobrara. Hybrid cattails are widespread in wetlands. Eastern red cedar, a native tree, is spreading onto grasslands and is developing dense thickets due to lack of prairie fires. In the uplands, woody species are encroaching into native grassland. Smooth brome is widespread in both the uplands and in the bottomlands. Russian olive has invaded many of the shrubland and bottomland forests especially those subject to heavy grazing (NPS 1997).

## WILDLIFE

Wildlife is plentiful in and along the study area. Small mammals, including mice, voles, bats, rats, and ground squirrels make up roughly 60% of the species. Furbearers contribute approximately 20%. White-tailed and mule deer are the only large mammals in the study areas. Coyote, red fox, and badger are common. Other small fur-bearing animals present include raccoon, mink, weasel, muskrat, opossum, striped and spotted skunk, beaver, rabbit, and bobcat (NPS 1997).

The Missouri River ecosystem has long been recognized as a significant pathway for migratory birds, including a number of passerines and birds of prey. Migrating species benefit from

bottomland habitat, which serves for wintering, feeding, breeding, and staging (NPS 1997).

### KNOX COUNTY, NEBRASKA

Knox County has a wide variety of wildlife habitat types for openland, wetland, woodland, and rangeland species. The kind and abundance of wildlife depend largely on the amount and distribution of food, cover, and water. The kind and amount of vegetation that is available to wildlife as food and cover, the availability of natural water sources, and the potential for construction of water impoundments are affected by the soils.

The areas associated with dry cropland, irrigated cropland, native rangeland, pasture and hayland can provide wildlife with cover and food and help control soil blowing and water erosion. The variety of openland wildlife include pheasant, gray partridge, cottontail rabbit, mourning dove. Shallow wetland basins and constructed ponds are in scattered areas and are used by migrating waterfowl and shore birds for feeding and resting. The high quality rangeland habitat in the association with native grasses, forbs, and a few scattered woody plants provides a quality of wildlife. Sharp-tailed grouse, prairie chicken, coyote, mule deer, white-tailed deer, jackrabbit, badger, small rodents, meadowlark, turkey, and horned lark are wildlife species in areas of this association.

The northern part of the county includes areas of upland along the Missouri and Niobrara Rivers, Ponca Creek, and Verdigris and Bazile Creeks. These areas are predominantly native range, but some areas are used for production of dryland or irrigated crops. The wildlife that generally inhabits this area are mule deer, coyote, prairie grouse, small rodents and reptile such as bullsnake, prairie skink, hognose snake, and six-lined racerunner. White-tailed deer, bobcat, turkey, and great horned owl are also in this area.

Areas of bottom land near major stream and rivers may provide habitat for openland, rangeland, woodland, or wetland wildlife, depending on the slope and the degree of wetness. The wildlife species that inhabit these areas include waterfowl, herons, shore birds, woodcock, bobwhite quail, muskrat, mink, raccoon, bobcat, beaver, opossum, skunk, squirrel, red fox, and songbirds. Areas of these associations and adjacent areas of water provide habitat for several threatened species of fish and wildlife. This includes the bald eagle, least tern, piping plover, pallid sturgeon, lake sturgeon, and daces. (NRCS, 1989)

Wetlands. Wetlands, many of which developed in the Lewis and Clark and Niobrara deltas after the construction of Gavins Point Dam, were mapped during the Gavins Point Dam Pool Raise Study in 1983. In the Springfield area, lacustrine wetlands included both shallow open waters near the delta terminus and some larger river backwaters and ponds, covering about 8,272 acres. Riverine wetlands, extending from below Bazile Creek (RM 828) to near Verdel, included 9,960 acres. Palestine wetlands also covered over 9,960 acres. The marsh habitat was the most common herbaceous vegetated type, followed by the mixed scrub-shrub herbaceous type. Small amounts of forested and scrub-shrub wetlands were also identified mostly on the Springfield bottomland. Wetlands, created by changes in channel shape, were maintained by periodic flooding. The lack of flooding has changed the species composition of remaining wetlands. Pool fluctuations above Gavins Point Dam have contributed to the development of monoculture plant (cattails and purple

loosestrife) stands on land that was once prone to flooding (USACE 1995). As this delta continues to form, the riverbed will rise and more adjacent land will flood (NPS 1997).

### ENDANGERED SPECIES

Bald Eagle. Bald eagles use mature riparian timber areas near streams and lakes. Evidence suggests that large cottonwood trees along the Missouri River have passed maturity and are beginning to degenerate. Eagles depend on these trees for nesting, perching, and roosting. Cottonwood regeneration has been almost nonexistent, due in part to the preclusion of natural overbank flooding along the Missouri River, which is necessary for cottonwood germination. Ultimately, successional changes will lead to replacement of the cottonwood habitat by smaller climax species, such as green ash. Loss of habitat and destruction of wild areas through land development and increase human activity are adversely affecting the suitability of both breeding and wintering areas (NPS 1997).

Piping plover. The piping plover nests on sparsely vegetated sandbars, sand, and gravel shorelines of rivers, and alkali wetlands. The amount and distribution of nesting site vegetation affects plover habitat and reproductive success. Plovers select sites away from the water's edge and relatively high above the water. Nesting habitats on the Niobrara and Missouri Rivers typically are dry sandbars located midstream in wide, open channel beds and with less than 25% vegetative cover. These conditions provide the essential requirements of wide horizontal visibility, protection from terrestrial predators, isolation from human disturbance, and sufficient protection from rising river levels. The optimum range for vegetative cover on nesting habitat has been estimated at 0% -1% and where vegetation was less than 10 centimeters high. Open, wet, sandy areas provide feeding habitat for plovers on the river systems and throughout most of the birds' nesting range. Studies suggest that forage areas include the nesting island itself as well as adjacent sandbar flats (NPS 1997).

Terns and plovers are currently using nearly 100% of the available habitat (islands and sandbars) that are considered to be in good condition. Available habitat has been decreasing since 1986. Under normal conditions, about 10% of nestable habitat has been lost each year through sandbar degradations and vegetation encroachment. A minimal amount of new habitat is created annually through sediment aggradation. Due to stabilized flows new habitat is generally of lower elevation (and hence more susceptible to inundation) than the habitat that was historically created under more violent hydrographs. The loss of habitat is due to the stabilization of river flows and the trapping of sediment in the reservoirs (NPS 1997).

Least tern. The interior least tern nests on sparsely vegetated sandbars or shorelines of the Missouri and Niobrara Rivers where there is an unobstructed view of a wide channel. The size of nesting sandbars varies from less than 1 acre to many acres. Varying river flows affect the size and quality of nesting habitat. The primary nesting and chick rearing period for these birds is from early May to late August. The short, free-flowing stretches of river, including the Missouri segment below Fort Randall dam and the lower Niobrara River, provide sandbar habitat needed for tern viability. Terns typically select nest sites away from the water's edge when sufficient habitat is available. Most terns nest in areas of less than 5% vegetative cover that is a few inches tall. The least tern primarily eats fish, feeding in shallow rivers, streams, and lakes (NPS 1997).

Least tern populations have declined as a result of alterations of habitat. According to the Draft Biological Opinion on the Missouri River Master Water control Manual Review and Study (USFWS 1994), channelization and construction of reservoirs and pools have contributed greatly to the elimination of much of the tern's sandbar nesting habitat in the Missouri River system. For example, 76% of the Missouri River in the tern's range is either channelized or impounded. Current regulation of dam discharge poses additional problems for terns nesting on remaining habitats. Lack of scouring of sandbars has resulted in the encroachment of vegetation along many rivers and greatly reduced channel width. In addition, river main stem reservoirs now trap much of the sediment load, which results in less aggradation and more degradation of the riverbed and, subsequently, fewer sandbars. Predation of chicks, disturbance by humans and pets, trampling by cattle, and flooding during the nesting season are other factors that have contributed to population decline (NPS 1997).

Pallid sturgeon. The pallid sturgeon is a native river fish found in the Missouri River and the lower reaches of the Niobrara River. This segment of the Missouri River contains some of the most significant habitat for potential natural reproduction of the sturgeon. The Pallid Sturgeon Recovery Plan (USFWS 1993) identified the area from 20 miles upstream of the mouth of the Niobrara River to the headwaters of Lewis and Clark Lake as one of four areas on the Missouri River for priority implementation of recovery actions.

Pallid sturgeons are well adapted to the swift water of large, turbid, free-flowing rivers. The floodplain, backwaters, chutes, sloughs, islands, sandbars, and main channel of the large-river ecosystem provide macrohabitat requirements for pallid sturgeon and other native fish, such as paddlefish, lake sturgeon, blue sucker, and various river chubs.

Destruction and alteration of habitats by human modification of the river systems believed to be the primary cause of the decline in reproduction, growth, and survival of pallid sturgeon (USFWS 1994). The physical and chemical elements of channel morphology, flow regime, water temperature, sediment transport, turbidity, and nutrients all once provided habitat for pallid sturgeon and other native species. On the Missouri River, approximately 36% of riverine habitat was transformed by construction of the six main stem dams, and another 40% of the river downstream from the dams has been channelized. The remaining 24% of river habitat has been altered due to changes in water temperature and flow caused by dam operations. The Missouri River dams also are believed to have adversely affected pallid sturgeon by blocking migration routes and by causing inundation of spawning and nursery areas (NPS 1997).

## CULTURAL RESOURCES

The Nebraska side of Lewis and Clark Lake possesses outstanding paleontological sites that have produced amphibian, insect, reptile, and rodent fossils from the Miocene and Eocene eras that have never been found elsewhere. Six sites along Lewis and Clark Lake's south shore have produced fossils that have been rated nationally significant. One of the outstanding sites of the lake area is the easternmost land deposit record of the Eocene epoch, and it provides the only evidence that the Eocene wildlife of the Great Plains differed from that of the rocky mountains (NPS 1997).

## SECTION IX - ECONOMIC ANALYSIS OF ALTERNATIVES

### WITHOUT FEDERAL ACTION ECONOMIC OUTPUTS

National Economic Development (NED) outputs, measured in dollars, are used to estimate the contribution Corps projects make to the National wealth. Project outputs, such as the production of hydropower, are easily measured. Others, like recreation and the level of flood damage reduction resulting from a project are more difficult. Losses, such as increased flood damage, the water logging of agricultural land, or the need for infrastructure replacement due to project operation are costs. These diminishing the net NED benefit and if avoided, would accrue as benefits to the alternative providing a solution to the sedimentation problem. The NED outputs of both the Gavins Point Dam and Fort Randall Dam projects are adversely affected by the sedimentation problem occurring in the area of the confluence of the Missouri and Niobrara rivers. The Corps considered future economic losses due to the continuation of the sedimentation problem in this area in a reconnaissance report, prepared by the Corps in 1994. The report, entitled, Lewis & Clark Lake/Lake Sakakawea Sedimentation Study, December 1994 (L&CL Sedimentation Study), considered the loss of NED benefits and the cost of damages at both projects resulting from continued sedimentation. Where relevant, the assumptions and findings contained in that study are incorporated in this report after appropriate updating.

Continuation of the sedimentation problem will reduce NED benefits over time. Additionally, cost incurred with the continuation of current operation or with the implementation of alternatives would occur at different future dates. To facilitate the economic analysis of the no action and other alternatives, a project economic life and annual interest rate are used. It is noted, that the “economic life” of a project is not necessarily the same as the actual project life. It is a reasonable time period used for the analysis of economic costs and benefits for the project. The actual project life could be significantly longer, but would not normally be shorter than the period used for economic analysis. An economic life or planning period of 100 years is frequently used for large dams. However, in this instance an economic life or planning period of 50 years will be utilized. This is because the alternatives being evaluated include equipment with much shorter useful lives than a large dam.

Flood Control. The Gavins Point Dam reservoir, Lewis and Clark Lake, is the smallest of the six reservoirs on the main stem of the Missouri River. With a total capacity of 492,000 acre-feet the lake comprises less than one percent of total main stem storage. Diminishing reservoir capacity due to the accumulation of sediment was considered during the design of the project. About 30 percent of total capacity is committed to flood control storage and multiple use. Flood control storage should not be affected by accumulated sediment during the 50-year planning period. Therefore, no flood control benefits will be lost. Flood control storage at Fort Randall would not be impacted by the Niobrara River sedimentation problem and no loss is considered.

Hydropower. One of the most important aspects of hydropower production is the ability of some facilities to come on line very rapidly. This is not a characteristic of coal fired or nuclear electric generation facilities, many of which takes hours, days, or even longer to come to full production. A

hydropower facility on the other hand can be brought up to full output in a matter of minutes, more closely tracking actual energy demand. The ability to utilize hydropower production in this manner is called peaking. Although actual water release is controlled by many factors in addition to power production, Fort Randall Dam is such a facility. Discharges from Gavins Point Dam are regulated to insure sufficient downstream flow to facilitate other project purposes, such as navigation and flood control. For this reason the Gavins Point powerhouse produces base load electricity, which is less valuable.

Fort Randall Dam – The continued reduction of channel capacity as a result of the deposition of sediment at the mouth of the Niobrara River could reduce the ability to produce peak power at the Fort Randall powerhouse. As the channel capacity is reduced in size, more flooding could occur during high discharges, thereby decreasing the ability to produce peak power at Fort Randall powerhouse. The L&CL Sedimentation Study estimated the annual value of dependable peak hydropower generating capacity lost at Fort Randall powerhouse due to channel size reductions above the Niobrara River's confluence with the Missouri River to be \$4,399,000. Capacity benefits are based on the cost of providing the least costly alternative means of providing the ability to generate electricity. The figure contained in the L&CL Sedimentation Study was updated using the Engineer News Record (ENR) Construction Cost index to reflect the change in the cost of constructing a thermal plant, which is the most likely alternative source of energy. The adjusted annual hydropower loss is \$5,140,000. The 1994 estimate of hydropower loss assumed that channel capacity would gradually deteriorate over a 25 year period. This has not been the case. Discharges from Fort Randall Dam have averaged 26,400 cfs on a daily basis since its closure in 1967. During a three year period from 1995 through 1997 high levels of discharge from the dam, necessitated by high basin runoff, cleared a great deal of sediment from the channel, increasing its capacity by roughly 10,000 cfs. Outflows peaked in 1997, a record year for basin runoff, with average annual daily discharge of 47,600 cfs. The highest discharge was recorded in November of that year with average daily discharge of 66,700 cfs. Some low level flooding was experienced at the higher discharges. These high level discharges were required to prepare the main stem system for flood control storage the following spring runoff. The channel capacity is expected to deteriorate again during prolonged periods of average or low flows.

A less costly alternative to reducing peak hydropower production would be to purchase flowage easements on affected land, thereby allowing current operation to continue. Such purchases have been done as a result of flooding and water logging problems since the closure of Gavins Point Dam. For purposes of estimating the cost incurred, it is assumed that hydropower production will not be reduced by future sedimentation problems, but that sufficient rights in real estate will be acquired to continue powerhouse operation at the current level.

Gavins Point Dam – Gavins Point powerhouse operates as a base load facility. Powerhouse operation is dependent on the need to discharge water from the system and to facilitate downstream uses such as navigation and water supply. Power is produced at a steady level as allowed by water release and does not track the need for power generation. The dam's power generating capability will not be impacted by the sediment problem during the 50-year economic life being considered and probably not until well into the next century. As long as sufficient water can access the turbines to

operate them with the existing head, no loss in hydropower production is expected.

Recreation. No adverse impacts to recreational activity at the Fort Randall Dam project are anticipated. The deposition of sediment in the study area has already limited the use of several recreation areas in the upstream end of Lewis and Clark Lake. The L&CL Sedimentation study reported that recreation opportunities at South Shore, Charley Creek, Sanatee, Springfield, Niobrara, and Weigand Creek recreation areas had already been limited by the sediment problem. In estimating the loss of future benefit for recreation usage, the study assumed that 50 percent of recreation would be lost over the 50-year economic period and that because of crowding, the quality and therefore value of the remaining recreational activity would be diminished. The study projected eventual recreational losses upstream from Charley Creek and the Lindy area. The areas included were Sand Creek, Springfield, Running Water, Charley Creek and Snatch Creek in South Dakota and the Niobrara Knox County, and Santee access areas in Nebraska. Recreation losses over the 50-year period were projected to reach 50 percent of previous activity. Losses were limited to 50 percent because fishing and hunting could both be pursued in the areas after general boating access had been curtailed. The unit day value method, which ascribes an average value to a recreation visitor day based on quality points, was used in estimating the value of the recreation loss. The loss was also present valued over time. The annual loss estimated in 1994 using an annual interest/discount rate of 8 percent was \$562,000. This figure was updated using fiscal year 2001 user day values and a water resources discount rate of 6.375 percent for an annual loss in recreational output of \$789,000.

### ADVERSE ECONOMIC IMPACTS

Land/Real Estate. Agricultural Land - The Corps has purchased real estate in the area above Lewis and Clark Lake as a result of water damage incurred due to the operation of the Gavins Point Dam and Fort Randall Dam projects. The damage is the result of water logging or frequent flooding due to the higher channel level and accompanying ground water level. As more sediment is deposited over time and the river channel aggrades additional real estate will be impacted and acquired. The L&CL Sedimentation Study estimated that flowage easements would be required on 6,400 acres of agricultural land as a result of aggradation over the 50-year study period. The estimated cost of these easements was \$1,350/acre (90% of \$1,500/acre). Since this figure is conservative and there have been no major increases in the value of agricultural land, this same figure is utilized in this study. The purchase price of these easements would be \$8,640,000. However, the land would be purchased as need and accordingly would be discounted somewhat over time. Assuming these purchases are distributed evenly over the 50-year planning period, results in an annual value of 2 percent of the total, or about \$173,000.

River front cabins and mobile homes developments – Several cabin and mobile home developments are located along the right bank (Nebraska side) of the Missouri River in the affected reach. A land use survey was conducted in the impacted area in 1994. Based on that survey, an estimated 100 mobile homes and 24 other structures, primarily cabins, were located in the area impacted by the sediment problem. Some of these structures are suitable for year round habitation, but for the most part they are simple cabins and older mobile homes that have been placed near the river for weekend use. The nominal cost for the purchase of real estate, including the cost of land at that time was

roughly estimated at \$2,463,000. The level of detail required for this analysis does not warrant a new land use survey. However, it is conservatively estimated that the number of structures has not been increased by more than 20 percent in the ensuing years. Several of these years were high water years when the placement of trailers or construction of cabins would not have been advantageous. Additionally the value of structures is increased based on the building cost index to reflect more recent construction cost. After these adjustments are made, the cost of land and structures along this reach of river is estimated to be \$3,444,000. Assuming these purchases are evenly spread over the 50-year planning period, results in an annual value of \$69,000.

Missouri River Mile 838 to 853 Flooding. In 1994, the L&CL Sedimentation Study projected a continued decline in the capacity of the Missouri River between RM 844 and 853. As discussed previously, due to sustained high flows during the 1995 through 1997 period, channel capacity increased significantly during this period. It is believed with a return to normal flows, that streambed capacity will be reduced by the sedimentation problem in the future. The least costly method of accounting for potential flood and other associated problems is to purchase flowage easements to compensate land owners for damages resulting from the operation of Fort Randall Dam combined with the sedimentation problem. For this reason flood damages are not estimated for the area adjacent to the Missouri River. The cost of obtaining flowage easements to address valid damage claims is considered in the real estate section of the economic analysis.

Bazile Creek Flooding. Niobrara River sediment deposits in the Missouri River and the deposition of sediment from Bazile Creek have caused the creek's streambed to raise several feet. Water stages in the lower reaches of the stream have increased accordingly. There are no communities located near the mouth of Bazile Creek so urban flooding is not a problem. To the extent flood damages are increased by the elevation of the streambed, it would impact agricultural land committed to row crops, pasture, and areas near the Missouri River utilized as wildlife habitat. Because of the low intensity mix of land uses, which do not include urban type structures, potential damages would be small or insignificant compared to the cost of the alternative solutions to the sedimentation problem. For these reasons damages were not quantified.

Ponca Creek Flooding. The Ponca Creek streambed elevation of increased 3.5 feet between 1955 and 1985 as a result of Niobrara River sediment deposits in the Missouri River. This increase has likely induced aggradations of a similar magnitude on Ponca Creek, thereby increasing water stages. The loss of capacity on the creek could increase the frequency and severity of flooding on surrounding agricultural land and in the small Village of Verdel, Nebraska, which is located several miles upstream from the creek's confluence with the Missouri River. Due to the size of the community and the frequency of flooding, damages would be small or insignificant compared to the cost of the alternative solutions to the sedimentation problem. For these reasons damages were not quantified.

Springfield Water Supply. The City of Springfield, South Dakota obtains its water supply from the Missouri River in the headwaters of Lewis and Clark Lake at RM 833. The sedimentation problem has threatened the city's water intake for over two decades. Past studies have found that the most reasonable alternative source of water for the city, if the Missouri River intake becomes inoperable,

would be to connect the city's water system to the Bon Homme-Yankton Rural Water System (B-Y RWS). Avoiding the cost of this connection and subsequent increases in water supply costs would result in savings, which would accrue as an NED benefit to the sedimentation project, allowing the continued use of the Missouri River intake. The annual cost of this connection as reported in the L&CL Study was \$254,000. The current cost based on updating construction costs, using the construction cost index and the current water resource discount rate results in an annual cost of \$246,000. The reduction in annual cost, despite increased capital and O&M costs is the result of a lower interest rate (6.375 percent versus 8 percent).

Highway 12 Road Raise. Nebraska State Highway 12 runs east and west. Starting at U.S. Highway 20 in Willis, Nebraska, a community located approximately 12 miles west of Sioux City, Iowa, it runs west, a distance of about 232 miles, to Valentine, Nebraska. In the Niobrara, Nebraska area, segments of the highway are located in the Missouri River flood plain. Parts of the highway, east and west of the Village of Niobrara, and the Niobrara River Bridge have already been raised as a result of problems caused by sedimentation. If the deposition of sediment continues, additional work on Highway 12 will be required. The cost of the additional work is estimated to be \$27,000,000. The timing of this work is dependent on the rate of sediment deposition, the channel capacity of the Missouri River in the area, and the discharge required from Fort Randall Dam. A low segment of the road was raised several miles west of the Niobrara Bridge, in anticipation of the high flows projected to occur and experienced in 1995. Road improvement will likely not be required in the immediate future. However, because of the uncertainty, and the length of time required to implement any potential solution to the sediment problem, it is assumed that the road improvements will be required at the same time as any implemented alternative. Therefore, avoiding the expenditure for a road improvement would accrue a benefit of \$27,000,000 to the alternative providing the solution.

Summary of Benefit Losses and Costs. Benefits would accrue to a project controlling future sediment deposition in the study reach to the extent future benefits would not be lost and future costs would not be incurred. A summary of the benefits, which would accrue to any project capable of continuing the current level of operation are presented below.

Sedimentation Project  
Benefit Summary

	Annual Benefit <u>(\$1,000)</u>	Present Value of Benefit (1) <u>(\$1,000)</u>
<u>Benefit Savings</u>		
Hydropower (2)	\$ 0	\$ 0
Recreation	\$ 789	\$ 11,813
<u>Cost Savings</u>		
Agricultural Land – Flowage Easements	\$ 173	\$ 2,590
Structure Purchase and easements	\$ 69	\$ 1,033
Springfield Water Supply (3)	\$ 246	\$ 3,683
Highway 12 Road Raise (4)	<u>\$ 1,803</u>	<u>\$ 27,000</u>
Total Benefit	\$ 3,080	\$ 46,119

Notes: (1) Value based on a 50-year planning period and an annual interest/discount rate of 6.375 percent.

(2) Restriction to future hydropower production is eliminated by the acquisition of flowage easements and structures on impacted real estate.

(3) Benefit assumes a change in the source of water supply would be needed the same year that a sedimentation project could come on line.

(4) Benefit assumes a road raise would be needed the same year that a sedimentation project could come on line.

## ECONOMIC ANALYSIS

As discussed elsewhere in this report, potential projects are screened to determine if additional consideration is warranted. Three alternatives are considered in sufficient detail to provide the cost estimates necessary for a cost benefit analysis. They are dredging River Mile 834.8 to 851.1, the relocation of the mouth of the Niobrara River, and the Coker Proposal to dredge and deposit the sediment below Gavins Point Dam. These alternatives are evaluated for economic feasibility below.

Dredging RM 834.8 to 851.1. Dredging would protect Fort Randall and Gavins Point dams from the loss of future beneficial economic outputs and eliminate the need for sediment problem related future infrastructure or real estate expenditures. Additionally, it would restore benefits lost previously to some unknown extent. To the extent these have not been quantified, the benefits might be slightly understated. As shown on the table below, this alternative is not economically feasible. Even with out the cost of real estate, the B/C is 0.77. Real estate would significantly add to the cost of this alternative further reducing its feasibility. It is anticipated that several square miles of real estate would be required for the purpose of disposing of the sediment. The net annual benefit for this proposal is a negative \$942,000. A large reduction in project cost or increase in project benefits would be required before this alternative would be feasible. The possibility of trucking the material to Gavins Point Dam, for the purpose of returning it to the river, was also evaluated. Disposing of the material in this manner increase the cost of the alternative by several magnitudes, and was accordingly eliminated from consideration.

Economic Analysis - Dredging	
	Cost
First Cost	<u>(\$1,000)</u>
Construction	\$32,900
Real Estate (1)	0
IDC	<u>524</u>
Total Economic Cost	33,424
Annual Cost	
Interest & amortization (1)	\$ 2,232
O&M (2)	<u>1,790</u>
Total Annual Cost	4,022
Economic Benefit	\$ 3,080
B/C	0.77
Net annual Benefit	-\$ 942
Present Value Net Benefit	-\$14,109

Relocation of the Niobrara River Mouth. The relocation of the mouth of the Niobrara River has many unresolved environmental issues. However, if these were resolved, as shown on the table below, the alternative is economically infeasible and would not likely ever be feasible. Even with out the cost of real estate, the B/C is 0.004, providing a return of less than one cent on each dollar invested.

Economic Analysis – Niobrara River Mouth Relocation

	Cost
	(\$1,000)
First Cost	(\$1,000)
Construction	\$11,000,000
Real Estate (1)	0
IDC	<u>1,400,000</u>
Total Economic Cost	12,400,000
Annual Cost	
Interest & amortization (1)	\$ 828,183
O&M (2)	<u>0</u>
Total Annual Cost	828,183
Economic Benefit	\$ 3,080
B/C	0.004
Net annual Benefit	-\$ 825,103
Present Value Net Benefit	-\$12,353,882

Coker Proposal. The Coker Proposal would provide benefits by maintaining the status quo. No project outputs at Fort Randall or Gavins Point dams would be reduced, flood damage losses would not increase, expenditures for real estate would not be required and infrastructure improvement on Highway 12 and the Springfield, South Dakota water intake would not be necessary.

There are many significant unknowns regarding the viability of this proposal. However, if these unknowns are resolved and found not to add greatly to the cost of this alternative economic feasibility would be a key factor in its further consideration. For this reason this alternative is included in the economic analysis even though its engineering feasibility at the scale proposed is uncertain. As shown on the table below, this alternative is economically infeasible by a wide margin. Even with out the cost of real estate, the B/C is 0.10. The net annual benefit is a negative \$27,433,000. A significant reduction in project cost or major increase in project benefits would be required before this alternative would be feasible.

Coker Proposal - Dredging

	Cost
First Cost	<u>(\$1,000)</u>
Construction	\$20,500
Real Estate (1)	0
IDC	<u>653</u>
Total Economic Cost	21,153
Annual Cost	
Interest & amortization (1)	\$ 1,413
O&M (2)	<u>29,100</u>
Total Annual Cost	30,513
Economic Benefit	\$ 3,080
B/C	0.10
Net Annual Benefit	-\$ 27,433
Present Value Net Benefit	- \$410,738

## SECTION X – SUMMARY

There is no requirement for a non-federal sponsor for the reconnaissance study phase. A plan of study was developed and coordinated with local interests. A range of alternatives is discussed including dredging, canals, diversions, sediment transport methods, and a plan to maintain access to recreation areas. The report focuses on the alternatives supported by the local interests. The results indicate construction projects of this nature are not economically feasible and the federal government cannot participate under current authorities.

Other options may be available for this area. They include adding environmental or recreational components, reducing the scope of construction projects, or providing concepts for a smaller scale or for a localized area. A project might be identified that will provide benefits for a smaller region. These plans might be feasible if the multi-purpose aspects are recognized, including ecosystem restoration, recreation, water supply, or other benefits. Identification of one feasible plan is an important part of deciding whether or not to continue to address a full range of alternatives in a cost-shared feasibility study. The project could be considered for future implementation under the Title IX authority, if funded, or specific legislation resulting from the feasibility study.

A Schedule and Cost Change Request (SACCR) for Niobrara and Missouri Rivers SD/NE (Reconnaissance Study) was approved by Division on 7 August 2001. The SACCR increases the total study cost from \$100,000 to \$200,000 and extends the completion date to July 2002. The additional time and funds are to allow coordination with local interests and identify other options that could be supported by a local sponsor.

## LITERATURE CITED

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Appendix A  
Outline of Proposed Sediment Bypass  
Lewis & Clark Lake – Gavins Point Dam  
September 2001

Outline of Proposed Sediment Bypass  
Lewis and Clark Lake – Gavins Point Dam  
September 2001

SITUATION: Sediment deposition in Lewis and Clark Lake is a significant problem in terms of reservoir storage, recreational and water supply impacts, and reduced efficiency for hydropower generation. E. Howard Coker of the University of South Dakota has discussed potential mitigative measures, with a focus on dredging the sediment and transporting the spoil past Gavins Point Dam via a pipeline.

REFERENCES

1. “The Costs and Benefits of Converting the Three Lower Missouri River Mainstem Reservoirs to Sustainable Systems, with Supporting Information,” E. H. Coker and R. E. Randall.
2. “Conversion of a Flood Control System to a Sustainable System: The Energy Requirements for Pipeline Transport of Silt,” E. Howard Coker
3. “Suspended Sediment Data Assessment Study, Missouri River at Sioux City, Iowa,” Omaha District, MRR Sediment Series Report No. 39a, Jan 2001.

PURPOSE: The Omaha District is evaluating the viability of practicable alternatives outlined by Dr. Coker. The District is focusing on the sedimentation problem in Lewis and Clark Lake, where the reduction in reservoir capacity is greatest of the six mainstem dams on the Missouri River.

GENERAL ASSUMPTIONS: Dr. Coker has presented various calculations, determinations and assumptions in the reference documents. The District’s approach has been to accept most of the

assumptions and calculations, after a cursory review for reasonableness. The analysis would be more rigorous if this initial evaluation would develop into a formal feasibility study.

### SEDIMENT INFLOW

Volume of material to transport: Sediment accumulation in the reservoir is estimated to be 2800 acre-feet (or AF), as indicated in the Coker documents. This represents the amount of storage volume that the reservoir loses in an average year, as the bed elevation of the river/lake increases. The sediment deposits are, of course, saturated, and therefore the sum of the sediment particles comprising such deposits is less than 2800 AF. The storage volume loss includes the water between the sediment particles, since that water could not be moved in and out of the sediment relative to reservoir operational requirements.

The relationship between sediment inflow and sediment deposits is seen in the sediment measurements tabulated in a June 1970 report (DM No. MG-91) that the District produced. The sediment rate between Fort Randall Dam and Springfield, SD was 2160 AF per year (not including 240 AF from the river's own sediment). The amount of sediment entering the river in this reach was 3.805 million tons. If this material has an average density of 165 pounds per square foot, the volume of this sediment (as a sum of the sediment particle volumes) would be 1186 AF. This indicates that the sediment inflow (sum of particle volumes, that is, the "dry" sediment) would comprise  $1186/2160 = 55$  percent of the sediment deposits. (This factor of 0.55 is the  $C_s$  in the Coker documents, defined as the volume fraction of solids in the settled sediment, also known as the packing efficiency).

The figure of 2800 AF is a refinement of the 2400 AF estimated in the 1970 report (2160 + 240). A system to remove sediment would be based on the volume of the dry sediment. In this case,

the amount of sediment that would need to be transported in aqueous form (pipeline slurry) would be  $0.55 \times 2800 = 1540$  AF per year. This is the volume removal requirement that Coker's proposal would target. The District is taking a more conservative approach, recognizing that any downtime in the system would compromise the system's intent to prevent future loss of reservoir volume. Consequently, our target is 110 percent of the estimated actual inflow. The reservoir already has lost the equivalent of 45 years of sediment deposition, so removing up to ten percent more than the annual inflow would not risk depleting the reservoir's accumulated sediment.

### PHYSICAL DESIGN FACTORS

- Design Life: 50 years
- Slurry requirements: The physical requirements for entraining the sandy sediment from the Niobrara River, as outlined by Dr. Coker, appear reasonable. That is, this gradation of sand could be transported by pipeline, as long as a minimum velocity was maintained.
- Pumping time: The Coker documents use 75% of the year for pumping the slurry. The District would deviate from this, to closely match the period during which Gavins Point Dam provides enough water to ensure prescribed depths in the navigation channel. The navigation season typically runs from 1 April to 30 November. Support releases from Gavins Point must be provided at least a week ahead, to reach the mouth of the Missouri River by 1 April. For this analysis, the slurry pumping would start 22 March. We took the end of the slurry operation as 15 November, to allow for the occasional shortening of the Navigation Season. The resulting period of operation thus was set at 239 days, as compared to 274 days in the Coker outline.

- Length of pipeline: If the pipeline originates near the primary source of sediment (Niobrara River, at Missouri River mile 843) and discharges a mile below Gavins Point Dam (mile 811), a pipeline generally following the reservoir would be  $33+1 = 34$  miles long. The pipeline probably will follow some roads rather than hugging the shoreline, so the pipeline would tend to be longer than the river length between the Niobrara and the dam. On the other hand, a reasonable location for the dredge would be one-third of the way into the delta, rather than right at the Niobrara's mouth. When a contingency factor is included for field constraints in locating the pipe, the 34-mile estimate is probably quite reasonable. A potential alignment for the pipeline is shown on the attached map.

#### SLURRY FLOW CALCULATION

The Coker analysis concluded that a 12-inch diameter pipe would be required to transport 2800 acre-feet per year. Allowing for at least 10 percent additional capacity in a shorter period would push the pipe size to 14 inches. The cross-sectional area of a 14-inch pipe is 1.069 sq. ft. The other values used by Coker are:

- Velocity: 9.84 feet /second
- Slurry concentration: 35%

The total flow through the 14-inch pipe thus would be:

$$\frac{9.84 \text{ ft.}}{\text{sec.}} \times \frac{1.069 \text{ ft}^2}{\text{day}} \times \frac{86400 \text{ sec.}}{\text{day}} \times \frac{\text{acre}}{43560 \text{ ft}^2} = 20.86 \text{ AF/day}$$

Running this pipeline 239 days thus would discharge 4986 AF of slurry per year. The sediment would comprise 35% of the slurry, or 1745 AF. The target quantity of sediment to be removed (i.e., the "dry" volume entering the reservoir) is  $1540 \times 1.1 = 1694$  (rounded up to 1700 AF/year). The 14-inch delivery system thus could surpass the target by 3 percent.

#### WATER FLOW CALCULATION

Pipe flow would be maintained year-round, even though the sediment slurry is not going to be transported during the winter. The water requirement for the 35% slurry will be 65 percent of the total pipe flow. During the winter, it will be 100 percent of the flow. The water flow in the slurry delivery is  $.65 \times 4986 = 3241$  AF per year. The water flowing through the pipe when the slurry is not being transported will be the total flow,

for 15 November through 24 March (average of 126¼ days per year) à 4986 x  
 $126.25/239 = 2634$  AF/year

The primary impact of using this water for the sediment bypass will be the resulting loss of the water for power generation. Statistics for the Gavins Point discharge through the powerhouse and the spillway were evaluated, to determine how much spillway water would be available for the bypass. These statistics include power generation. The water flow analysis is presented later in this document.

### DREDGE PRODUCTION

Cutterhead suction dredges would be appropriate for this type of operation. A 24-inch dredge should be able to move 1000 c.y. sediment per hour, and an 18-inch would have a production rate of at least 500 c.y. per hour. Since pipeline operation would be continuous for 8 months, it would be appropriate to run the dredges 24 hours a day. Production thus would be 7.44 acre-feet per day for the 18-inch dredge, and 14.88 acre-feet per day for the 24-inch unit. The discharge velocities of the dredges are assumed to be the same as for the pipeline, 9.84 feet per second.

### BUFFER POND

The pipeline should have a holding area at its intake, so that the slurry can be kept at near its optimum concentration. Dr. Coker noted how this feature should be accounted for, but that it was beyond the scope of his analysis. He assigned this a cost of \$1 million, apparently covering the full actual cost. The District went a little further with its cost estimate, setting a minimum capacity of 14 days of 24-hour dredging:  $45 \text{ AF} \times 14 = 630 \text{ AF}$ . A depth of 10 feet would be reasonable, leading to an area requirement of 63 acres (approximately 1700' x 1700').

For estimating cost, assume that the average berm height is 15 feet (including freeboard). If the berm side-slopes are 1V:2.5H, the material requirement for the sides of the pond will be  $562 \text{ sq. ft.} \times (4 \times 1700')/27 = 142,000 \text{ c.y.}$  If it costs \$3.00 per c.y., the holding pond would cost \$426,000. Due to the coverage of the operation over fifty years, at least 2 ponds will be needed. This brings the cost close to the \$1 million that Coker used in his tabulation. If we apply a 25% contingency, the cost of the holding ponds becomes  $\$426\text{k} \times 2 \times 1.25 = \$1.07\text{M}$  (rounded to \$1.1M).

### PRACTICALITY CONSIDERATIONS

A critical procedure in the proposed transport system is the buffer or transition pond, where dredge output would settle to an optimum concentration, and then be pumped into the pipeline. First of all, dredges normally discharge at a concentration of 10 to 20 percent, compared to the 35% that desired for this pipeline system. In addition, the rapid settling rate for these sands will make it difficult to keep the slurry concentration within a tight range of concentration. Also, the mechanics of processing the dredge discharge into

a ready supply of slurry is not defined. These conceptual uncertainties led this office to explore variations on the original concept.

A transition pond can improve the control of slurry concentration, and may serve an important function as an area where undesirable material (rocks, tree roots, etc) can be screened out of the pipe intake. On the other hand, it requires that 2 dredging operations be used to feed the pipeline. It may be practical to run the dredge directly into the pipeline, if the lower slurry concentration and the higher velocities are acceptable.

## ALTERNATIVES

Five configurations were evaluated, starting with the basic project that Dr. Coker put forth. All five meet the production target. A critical feature in these systems is the requirement for numerous booster pumps. We assumed that a pump will be needed every two miles. These pumps are expensive (especially for larger units), and the sand likely will cause critical wear during the eight months of pumping sand. Therefore, the cost evaluations look at annual replacement for all the pumps.

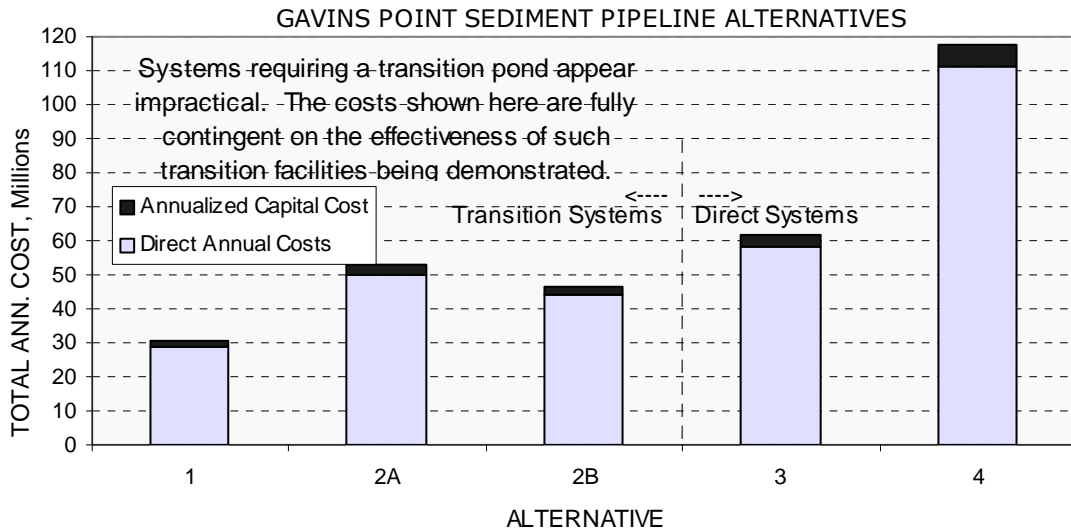
The 34-mile pipeline would need 17 booster pumps, working continuously. It is reasonable to assume various critical components may fail during the 8-month slurry transport operation. Any such failure would shut down the entire operation. Some of the alternatives include dual dredges and/or dual pipelines, which potentially would allow at least some sediment transport while one-half of the system is down.

Pumping water during the winter has its benefits (e.g., keeping the system from freezing up), but it may not be necessary. If the system is properly drained at its late autumn shutdown, the water and the energy to pump it would be saved. For this evaluation, the winter operation was disregarded. However, the small amount of lost hydropower under the winter pumping scenario was left part of the overall cost (to ensure that any worst-case hydropower impacts are fully considered). The five following configurations were evaluated.

- 1 Two dredges (24-inch), transition pond, 14-inch pipeline
- 2A Two dredges (18-inch), transition pond, 18-inch pipeline
- 2B Two dredges (18-inch), transition pond, dual 12-inch pipeline
- 3 One 24-inch dredge, connected directly to a 24-inch pipeline
- 4 Two 24-inch dredges, connected directly to dual 24-inch pipeline

The following chart shows the total annualized cost for the five alternatives. Capital costs were annualized using a 50-year term, at an annual interest rate of 6.375 percent. The large component of the total annual cost for each alternative consists of the direct annual cost (pump replacements, O&M, etc). The annualized capital costs comprise the small additional cost on the top of each column.

Fig. 1



The costs in this chart are included in the following table, along with the estimated sediment removal and slurry concentration. The table also indicates which proposals have the potential to continue at least partial operation when any critical component fails (that is, systems with any dual features).

Alternative	Sediment Removal (relative to target)	Slurry Concent.	Partial Operation Possible		Annual Cost (\$ millions)
			Dredge	Pipeline	
1	103%	35%	+	-	30.5
2A	170%	35%	+	-	52.7
2B	150%	35%	+	+	46.3
3	210%	24%	-	-	61.6
4	430%	24%	+	+	117.8

### REVIEW OF ALTERNATIVES

Due to the high degree of uncertainty for working the dredge discharge into the a pipeline at an acceptable concentration and velocity, the chart in Figure 1 separates the alternatives on whether they are direct or transition systems. Alternatives 3 and 4 do not depend on transition facilities, and therefore are considered more favorably at this time. The dual 24-inch system would allow for partial operation if a critical component would fail, but the cost is so much higher than the single 24-inch system that the partial operation capability probably would not be cost effective. Its ability to remove more than 4 times the target volume of sediment each year is not a significant advantage, since the targeted volume already accounts for removing at least the 1700 AF. In addition, its cost is more than twice that of any of the transition systems. Therefore, Alternative 4 should be removed from consideration.

The advantage of Alternative 2A relative to its transition system counterparts is its ability to remove 170 percent of the targeted sediment inflow, compared to 150% or 103%. However, that advantage has little significance if the other two systems can deliver according to the according to the schedule laid out. Alternative 2A therefore also has no advantage that merit keeping it in the list of available options.

The dual pipes on Alternative 2B possibly could justify a cost that is 50% higher than Alternative 1. Not only could it maintain partial operation during a component failure, it also could justify a more relaxed pump replacement schedule. For example, the change-out period possibly could be extended to 2 years.

The likely alternatives to consider in greater detail in any follow-up study thus would be as follows.

- No. 1 two 24-inch dredges à transition pond à one 14-inch pipeline
- No. 2B two 18-inch dredges à transition pond à two 12-inch pipelines
- No. 3 24-inch dredge direct into 24-inch pipeline

## INSTREAM SEDIMENT TRANSPORT

Although the river below Gavins Point Dam presently is flowing in a sediment-deficit mode due to the entrapment of the sediment in the reservoir, the river's change in configuration since the dam closed could lead to a reduced transport capacity. That is, the sediment that the river transported prior to the dam closure theoretically could be more than the present river can carry. We reviewed the transport capacity as predicted by two transport functions, Ackers-White and Yang stream power. Both functions should be applicable for the sandy sediment in this reach of the Missouri. The results of these equations were compared to 20 years of sediment data at Sioux City.

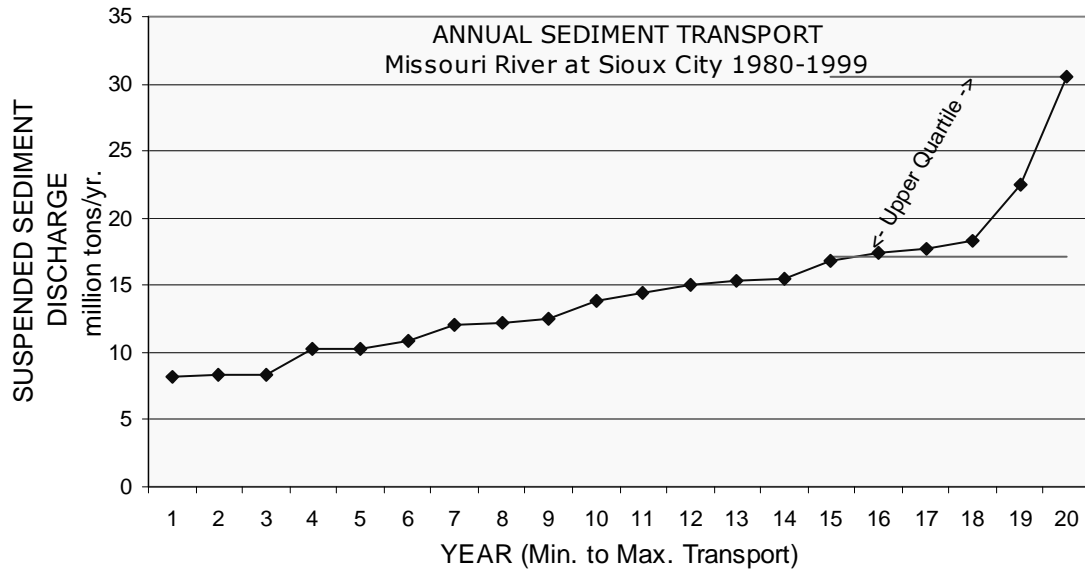
The above application of transport equations failed to produce a reliable estimate of the river's capacity to transport sediment. A mathematical model (e.g. HEC-6) may need to be set up to better assess the river's capacity at moving the transported sediment downstream from the dam.

The 20 years of data at Sioux City showed that the river's annual sediment transport has ranged between 8.2 million and 30.5 million tons. The upper quartile has a floor of 17.1 million tons.

The 2800 AF of in-place sediment is equivalent to 5.5 million tons of solids, based on a 55% packing efficiency. The target rate of removal thus would be  $1.1 \times 5.5$  million = 6.05 million tons per year. The 20-year average for suspended sediment passing Sioux City is 14.5 million tons. The chart shows that significantly more sediment can be transported when there are sufficient high flows. The maximum sediment discharge in this period was 30.5 million tons. In theory, sediment introduced below the dam during low water years would be available for transport when the high flows arrive. If the average value of the upper quartile (21.3) is considered indicative of the river's capability to move sediment, then the river theoretically should be able to pick up 6.8 million tons

more than it currently carries ( $21.3 - 14.5 = 6.8$ ). So, if the material reaches the navigation channel (starting 58 miles below the dam), the channel should be able to carry at least 110 percent of the targeted piped-in sediment. Several problems could reduce this theoretically “balanced” sediment system, as itemized below.

Fig. 2



- Figure 2 shows how the highest years for sediment transport rise significantly from the rest of the values. For most of the data points, a year’s value is between 1½ and 10½ percent above the previous value. The next-to-highest value (for the year 1996) is 23% higher than the previous value. The year of greatest sediment transport (1997) is 35% higher than that of 1996. It may be that such high flows will be too infrequent to adequately flush the piped-in sediment. That is, without such more extreme flows, the upper quartile would have a lower value, and the theoretical transport capacity would be less than estimated.
- The channelized river beginning 58 miles downstream of the dam ensures relatively high velocities, as the flow is constrained between dikes and revetment. The river in the natural 58-mile reach spreads out between the high banks, allowing sand to drop out in the form of sandbar reefs. Before the dams were built, such sand deposits would tend to raise the average bed elevation. The average elevation then would drop when flood flows would scour out new primary channels. The dams now truncate the flood peaks, thereby greatly reducing the river’s scour potential. While the piped-in sediment would halt most of the degradation, it likely would tip the balance significantly in favor of aggradation. Overall, this might not be a major problem, since degradation has been so prevalent over the last 45 years. However, localized aggradation could indeed be problematic, causing such problems as difficult passage for boats, lowland flooding and localized channel instability.

- The theoretical capacity of the river to entrain the new source of sediment relies on that material to be “available” for suspension when high flows arrive in the reach. If such flows aren’t frequent enough, the sediment will be able to consolidate more, and actually armor itself. Consequently, the high-flow energy may end up exiting the reach without picking up its maximum load. Over time, such flow regimes could allow the introduced sediment to accumulate.

## HYDRAULICS

Dr. Coker’s documents included an extensive discussion of the sediment transport characteristics of the type of sand that would be pumped past the dam. He also discussed the abrasiveness of the sand, and available measures to prevent premature pipe wear. On the surface, his assumptions appear reasonable. Our review did not delve into the details of the hydraulic assumptions and calculations. Thus, at this time, we do not question his conclusions that a transportable slurry can be made from the sandy sediment, and that a polyurethane liner can virtually eliminate significant pipe wear. Our cost estimates used polyethylene pipe, which is relatively resistant to wear from silts and clays, and may also be adequate against the type of sands in this project. If this project moves into a feasibility level of study, all hydraulic and product durability issues will have to be verified.

## IMPACT ON POWER GENERATION

The amount of water for a slurry in a 14-inch pipe is small relative to the dam’s normal discharge, but the diversion of this water from power generation represents a definite loss of revenue. This would occur whenever flows aren’t exiting through the spillway. We looked at 34 years of the dam’s discharge records, broken down by powerhouse and spillway. This was evaluated by month (as well as the partial months of March and November, at the transition into and out of the navigation season). The average spill for each of these months and split months was greater than the pipeline water requirement. However, the water diversion from the powerhouse would be needed for any month where there is no spill. During the 34-year period of record, this condition occurred during 61 percent of the navigation months, and 74 percent of the winter months. The pipe flows for these categories are 6.8 cfs for 146 navigation days, and 10.5 cfs during 93 winter days. The typical power conversion is 80 MWhr per 1000 cfs per day. Thus, the power lost to the pipe water is  $80 \times 79 = 159$  MWhr per year. For a price of \$40 per MWhr, the annual revenue loss would be \$6300.

The additional water that would flow through the other pipes also was calculated, and the resulting costs were incorporated in the total cost for each alternative design. This is to ensure that any potential loss of hydropower revenue is accounted for. Conversely, costs for operating the pipeline during the winter were not itemized, since that extra four months of operation has not been demonstrated as essential.

## CONCLUSIONS

- The basic concept of transporting sandy sediments from the Niobrara River delta to below Gavins Point Dam has not shown any fatal flaws. Material and equipment for such a system apparently are available.
- Transporting Niobrara River sand poses several problems that will require further analysis, research, or modeling. Some critical items are:
  - ⌘ How would the dredged material be transformed into the correct range of slurry concentration, and what quality control measures would that require? That is, how would the transition pond be operated?
  - ⌘ What ranges of slurry concentration would be acceptable (based on the apparent optimum value of 35%)?
  - ⌘ Although pipe wear apparently won't be a major problem, pump wear is expected to be critical, in terms of full replacement every year, and for the potential for unit failure during operation. Is there any possibility of obtaining specialized wear-resistant pumps? What provisions would be needed to get the system on line after a pump fails (backups, restart procedures, etc.)?
  - ⌘ If the system should prove to be fully successful, the dredge will have to be moved into adjacent deposits. How would this translate into the need for building new transition ponds, and increasing the pipeline length?
  - ⌘ A rigorous analysis of sediment transport should be conducted, which should identify the potential for sediment accumulation below the dam.

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