EVALUATING SUSTAINABLE SEDIMENT MANAGEMENT ALTERNATIVES FOR LEWIS AND CLARK LAKE

Paul M. Boyd, Ph.D. P.E, Hydraulic Engineer, U.S. Army Corps of Engineers, Omaha, NE, paul.m.boyd@usace.army.mil; Stanford Gibson Ph.D., Hydraulic Engineer, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA, Stanford.gibson@usace.army.mil

The views expressed in this paper are those of the author(s) and do not necessarily reflect the official policy or position of the United States Army Corps of Engineers, the Department of the Army, Department of Defense, or the United States Government.

Abstract

The Missouri River Recovery Program initiated the Lewis and Clark Lake Sediment Management Study (LCLSMS) to evaluate sediment flushing scenarios at Lewis and Clark Lake/Gavins Point Dam near Yankton, South Dakota. Phase I of the report examined large discharges for short durations, and was published in April 2013. Phase II utilized new features in HEC-RAS (e.g. unsteady sediment transport and bank erosion modeling) to develop an updated reservoir model to examine additional scenarios. The second phase considered in-channel discharges of varying durations to estimate delta progression, evaluate dam and spillway modifications, and predict sediment delivery through Gavins Point Dam.

This paper describes the application of these new tools to the reservoir model and a downstream model to assess impacts of the predicted sediment discharge. Results of the modeled scenarios are summarized and conclusions made about the effectiveness of using HEC-RAS for reservoir modeling.

INTRODUCTION

The deposition of hydraulically transported sediments occurs in all flow impoundments, whether they are constructed or naturally occurring. Sedimentation occurs when flow velocities drop below the threshold required for transport. This deposition can cause an impediment to flow and an eventually redirection of flow. This usually occurs when the impoundment is completely or nearly full of sediment. If left in the current flow regime, Lewis and Clark Lake will eventually fill with sediment, albeit more than 150 years in the future according to current projections.

Lewis and Clark Lake is impounded by Gavins Point Dam on the Missouri River. Its existing uses would be severely compromised if the reservoir is allowed to fill with sediment. The reservoir is operated for flood risk reduction, hydropower, navigation, recreation, water supply, water quality, fish and wildlife, and irrigation. The Lewis and Clark Lake Sediment Management Study is evaluating a wide variety of scenarios for managing the reservoir and the sediment within it to continue to provide the intended benefits.
Lewis and Clark Lake

Lewis and Clark Lake was formed by the closure of Gavins Point Dam in 1955. The dam is located at river mile 811.1 (RM 811.1), approximately five miles upstream of Yankton, South Dakota, on the Missouri River as shown in Figure 1. Gavins Point Dam is one of six mainstem dams on the upper Missouri that are operated by the Northwestern Division of the U.S. Army Corps of Engineers. The Missouri River dams and reservoirs provide significant benefits to the nearly 15 million people that reside in the states through which it flows.

Figure 1 Lewis and Clark Lake behind Gavins Point Dam

Lewis and Clark Lake reached its full water surface elevation of 1208 feet (NGVD 1929) in early 1957 and has been managed with water elevations between 1206 feet and 1210 feet (NGVD 1929) ever since. When closed, the lake extended to approximately RM 836, creating an open-water lake that was approximately 25 miles long.

Since closure, sediment surveys have been performed approximately every decade to determine the amount of sediment deposition and changes in the reservoir’s storage capacity. These surveys have indicated that approximately 2,600 acre-feet of sediment have been deposited per year below elevation 1210 feet (NGVD 1929) through the 2011 surveys (USACE, 2013a). In the reach between Gavins Point Dam and Fort Randall Dam at RM 880, sediment is delivered from tributaries including the Niobrara River, Ponca Creek, and Bazile Creek, as well as from the banks and bed of the river upstream. Figure 2 shows the two largest deltas in the river reach. Additional sediments are deposited in the overbanks of the river and in the Niobrara River delta at RM 844, yielding a total sediment input into the reach in excess of the volume below the 1210-foot threshold.
The deposition of sediments in the Lewis and Clark Lake delta has effectively shortened the length of the lake over the past 50 years. Currently, the open reach of the lake extends to near RM 826, a distance of 15 miles of open lake. The migration of the delta appears from visual observations to be approximately 500 to 600 feet per year, although the deposition rate has remained fairly constant over the past 50 years (USACE, 2011).

The migration of the delta both up- and down-river reduces the storage capacity of the reservoir. The initial capacity of the lake was 575,000 acre-feet below the 1210-foot elevation, and the 1995 capacity was 470,000 acre-feet, which is a storage loss of approximately 18.5 percent. Storage loss was updated with the 2011 surveys for this project. These surveys indicated the total storage loss at the 1210-foot elevation was 26 percent (USACE, 2013).

THE LEWIS AND CLARK LAKE SEDIMENT MANAGEMENT STUDY (LCLSMS)

The LCLSMS was developed to examine the engineering viability of moving the sediments deposited behind Gavins Point Dam into the river downstream of the reservoir. In the 2003 amended Biological Opinion (BiOp) for the Missouri River, the U.S. Fish and Wildlife Service stated “The Corps shall research and develop a way to restore the dynamic equilibrium of sediment transport and associated turbidity in river reaches downstream of Fort Peck, Garrison, Ft. Randall, and Gavins Point Dams. Sediment bypass around large dams is feasible (Singh and Durgunoglu, 1991). Bed degradation below dams and head cutting at the mouths of tributaries might be addressed with grade control structures. Weir notches at grade control structures would allow for fish passage to the tributaries. Because of the large sediment deposition zone at the upper end of Lewis and Clark Lake and its proximity to Gavins Point Dam, Gavins Point may provide the best opportunity for a pilot study (USFWS 2003).”

Initial consideration of using flows through the reservoir to transport sediment was not strongly supported. Additional research on the reservoir system in the Lewis and Clark Lake reach showed that there is the possibility that sediments can be transported through Lewis and Clark Lake (Engineering and Hydrosystems, 2002). A number of different flow and stage...
scenarios have been suggested by this research. With the recommendation for a study at Gavins Point Dam through the BiOp, and proof of concept provided by the 2002 study by E&H, the LCLSMS was initiated in 2005.

**Project Goals**
The LCLSMS is an engineering viability study. As defined, the study will deal only with the physical processes of hydraulic flow, and sediment erosion, transport, and deposition. Environmental, economic, political, and quality of life issues will not be considered in the scope of this study. The project goals are to:

- Determine the hydraulic capacity to transport sediment in and below Lewis and Clark Lake
- Develop estimated final reservoir geometries as a result of flow alternatives
- Determine downstream sediment transport capacity and possible deposition zones
- Develop a test flow to mimic the hydraulic alternative most likely to result in the desired outcome
- Protect existing project infrastructure

Since the study began, it has grown to include two modeling phases to evaluate hydraulic drawdown flushing, a modeling effort to examine the future depletion of available sediments below the dam, and a cost analysis of dredging alternatives.

**LCLSMS Activities**

**Phase I – Using GSTARS-HTC to Examine High Flow Single Events**
The LCLSMS project began with the development of the project plan and scope of work for modifying GSTARS3 by Colorado State University’s Hydroscience and Training Center (HTC) in 2005. Award of the work to develop GSTARS-HTC signaled the beginning of the project in late 2005. This effort was considered Phase I, and was completed in 2012.

**Phase II – Using HEC-RAS to Examine Repeated Flow Events**
Based on the results of Phase I and stakeholder feedback, the Missouri River Recovery Program (MRRP) chose to continue the study by expanding it to include more flow scenarios and examine the impacts of repeated events into the future. This phase also included the transition to the HEC-RAS one-dimensional model for analysis (HEC-RAS v.5.0). This phase began in latter 2011 and is expected to be completed by the fall of 2015.

**Projection of Future Conditions below Gavins Point Dam**
In coordination with the Emergent Sandbar Habitat (ESH) Program, the LCLSMS expanded the study to include an analysis of future sediment availability in the reach below Gavins Point Dam in 2012. It is expected to be completed in the fall of 2015.

**Cost Analysis of Dredging Alternatives for Lewis and Clark Lake**
Dredging is a common management action for rivers, lakes, and harbors. Many stakeholders have inquired about the Corps’ ability to dredge Lewis and Clark Lake and the magnitude of the effort needed to maintain the current reservoir capacity. The study has teamed with the Corps of Engineers Research and Development Centers (ERDC) Dredging Operations Technical Support
Program (DOTS) (http://el.erdc.usace.army.mil/dots/) to consider three dredging configurations for Lewis and Clark Lake. The dredging alternatives study was begun in mid-2013 and is expected to be completed by the fall of 2015.

ANALYSIS AND RESULTS

Phase I Results
Two numerical sediment transport models were developed to predict the movement of sediment through and below Gavins Point Dam. The Lewis and Clark Lake Model used the GSTARS-HTC (USACE, 2013b) code to predict sediment transport through the Missouri River delta and past the spillway at Gavins Point Dam. The model extends from Fort Randall Dam (RM 880) to Gavins Point Dam (RM 811). The model for the reach from Gavins Point Dam to Sioux City, Iowa (RM 730) used HEC-RAS to route the flow and sediment output from the reservoir model through the recreational river reach below the dam, and deliver it to the downstream navigation channel.

Five flushing scenarios were developed based on guidance from a flushing-reconnaissance report (Engineering and Hydrosystems Inc, 2002) that recommended very high river flows for short durations. Flow scenarios varied from 88,000 to 176,000 cfs, with the peak flow lasting up to seven days.

The largest event was also simulated with a section of the Gavins Point Dam spillway lowered by ten feet to increase the energy available to move sediment. For the study analysis, all flows were released through the spillway at Gavins Point Dam to avoid sending sediment through the powerhouse. All the scenarios included draining Lewis and Clark Lake (to increase effectiveness), increasing discharge at Fort Randall Dam upstream to the peak flow, maintaining the flow for the flush duration, and reducing the flow as the reservoir refills.

All the flushing scenarios predicted transport of silt and clay size particles through the dam. In the cases of the high flow and modified spillway, the model predicted very high sediment concentrations and total mass of sediment transported. Each scenario also predicted the redistribution of sand-size particles throughout the delta and bottom of Lewis and Clark Lake. However, due to the length of the reservoir and the location of the spillway gates, which are 20 feet above the lake bottom, almost no sand passed through the spillway for any scenario. Only the flushing scenario with 176,000 cfs and the modified spillway gates, when sediment concentrations were the highest, predicted 0.07% of the mass of sediment passing the spillway as sand; the remaining 99.93% was silt and clay (USACE, 2013c).

While these high-flow, short-duration scenarios did not predict the delivery of enough sand to support sandbar habitat below the dam, a number of conclusions indicate that there may be scenarios not modeled in this study that would hold promise. Study results are summarized as:

- All the modeled scenarios showed erosion of delta deposits and redistribution of sand within the reservoir, with much of the sand settling in the deepest area of the lake. Repeated flushing events may result in better sediment transport to the downstream channel once the deeper areas are filled in.
• Modifying the spillway resulted in a significant increase in sediment transport. The modification of the spillway or inclusion of low-elevation outlets in the dam structure could greatly increase flushing efficiency.
• The spillway crest elevation above the reservoir bottom prevents complete draining of the reservoir through the spillway, resulting in a sediment trap at the face of the dam. As the delta migrates closer to the dam, transport of sand to the face of the dam will increase during any flushing event. Therefore, flushing effectiveness will increase in the future.
• The downstream model predicted minor aggradation of the channel only with the highest sediment discharge from the dam. Since the sediment in the dam discharge was comprised of silts and clays, most were transported through the reach and into the navigation channel.

These conclusions directly led to the development of Phase II and the inclusion of longer and more varied management scenarios. All the documents associated with the Phase I and Phase II modeling studies are available at http://moriverrecovery.usace.army.mil/mrpp/f?p=136:155:2604171657024::NO::PIS_ID:28.

**Phase II Analysis - Using HEC-RAS to Examine Repeated Flow Events**

Stakeholder feedback and additional questions from other Federal agencies prompted the MRRP to expand the LCLSMS study to include flushing scenarios that limited flow to the bank-full condition coupled with a long term view to sediment management.

**Table 1 Gavin's Point Dam and Lewis and Clark Lake Advantages and Challenges to Alternative Sediment Management (USACE, 2015)**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gavins Point is the most downstream dam of the Missouri cascade and immediately upstream of the target reach to increase sand load.</td>
<td>Eighteen miles of open water between the current sediment delta and the dam.</td>
</tr>
<tr>
<td>Relatively small reservoir for the Missouri River.</td>
<td>The dam has no low-level outlets. So even when drained, the reservoir has a standing pool and multiple miles of open water between the delta and the structure.</td>
</tr>
<tr>
<td>Niobrara River delivers a substantial sand load 33 miles upstream of the dam.</td>
<td>There are social and policy constraints on the releases that can be made from Gavins Point dam.</td>
</tr>
<tr>
<td>Fort Randall Dam allows managers the flexibility to specify an optimal inflowing hydrograph with unusual precision.</td>
<td>The impoundment volume of the upstream Missouri cascade removes the standard refilling uncertainties associated with sediment management draw downs in other systems.</td>
</tr>
</tbody>
</table>

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

The reservoir model was constructed using a developmental version of HEC-RAS 5.0. HEC-RAS was selected primarily for institutional and transparency reasons. Since the Omaha District has constructed 1D hydraulic models of this system with HEC-RAS, it was advantageous to use HEC-RAS for the sediment modeling. Keeping the sediment model in the same modeling platform as the hydraulic analyses leverages District data and expertise. However, Omaha and HEC identified several limitations of the release version of HEC-RAS 4.1 that complicated flushing analyses in this system. Therefore, this analysis integrated project modeling with software development to implement new methods in HEC-RAS and apply them to the Lewis and Clark Lake analysis.

The scenarios to be modeled were vetted through stakeholder and local and Federal agency feedback. While the list is not all-inclusive, it does cover most of the commonly considered management modifications for reservoir flushing. Many of these scenarios would require significant investment in the project infrastructure. However, any cost comparisons should include the cost of lost benefits due to sedimentation. Table 2 summarizes the scenarios modeled in the HEC-RAS Lewis and Clark Lake model.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Flushing Flow (cfs)</th>
<th>Flushing Duration</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>II-1</td>
<td>None</td>
<td>None</td>
<td>No Action – 53 year projection to determine delta progression through 2064</td>
</tr>
<tr>
<td>II-2</td>
<td>60,000</td>
<td>7 days</td>
<td>Base alternative – single drawdown flushing event</td>
</tr>
<tr>
<td>II-3</td>
<td>60,000</td>
<td>7 days</td>
<td>Scenario II-2 with 2064 geometry</td>
</tr>
<tr>
<td>II-4</td>
<td>60,000</td>
<td>7 days</td>
<td>Seven spillway gate inverts lowered to 1,170 feet</td>
</tr>
<tr>
<td>II-5</td>
<td>30,000</td>
<td>7 days</td>
<td>Half magnitude version of II-2</td>
</tr>
<tr>
<td>II-6a</td>
<td>60,000</td>
<td>7 days</td>
<td>Low Elevation Tunnels (invert 1,157 feet)</td>
</tr>
<tr>
<td>II-6b</td>
<td>30,000</td>
<td>7 days</td>
<td>Low Elevation Tunnels (invert 1,157 feet)</td>
</tr>
<tr>
<td>II-7a</td>
<td>180,000</td>
<td>~8 days</td>
<td>Repeat of Scenario I-1 from Phase I</td>
</tr>
<tr>
<td>II-7b</td>
<td>88,000</td>
<td>~10 days</td>
<td>Repeat of Scenario I-2 from Phase I</td>
</tr>
<tr>
<td>II-8</td>
<td>30,000</td>
<td>7 day repeating</td>
<td>Annual flushing event through 2064</td>
</tr>
<tr>
<td>II-9</td>
<td>30,000</td>
<td>7 day repeating</td>
<td>Annual flushing event with longitudinal revetment through 2064</td>
</tr>
<tr>
<td>II-10</td>
<td>30,000</td>
<td>7 days</td>
<td>Annual flushing event with dredging 675 tons per day during flush through 2064</td>
</tr>
</tbody>
</table>

The model was calibrated from 1955-2012 to water surface profiles, bed volume change, and grain size distributions. All the scenarios were run in HEC-RAS 5.0, and a short summary of results follows.
Scenarios II-1 and II-3 were compared to determine if there would be an increase in flushing efficiency if the delta were closer to the dam. While results showed that sediment delivery during the event was higher with the future delta conditions, it was not appreciably so.

The highest increases in sediment delivery downstream of Gavin Point Dam were seen in scenarios where physical modifications were made to the dam or reservoir infrastructure. Figure 3 shows the five low-level tunnels simulated in scenario II-6. They are placed below the spillway gates and would allow for nearly complete dewatering of the reservoir to a run-of-river condition, which is ideal for drawdown flushing.

In both cases (II-6a and 6b) the low level outlets drained the reservoir more effectively, which reduced the total event duration by decreasing the draining time and almost eliminating the transition phase required to reach an equilibrium run-of-river flow. Local bed change was computed for Scenario II-6a and 6b and is shown in figure 4.
The low level gates flush sediment because they decreased trap efficiency (or increased pass thorough efficiency). In both cases, the low-level outlet models passed most or all of the sediment scoured from the delta and even scoured some pool deposits on the way to the outlets. Scenario II-6 flushes more sediment of every size class than the other scenarios. But more importantly, it flushes sand. In fact, the 30,000 cfs version of Scenario II-6 releases more than half of the 60,000 cfs volume of each size class and orders of magnitude more sand than any of the other higher flow scenarios.

Scenario II-9 included an underwater revetment that would be approximately 15 feet below the water surface at full pool. It would be exposed during drawdown to channelize flows on the south bank of the reservoir, increasing flow velocity and transporting sand-size sediments to the spillway. Figure 5 lays out the approximate location of the revetment.

![Figure 5 Approximate alignment of modeled revetment.](image)

Figure 6 Time series of sediment released from Gavin's Point dam for Scenario II-1 (no action) and II-9 (revetment and flush), including total release and the sand component.
Figure 6 shows a comparison of scenarios II-1 and II-9. Scenario II-9 included two management alternatives, a drawdown flush and the revetment. A sensitivity analysis suggests that most of the value in this alternative comes from the revetment and that the reservoir may start passing sand before 2065 with just the revetment.

**Modeling a Drawdown Flush on the Niobrara River**
In August 2014, USACE Omaha and HEC began a joint project to model a scheduled drawdown flushing event at Spencer Dam on the Niobrara River. This project is intended to determine the uncertainty associated with using HEC-RAS to model a reservoir drawdown flush in a sand-bed river system. The results will be used to improve the LCLSMS Phase II reservoir model. The Spencer Dam flush study is supported by the Corps’ Regional Sediment Management (RSM) Program.

**Projection of Future Conditions Below Gavins Point Dam**
The reach of the Missouri River directly below Gavins Point Dam has been historically significant as nesting habitat for the Interior Least Tern and Piping Plover. These shore birds rely on bare sandbars to forage and provide clear lines of sight to identify predators.

The construction of dams on the Missouri River has resulted in the loss of nearly 100% of the sediment load from the upper river into this reach. Without sufficient sediment load, the bed and banks of the river have degraded, resulting in channel armoring, bank erosion, and the loss of emergent sandbar habitat for these and other birds.

The question has often been raised as to when, under the current management regime, the reach will effective run out of available sand in the bed and banks. This would seriously inhibit the ability to build sandbars through any means, whether with designed flows or through traditional construction methods.

USACE Omaha is developing a HEC-RAS 5.0 model with WEST Consultants, Inc. to examine future sediment erosion and project bed armoring and bank erosion over the next 100 years. In addition, the model will test the threshold for the projected sediment loads required to prevent future degradation. Finally, the model will be tested with varying discharges to observe what sandbar building can be expected in the future. The analysis and the completed report are expected by the end of 2015.

**Cost Analysis of Dredging Alternatives for Lewis and Clark Lake**
Coker et al. (2009) suggested a sediment management plan for Lewis and Clark Lake that includes yet undeveloped autonomous vehicles for material movement. While the Corps does not current have any technology of this design, the agency has considerable experience in traditional sediment movement methods including mechanical movement and hydraulic dredging.
The LCLSMS has teamed with ERDC and the Corps’ New Orleans District to develop practical cost estimates for three systems for moving sediment from the Lewis and Clark Lake delta to the Missouri River directly below Gavins Point Dam. These three systems are:

- Mechanical excavation with barge transport
- Staged dredging
- Single line dredging with booster pump

Each of these systems is being analyzed with production rates varying from 10,000 to 30,000 tons per day of sediment delivered.

The ability to discharge sediment below the dam is dependent upon the river’s ability to transport this sediment without incurring significant aggradation. To address this concern the number of days per season where discharge is above thresholds is being evaluated. The cost analysis is ongoing, and a report is expected with the release of the Phase II modeling reports.

FUTURE ACTIVITIES

There are four ongoing research efforts within the greater LCLSMS. Each of these will add to the original, single-event drawdown flushing analysis in phase I, and give a more complete view of possible management actions that could be considered in the future. However, these studies all deal with the existing sediment in the system and do not examine ways to reduce sediment delivery to the reservoir. While sediment delivery from upstream on the Missouri River has been significantly reduced due to the mainstem dam system, tributaries, primarily the Niobrara River, continue to be the major contributor to the delta sediments at Lewis and Clark Lake. The influence of the tributary sediment delivery warrants further examination.

The results presented in this paper should be considered provisional and subject to change. Once the Spencer Dam flushing model and analysis are complete, minor modifications may be made to the Lewis and Clark Lake model before publication.

However, there are some actions that clearly result in increased sediment transport when compared to the current infrastructure and management regime. These include lowering of spillway gates, low-level tunnels, and prioritizing flow to improve flushing efficiency. These are all techniques that have been included in dam designs over the past half century, but not originally included in the design of Gavins Point Dam.

The Corps intends to complete the LCLSMS in 2015 and provide all the associated reports via the MRRP website page at:
REFERENCES


