

## **SEDIMENT TRANSPORT MODELING WITH GSTARS-HTC AS PART OF THE LEWIS AND CLARK LAKE SEDIMENT MANAGEMENT STUDY (LCLSMS)**

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**Abstract** The Lewis and Clark Sediment Management Study (LCLSMS) was developed in support the Missouri River Recovery Program (MRRP). It is in the last year of a four and a half year study. The study examines engineering viability of moving sediments deposited in the reservoir delta through Gavins Point Dam using managed river flows in an effort to regain a partial sediment balance in the river reach above and below the dam. The study includes a reservoir sediment model using GSTARS-HTC (Generalized Stream Tube model for Alluvial River Simulation – Hydroscience and Training Center), and a hydraulic/sediment model downstream of the dam using HEC-RAS w/sediment.

The history and sediment trends in the river and reservoir will be reviewed. The process of model creation and calibration will be covered and the decision making process for determining model scenarios based on end-state goals will be discussed. Initial modeling results for the flow scenarios through the reservoir, as well as the basic setup for the model below the dam are discussed.

### **INTRODUCTION**

The deposition of hydraulically transported sediments occurs in all flow impoundments, whether they be naturally occurring or man-made. The natural system way of managing the deposition is to fill the impoundment with sediment until a point is reached where the flow of water finds a new path requiring less energy. This is very often caused by an impoundment completely or nearly full of sediment. If left in the current flow regime, Lewis and Clark Lake will eventually fill with deposited sediment, albeit more than 150 years in the future.

The man-made reservoir, Lewis and Clark Lake, formed by Gavins Point Dam, has existing uses that preclude merely allowing the reservoir to fill up. The lake is used for hydropower, navigation re-regulation, recreation, water supply, and flood storage. In an effort to find ways to maintain all of the interests on the lake, management of the deposited sediments in the reach is vital. While the specific management process for the reservoir is yet to be determined, the Lewis and Clark Lake Sediment Management Study aims to develop tools to evaluate a wide variety of possible management proposals.

**Lewis and Clark Lake** Lewis and Clark Lake was formed by the closure of Gavins Point Dam in 1956. 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 seen in Figure 1. Gavins Point Dam is one of six mainstem dams on the upper Missouri that are operated by the US Army Corps of

Engineers, primarily from the Corps offices in Omaha, NE. The dam and reservoir system provides navigation, hydropower, flood control, water supply, and recreation to the nearly 15 million people that reside in the states through which it flows.



Figure 1 Project Location Map.

Lewis and Clark Lake reached its full water surface elevation of 1208-ft MSL in early 1957 and has been managed for hydropower and navigation re-regulation between 1206-ft and 1210-ft ever since. When closed, the lake extended to approximately RM 836, resulting in an open water lake approximately 25 miles long.

Since closure, the reservoir has been surveyed approximately every 10 years to determine changes in storage capacity and sediment deposition. These surveys have indicated that approximately 2,400 acre-feet of sediment per year are deposited below elevation 1210-ft in the reach between Gavins Point Dam and Fort Randall Dam at RM 880, the next impoundment structure upstream. This sediment is sourced from tributaries including the Niobrara River, Ponca Creek, and Bazile Creek, as well as from the banks and bed of the river above the reservoir. 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-ft threshold.



Figure 2 Niobrara River Delta and Lewis and Clark Lake Delta.

The deposition of sediments in the 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 828, resulting in a 17 mile long lake. The visual migration of the delta appears to be approximately 500 to 600 feet per year. The deposition rate has remained fairly constant over the past 50 years.

The migration of the delta both upriver and downriver, reduces the storage capacity of the reservoir. The initial capacity of the lake was 575,000 ac-ft below 1210-ft elevation, and the 1995 capacity was 470,000 ac-ft, approximately 18.5% of its original maximum storage. Storage loss was updated with the 2007 surveys for this project. These surveys indicated a total storage loss at 1210-ft elevation was 21.7%.

### **THE LEWIS AND CLARK LAKE SEDIMENT MANAGEMENT STUDY (LCLSMS)**

The LCLSMS was developed to examine the engineering viability of moving deposited sediments from behind Gavins Point Dam into the river downstream of the reservoir. In the 2003 amended Biological Opinion (BiOp), the US 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 deposited sediment was not strongly supported. Additional research on the reservoir system in the Lewis and Clark Lake reach showed that there is the possibility of physically transporting sediments 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 E&H study, the LCLSMS was initiated in 2005. The LCLSMS is supported by the Missouri River Recovery Program (MRRP).

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

- 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

**Timeline** The LCLSMS project began with the development of the project plan and scope of work for modifying GSTARS3 by Colorado State University Hydroscience and Training Center (HTC) in 2005. Award of the work to develop GSTARS-HTC signaled the beginning of the project in late 2005. The current schedule expects to see the completed project in late 2010.

The LCLSMS project has been broken down into seven phases. Those phases are:

- Phase 1: Modification of the GSTARS3 Sediment Transport Model to allow for unsteady state flow analysis.
- Phase 2: Collection of river and reservoir geometry and sediment samples between Ft. Randall Dam and Sioux City, IA. Agency workshop and public meeting to gather input on developing alternatives.
- Phase 3: Verification of the GSTARS-HTC reservoir model by Colorado State University HTC.
- Phase 4: Development of alternatives, and analysis of alternatives using the GSTARS-HTC reservoir model from Ft. Randall Dam to Gavins Point Dam.
- Phase 5: Development of the HEC-6T downstream computer model from Gavins Point Dam to Sioux City, IA.
- Phase 6: Analysis of GSTARS-HTC reservoir model output by HEC-6T downstream river model.
- Phase 7: Completion of study and recommendation of an alternative for possible further testing. A public/agency meeting will be held to disseminate results during this phase, currently scheduled for Fall 2010.

**Alternative Development** There is a very high level of concern associated with sedimentation issues in the Missouri River reservoir system. These concerns have been magnified in the Lewis and Clark Lake delta, where a combination of high sediment load, small reservoir, and the resultant visibly moving delta that is slowly encroaching on the open lake. With these factors comes significant interest in the future of the reservoir. In an effort to ascertain the wants and needs of local residents, and federal, state, and local agencies, the US Army Corps of Engineers held an agency meeting coupled with a public meeting on June 14<sup>th</sup>, 2007. This meeting was part of Phase 2.

At the meetings, attendees were supplied with information about the project, and asked to provide input on their ideal future state of the reservoir. Depending on what entity each person was representing, responses were widely varied. As part of Phase 4, the project will develop flow alternatives based on this input, in an effort to design scenarios to run through the models that would reach the recommended future conditions in the reservoir. Alternative development was completed in early 2009, and the CSU team will run these scenarios during spring 2010.

**LCLSMS Model Selection** To create useful modeling tools that can be used for modeling current and future scenarios, including other possible mechanisms for transporting deposited

sediment, it was determined that two models should be used. One to model the reservoir, and one to model the downstream reach below Gavins Point Dam.

**Data Collection for Modeling** To provide data for accurate modeling of the river and reservoir reaches in the study area, new hydrographic surveys were required. During the summer of 2007, new surveys were collected from Sioux City, IA (RM 728) to Ft. Randall Dam (RM 880). These surveys included river/reservoir bathymetry, ADCP velocity profiles, and RTK overbanks.

In addition to the current surveys, data from the 1955, 1975, 1985, and 1995 surveys is available for evaluating the models' ability to mimic historic change. Additional data including temperature, suspended sediment, bed sediment, tributary inflows, and rating curves for gauging stations has been compiled.

**Reservoir Model** Through a joint effort with the Hydroscience and Training Center (HTC) at Colorado State University (CSU) and the Omaha District of the US Army Corps of Engineers, development of a quasi-2D version of the GSTARS3 (Generalized Sediment Transport Model for Alluvial River Simulation version 3) (Yang and Simões, 2002) model was completed. The effort includes merging many of the features of GSTAR-1D (Generalized Sediment Transport for Alluvial Rivers – One Dimension, Version 1.0) (Yang, et al 2005) with the advanced tools of GSTARS3 to result in GSTARS-HTC, which provides the quasi-2D flow characteristics of stream tube modeling with unsteady flow capability.

This approach to modeling the river reach between the dams was selected because GSTARS3 has the ability to simulate and predict longitudinal and lateral verification of sediment movements and channel morphologic changes under quasi-steady flow conditions. During the process of sluicing, a model applicable to truly unsteady flow conditions is required. GSTAR-1D is a truly one-dimensional model for unsteady flows. Revising GSTARS3 to include all the functions of GSTAR-1D will create a semi-two-dimensional model applicable to sediment sluicing operation under unsteady flow conditions with limited field data.

**Downstream Model** The downstream river model will encompass the river reach from Gavins Point Dam to Sioux City, IA, a reach of approximately 83 miles. The first half being a river reach similar to the pre-dam/navigation river; the second half a channelized reach approximately 600 feet wide. This model will use the output of the GSTARS-HTC model as the input boundary condition. HEC-RAS (River Analysis System v.4.0). has been selected as the modeling tool for this reach of the river. When completed, it will allow for the results of any flow scenario in Lewis and Clark Lake to be used as a boundary condition to evaluate that scenarios' impact on the lower reach.

Currently the model has been built with the 2007 survey data, inflows for the tributaries in the reach added and calibrated for measured steady state discharges between 15,000 and 45,000 cfs. The un-steady model is being developed from the steady state model and once calibrated, existing bed sample sediment data will be added.

The same process will be completed with the 1955 and 1975 survey and sediment data. System control parameters that will be used to model the 1955 to 1975 to 2007 system will be then used

to predict future impacts using the GSTARS-HTC model output as input for the downstream model. This is expected to be completed late summer 2010.

### **DEVELOPMENT OF THE GSTARS-HTC MODEL**

GSTARS3 has the following capabilities needed for reservoir water and sediment routing computations:

1. It can compute reservoir hydraulic parameters with fixed as well as variable width.
2. It can simulate and predict the hydraulic and sediment variations in the longitudinal and in the transverse direction in a semi-two dimensional manner based on the stream tube concept. If only one stream tube is selected, the model becomes one-dimensional. If multiple stream tubes are selected, both the lateral and vertical bed elevation changes can be simulated.
3. It can rout sediment by size fraction. The bed sorting and armoring algorithm can provide a realistic long term simulation of the scour and deposition process in a reservoir.
4. It can simulate and predict channel geometry changes in width and depth based on minimum total stream power.
5. The channel side stability option allows simulation of channel geometry changes based on the angle of repose of bank materials and sediment continuity.
6. It can simulate non-cohesive and cohesive sediment transport.
7. Sediment particles are allowed to cross the boundaries of stream tubes due to lateral bed slope or sharp bends.
8. It can simulate equilibrium and non-equilibrium sediment transport.
9. It has 15 sediment transport formulas for users to select.

The above capabilities are adequate for most reservoir sedimentation studies. However, during sluicing, the flow is highly unsteady, GSTARS3 may not accurately simulate the sedimentation process. It is desirable to expand GSTARS3 capabilities from quasi-steady to truly unsteady flow conditions.

GSTAR-1D is a truly unsteady flow model for water and sediment routing. The stream tube and minimum total stream power concepts are not used to simulate lateral bed and width changes. The Bureau of Reclamation is in the process of improving GSTAR-1D and renaming it SRH-1D (Huang and Greimann, 2007). GSTARS-HTC will integrate the unsteady flow capacities of GSTAR-1D or SHR-1D into GSTARS3 to form a new model GSTARS-HTC for a semi-two-dimensional simulation and prediction of channel geometry changes under truly unsteady flow conditions.

Hydrology and bed profile data from the Tarbela Reservoir in Pakistan was used to test and compare simulated longitudinal bed profiles using the GSTARS3 and GSTARS-HTC models. Figure 3 is a plan view of the Tarbela Reservoir. Only one stream tube is used for the simulation. Figure 4 shows the comparison between the observed and simulated longitudinal bed profiles using GSTARS3 and GSTARS-HTC. The two models show identical results. Both models can give reasonable simulations of the delta formation process of the Tarbela Reservoir. Yang's (1973) sediment transport formula and Han's (1980) non-equilibrium sediment transport function

are used in the simulations. To further testing the merit of using unsteady model during a sediment sluicing process, field data collected before, during, and after a sluicing process are needed. These data will be used to test, verify, and improve the GSTARS-HTC.

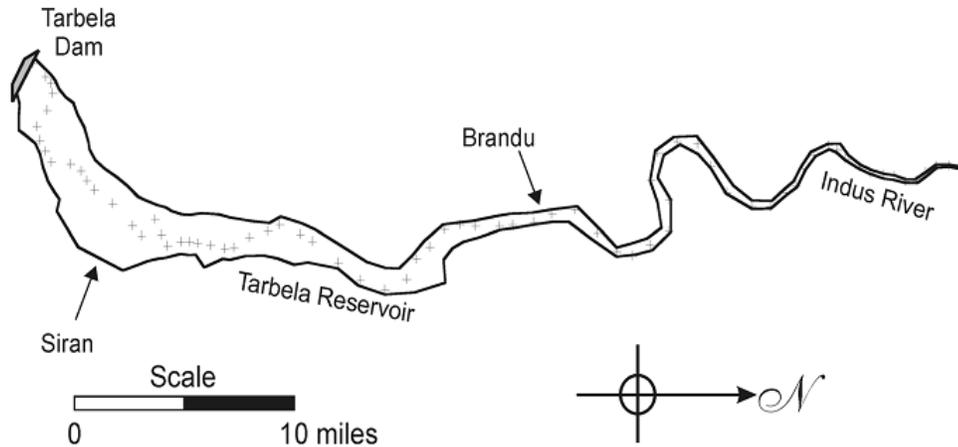


Figure 3 Tarbela Dam and Reservoir. The point (+) marks the thalweg.

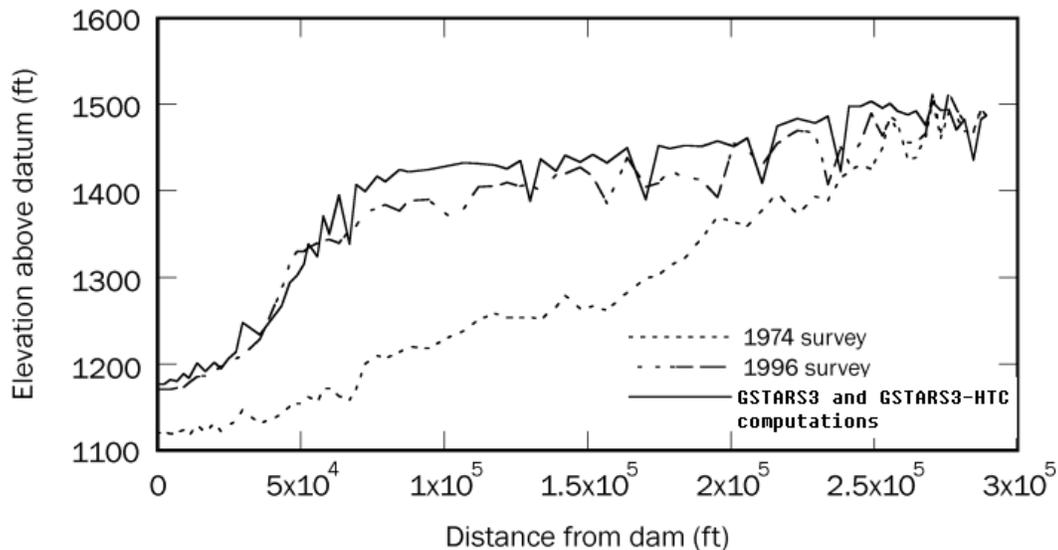


Figure 4 Result of the simulation of the Tarbela Reservoir thalweg change in 22years.

**Model data** The 2007 hydrographic surveys for the reach between Gavins Point and Ft. Randall Dams were delivered to HTC in late January 2008. Surveys were filtered from thousands of points per section to between 50 and 100 points per section. In addition to the station-elevation format, the XYZ format of the data was submitted to determine overbank flow lengths in the model by GIS. Additional surveys were taken at the Gavins Point Dam structures to accurately represent the spillway and spillway basin for the models. Sediment data in the form of bed samples was collected along both modeling reaches in summer 2008.

**Model Progress** The GSTARS-HTC model integrates advantages of previous versions of GSTARS models, GSTARS3 and GSTAR-1D. Each model has advantages and disadvantages.

One of the important features of GSTARS3 is the use of the stream tube concept, which is used in the sediment routing computation. The adoption of this concept allows simulation of lateral movement of sediments. In the GSTARS3 model, hydraulic parameters and sediment routing are computed for each stream tube, thereby providing a transverse variation in the cross section in a semi-two-dimensional manner. Although no flow can be transported across the boundary of a stream tube, transverse bed slope and secondary flows are phenomena accounted for in GSTARS3 that contribute to the exchange of sediments between stream tubes. The position and width of each stream tube may change after each time step of computation. The scour or deposition computed in each stream tube give the variation of channel geometry in the vertical (or lateral) direction.

GSTARS3 uses quasi-unsteady flow concepts, which assumes that water discharge hydrographs are approximated by bursts of constant discharge. Consequently, GSTARS3 is not intended to be applied to truly unsteady flow conditions. Thus GSTARS3 model may not be accurate for unsteady conditions, such as the sluicing of water and sediment at the dam and sudden water surface drawdown. Therefore, GSTARS3 has some disadvantages when applied to simulating unsteady conditions during a sudden drawdown for sediment sluicing, whereas GSTAR-1D allows the model to simulate unsteady flow characteristics more accurately than GSTARS3 which uses quasi-unsteady approximation.

GSTARS-HTC uses the stream tube concept, the advantage of GSTARS3, to simulate lateral sediment movement. Additionally, GSTARS-HTC can simulate unsteady conditions by adopting GSTAR-1D unsteady scheme. Usually, stream flows can be simulated as quasi-unsteady flow by assuming that the flow rate changes gradually. The sluicing of water at the dam and water surface drawdown needs an unsteady flow model. Unsteady flow simulation computes more accurately than quasi-unsteady model if the flow condition is not steady. GSTARS-HTC has several boundary options, such as weir and gate operation. Consequently, GSTARS-HTC should be capable of simulating a dam's operation for reservoir sedimentation and sluicing study. Other development and improvement of HTC model is still in progress.

To further calibrate the model, data from the Xiolangdi Reservoir on the Yellow River in China was used. Sediment flushing data has been collected at the reservoir for the last few years, providing a valuable pre- and post-flush dataset to calibration the GSTARS-HTC model to.

This testing was done to fine tune the Recovery Factor, Sediment Density Variation, sediment distribution, and wash load percentage. Figure 5 (Anh & Yang, 2009) shows a comparison between the surveyed bed elevations and those modeled by GSTARS-HTC for measured flushing events.

The results of this calibration show a reasonable replication of survey data for the flushed measured. Additional testing of the control variables in spring 2010 yielded similar results when comparing bed material composition and cross-section geometry.

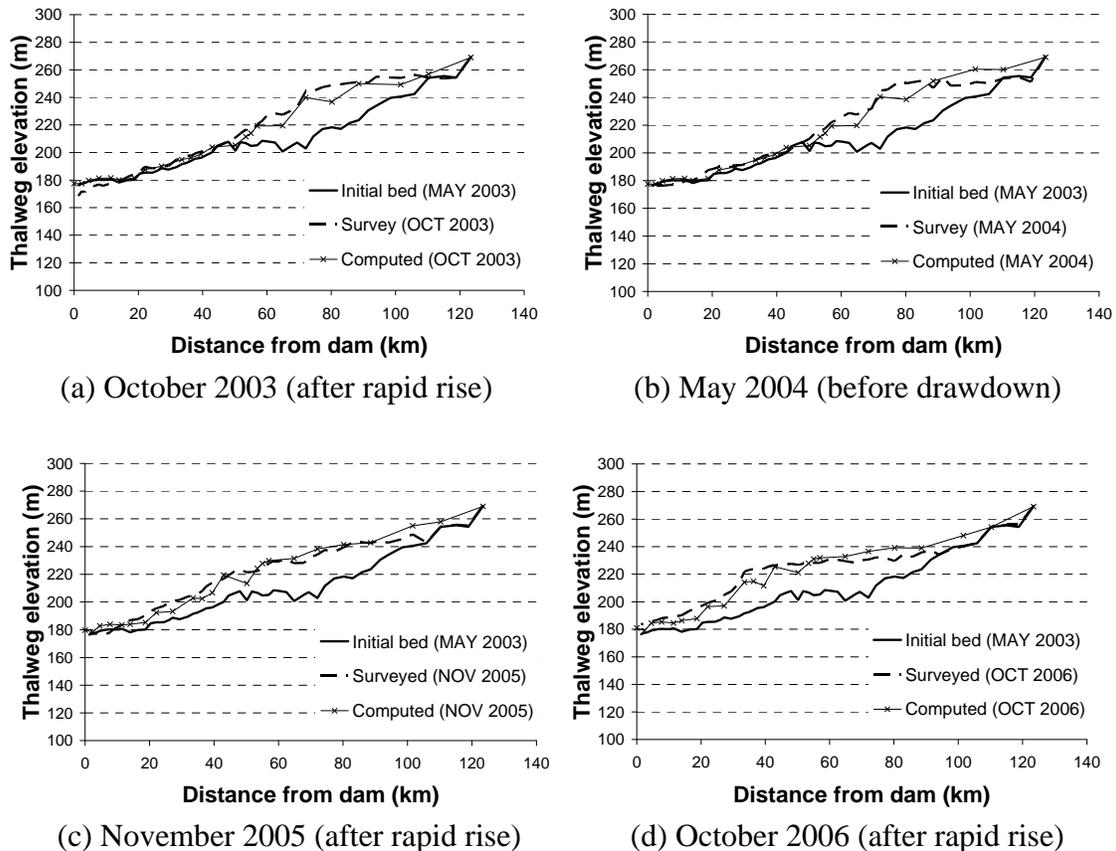


Figure 5 Comparison of bed profile between surveyed and simulated.

## CONCLUSIONS

At the time of publication, the GSTARS-HTC model has completed testing and calibration with both reservoir datasets and a model using the Lewis and Clark Lake survey and sediment data had been built. Calibration was underway with historic unsteady flow events. The presentation at the JFIC 2010 will discuss the specific results of the initial flow scenario runs in the model. In addition, discussion of the calibration of the HEC-RAS downstream model will be discussed.

The project is tentatively scheduled to be completed in late fall 2010. Please contact the author for follow up information on the study.

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