TWO-DIMENSIONAL MODELING TO EVALUATE SHALLOW WATER HABITAT ON THE MISSOURI RIVER

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Abstract

Two-dimensional hydraulic flow models were developed using the SMS/RMA2 modeling package to support dike modifications made to comply with recommendations made in the 2003 revised Biological Opinion issued by the USFWS. Extensive surveys were collected to accurately model existing conditions and new modifications that include dike notching, dike sills, and chevrons. Models were built for control bends and those with new modifications. The flow solutions indicate the extent of change in the flow regime and can be used as an indicator of future performance of similar structures.

Sensitivity testing of the Hamburg Bend model resulted in a set of control parameters that effectively represent the flow dynamics on the Missouri River. These parameters can be used as a baseline when evaluating changes on the river due to structure modifications.

Keywords: RMA2, SMS, 2-D modeling, Missouri River, Biological Opinion, dike, levee, chevron

INTRODUCTION

Missouri River Biological Opinion Background

The Missouri River Biological Opinion (MRBO) states that the United States Army Corps of Engineers (USACE) provide the primary operational management of the Missouri River and is therefore responsible under the Endangered Species Act to take action within its authorities to conserve listed species (USFWS, November 2000 and December 2003). The Reasonable and Prudent Alternative (RPA) includes five applicable parts. These actions are as follows:

1) Flow Enhancement
2) Habitat Restoration/Creation/Acquisition
3) Unbalance System Regulation
4) Adaptive Management/Monitoring
5) Propagation/Augmentation

Of the five actions listed by the Fish and Wildlife Service (USFWS), Habitat Restoration/Creation/Acquisition is the focus of the modeling effort. Through the modeling effort, USACE hopes to better understand the dynamic environment of the river and the forces that change the river on a daily basis. USFWS has determined that a portion of the historic habitat base must be restored, enhanced, and conserved in riverine sections that will benefit the

three species of concern, the least tern, the piping plover, and the pallid sturgeon. The habitat restoration goals are to create 20-30 acres of shallow water (<5 feet deep, < 2.5 feet/second velocity) per mile. In addition, similar variable goals by river segment for emergent interchannel sandbar habitat are also identified. The near term goals of the project are to reach 10% (2000 acres) of shallow water habitat by 2005 and 30% (5,870 acres) of shallow-water habitat by 2010. Additional information on the RPA and the implementation objectives can be found in the MRBO Table 24.

USACE has designed a plan (USACE, 2002) by which USACE will modify the existing Missouri River Bank Stabilization and Navigation Project (BSNP). This modified plan attempts to meet the MRBO goal of 2000 acres by the year 2005.

The shallow water habitat development program aims to develop the required habitat acreage, develop design tools for future habitat creation, and allow for more dynamic alluvial processes and increased depth/velocity diversification; all while maintaining the authorized project (BSNP) purposes on the Missouri River.

Modeling Purpose and Attempts

The purpose of building the models is to monitor and evaluate the proposed USACE plan and apply the knowledge gained to future projects. Two-dimensional modeling has been recommended based on previous modeling attempts and on the type of data the two-dimensional model will provide.

Past mitigation projects used the one-dimensional model HEC-6 (USACE, 1995). HEC-6 did not provide sufficient results to evaluate depth diversity and velocity changes. The Iowa Institute of Hydraulic Research used a three-dimensional model on the Missouri River at Leavenworth Bend (Spasojevic et al., 2001). The three-dimensional model resulted in an inefficient and expensive method to model the river; as the model took longer than real time to run.

A micro model (a.k.a. table top model) of Copeland Bend on the Missouri River was modeled various widths for channel widening. The results set thresholds of channel widths that the river could withstand and satisfy the goals of the MRBO. These results will be used in future modeling efforts.

The choice to use the two-dimensional model SMS/RMA2/SED2D was driven by the need to evaluate a wide range of flows and estimate velocity magnitude and direction in the Missouri River dike fields. The modeling results are anticipated to be used as a benchmark in not only evaluating alternatives, but in monitoring performance over the life of any implemented channel geometry changes. During 2004, CCHE-2D, a structured mesh two-dimensional model, was evaluated for possible use with mitigation project area. While the model showed promise for small models with high resolution, the structured mesh limitation did not show it to be easily applicable at the scale of the existing mitigation models.

HAMBURG BEND MODELING SITE

The Hamburg Bend modeling site includes two river bends approximately three miles below Nebraska City, NE, and three miles west of Hamburg, IA, in Otoe County, NE. A stream gage at Nebraska City, NE provides flow data for the site. The project site covers 1960 river miles 550 to 557. In 1995 and off-channel mitigation site was opened on the Nebraska side of Upper Hamburg Bend to provide increased shallow water habitat in a continuously flowing

chute. A second chute, on the left bank in Lower Hamburg Bend was opened in the fall of 2004. Future modeling efforts will include geometry for the left bank chute. Figure 1 shows the Hamburg Bend Mitigation Project Area.

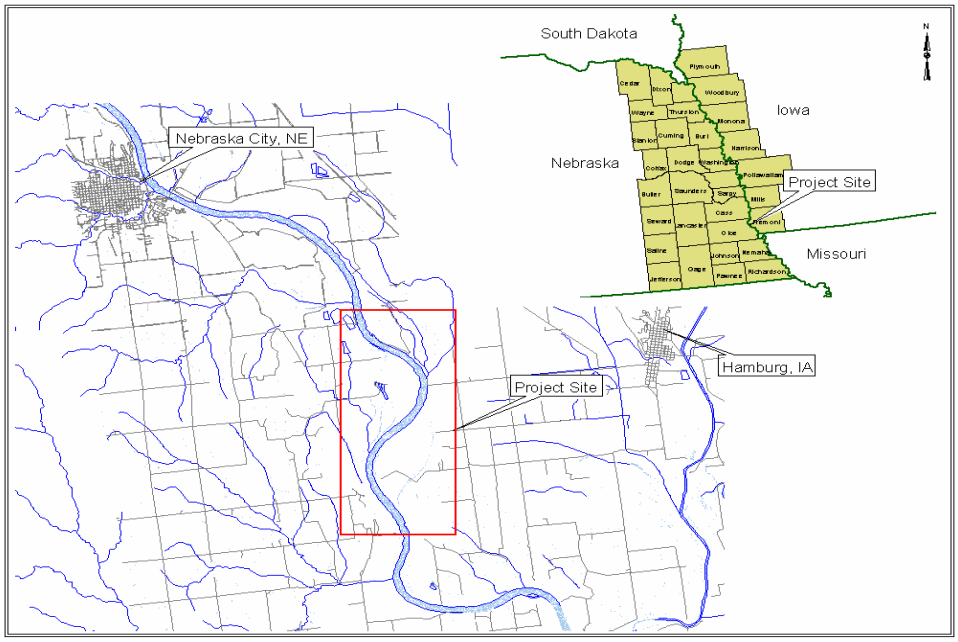

Figure 1. Hamburg Bend Mitigation Project Area

Figure 2. Model Mesh

Initial runs were made to reproduce results observed by WEST consultants and ensure compatibility. Based on the results of these runs and a steering meeting to establish finite goals for the modeling effort, it was determined that additional work would need to be invested in refinement of the model mesh. Semi-annual steering meetings have continued in an effort to examine and refine the initial goals set forth for the modeling effort. Figure 2 shows the Hamburg Bend 2-D model mesh and aerial photo of project area.

Phase I Model Revisions

To meet the design goals set forth for the Hamburg Bend model it was determined that the model mesh would need to be refined to include higher resolution of elements in selected areas of the model mesh. While a vast increase in resolution throughout the mesh would have been desirable, such action would have resulted in excessively long model run times, possibly approaching real-time.

To create smooth flow transitions for the eventual dynamic flow solutions as well as more accurately estimate

sediment deposition, areas in the model mesh with significant elevation changes and complex bends and turns were refined by two to four times. Initial testing had shown some instability in areas around dikes and when using the delivered mesh in a dynamic flow solution. In general, increasing resolution of mesh elements, which in turn shortens the distance between flow point solutions, increases stability. This increased stability will allow for areas that were included in the model mesh refinement to handle shallow water depths and deposition in the SED2D model. The delivered model included approximately 9000 elements. After initial refinements to increase resolution, eliminate ambiguous gradients, reduce narrow triangle elements, and remove mesh boundary notches, the mesh contained nearly 13,000 elements.

In addition to mesh refinements, the material types assigned to elements in the mesh were modified. The delivered mesh included four material types. This was increased to seven, including 1) top channel, 2) off-channel chute, 3) dike tops, 4) edge of bank, 5) middle channel, 6) dike sides, and 7) bottom channel. Increasing the number of material types allowed for greater flexibility in assigning roughness and wetting/drying parameters to elements.

Model Control Parameters

During initial model development, two key control parameters were identified as ones that could have significant effects on model stability and faithful reproduction of the flow regime in the 2-D mesh. The parameters that controlled eddy viscosity and the wetting/drying function were used extensively to control model output.

The delivered model used the Peclet method of determining eddy viscosity for the model runs at 45k and 60k cfs. The Peclet method defines the relationship between the average elemental velocity magnitude, elemental length, fluid density, and eddy viscosity (E). This method allows for stable transitions between high and low flow velocities and flow depths. However, the model was not capable of solving to a stable solution using the Peclet method at 28k cfs, and fixed individual eddy viscosities had to be assigned.

The elemental drying function was used in initial test runs of the model. This function simply uses a preset percentage of the element area as the determining factor of whether the element is considered wet or dry. On mesh elements with higher slopes, this method can cause errors that result in incorrect velocity magnitudes, and in extreme cases, errors in water surface elevation. The model was modified to use the marsh porosity function for wetting/drying. This function allows elements to transition gradually between wet and dry states. The residual water volume existing on a partially wet element is calculated at each node of the element. Partially wet elements are retained as wet until all nodes are dry, and elements become wet again as soon as a single node is re-wet (Donnell, 2002).

The bendway correction, known as vorticity in RMA2, is designed to reduce over prediction of streamwise velocities on the inside bank of a river bend. Sensitivity analysis performed to evaluate changes in flow velocities with the bendway correction active resulted in less that two percent changes in velocity magnitude in the most severe instances and well below one percent change in the remainder of the model mesh. The bendway correction was removed from model execution code after this analysis in an attempt to reduce model run time.

Geometry Refinements

In certain cases, actual changing of the geometry of the model mesh was necessary to ensure model stability. Every effort was made to minimize changes. In many cases only refinement by increasing in the number of elements in an area was necessary. During the spring

of 2004, considerable calibration work resulted in a consistent error between measured and modeled flow. It was determined that because the geometry used to create the original mesh was collected in 1999, it would not calibrate properly with flow data collected in 2001-2003. This was especially evident when comparing ADCP velocity data. See section 3.5 for a discussion ADCP.

The geometry data collected with the ADCP data in the summer of 2003 was projected onto the existing model mesh, changing slightly the overall shape of parts of the river channel. Once the geometry was the same as when the ADCP data was collected, calibration values were much closer. The model calibrated with the 2003 data will be used as the existing conditions model when modeling river changes.

A survey in 2004 collected information about the changes the river had undergone after a number of modifications had been implemented. This data will be used in a future attempt to model the modified river.

Model Mesh Split

In an effort to reduce run time and be able to increase mesh resolution while still working with a manageable mesh size, the complete Hamburg Bend model was cut into two models. There is an overlap of approximately 1.5 river miles to ensure that the models could be calibrated with matching water surface profiles and velocities. A second inflow was added to the Lower Hamburg mesh to provide the outflow from the right bank chute. Inflows at this point were adjusted during the calibration procedure to match the flow split measured by the HEC-RAS model. Figure 3 shows the two models, Upper and Lower Hamburg Bend.

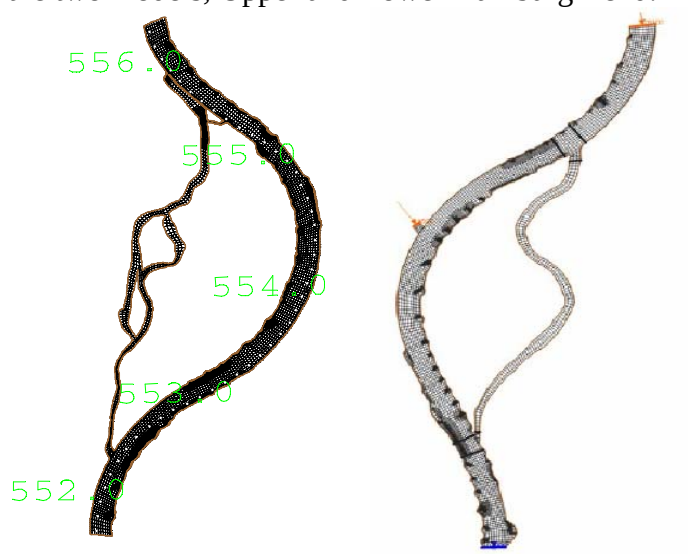

Figure 3 Upper (left) and Lower (right) Hamburg Bend model meshes

Initial Steady-State Calibration

During 2003, a one-dimensional flow split analysis at the Hamburg Bend chute was completed. This report matched a calibrated HEC-RAS model with measured water surface elevations and flow split measurements collected during the prior 10 years. The water surface elevations developed along the main channel of the Missouri River at Hamburg Bend were used as an initial calibration tool for the Hamburg Bend 2-D mesh. The 2-D model results were matched to the HEC-RAS solutions at 28.6k, 39.5k, and 54.6k cfs. As model parameters and

boundary conditions changed, the results were continually verified with the water surface elevations from the HEC-RAS model. Figure 4 plots water surface elevations for the HEC-RAS model, Upper and Lower Hamburg RMA2 models, and measured points.

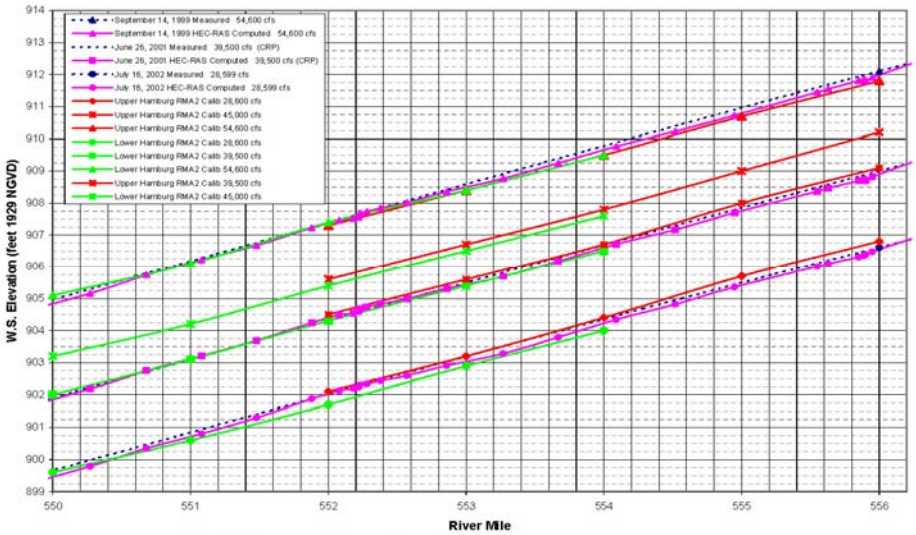

Figure 4. Calibrated Water Surface Elevations for Upper and Lower Hamburg Models

To create accurate water surface elevations, the model was required to incorporate flow passing through the chute on the right bank in Nebraska (RBC). While water surface elevations in the RBC were not critical as no shallow water habitat design will be considered, the flow split between the channel and the RBC has a significant effect on the water surface elevation in the channel. The model mesh geometry in the RBC was slightly modified to create the proper splits with varying flow rates. Multiple measured data point and the flow splits in the HEC-RAS model for Hamburg Bend were used to develop a flow split curve. Figure 5 plots the flow splits for the HEC-RAS model, RMA2 model, the chute design split, and a number of measured flow splits.

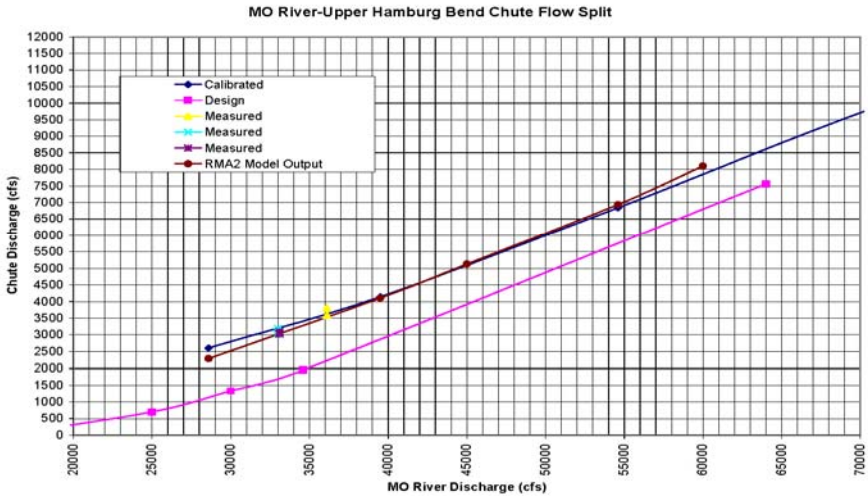

Figure 5. Flow split for RBC, Upper Hamburg Model

To further verify 2-D model results, the model output was evaluated against Acoustic Doppler Current Profiler (ADCP) data.

Phase II Model Revisions

As new model control functions have been developed by CHL and in an attempt to create the most stable model possible, additional advanced control features were added to the Hamburg Bend model. Addition of all the following control modifications increased stability greatly.

Revised Model Control Parameters

In an effort to receive the maximum impact of modified model control parameters by tailoring to very specific areas of the model mesh, additional material types were added. Adding three channel material types allowed for minor changes to control parameters that produced better fit of model water surface profiles to the HEC-RAS model.

The Smagorinsky method for assigning eddy viscosity provides real-time adjustment of eddy viscosities based upon the computed velocity field. The method, based on material type, takes into consideration the gradients of velocity to determine the appropriate turbulence coefficients to meet the conditions of the hydrodynamic solution.

This method was applied around the dike areas of the model mesh. Improved stability as well as better defined transition between eddy and channel currents resulted.

The automatic roughness by depth function has shown positive results. The assignment of roughness, based on user inputs for upper and lower limits and a slope between them, allows for changing roughness with changing depth. This function produces excellent results with the dynamic flow solutions.

Automatic Marsh Porosity

The marsh porosity function was added as part of the Phase I revisions and provided increased stability. The automatic marsh porosity function includes the additional step of modifying the marsh porosity slightly throughout the model run based on the average regional and local bed elevations.

ADCP Flow Calibration

Following the model mesh split and calibrating the new boundary conditions parameters of the two models to the HEC-RAS model, Acoustic Doppler Current Profiler (ADCP) data was compared to the model solution. The ADCP data was collected by a survey crew from the Costal and Hydraulics Lab (CHL, Vicksburg, MS) between 01JUL03 and 03JUL03, and again during June 2004. The ADCP data provided water velocity magnitude and direction data collected at approximately Q=45k cfs. A high density grid of data points was taken at three points in the Hamburg Bend area to define eddy shape, dike impact on flow, and the extents of the high velocity flow in the navigation channel. In addition to these areas, a bank to bank cross-section was measured approximately every 1000 feet for the extent of the area to be modeled.

Post processing of the data was completed by CHL and delivered to USACE Omaha by mid-summer in 2003 and 2004. Using HyPAS (Pratt and Cook 2001), an extension to ArcView 3.X, ADCP data was plotted and examined visually. The 2003 ADCP data was also plotted in SMS to attain visual representation of velocity magnitude and direction. This was plotted along with the steady state model solution at Q=45k cfs. Figure 6 provides a visual comparison of the velocity vectors.

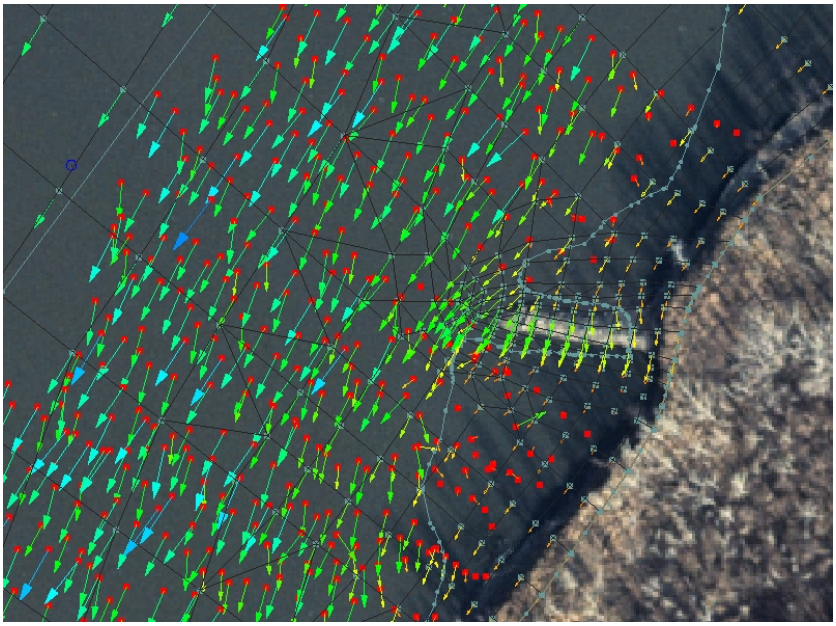

Figure 6. ADCP data (in red) as compared to the model solution in the dike field

In the river channel, the ADCP data matches the model solution very closely. While the model solves to create a consistent velocity with very gradual changes, the collected ADCP shows noticeable fluctuations in velocity between adjacent points. This may be attributed to actual variations in velocity and data collection error. Velocity vectors figure 6 have the same vector length scaling for the model and ADCP data, allowing for direct visual comparison.

Dynamic Flow Solution

Once the steady state solution was stabilized and calibrated, a dynamic flow solution was created. This solution is the first step in creating a model that can replicate the navigation season on the river. The dynamic solution also allows for examination of the stability of the model and identifies any wetting/drying issues that may become apparent with the changing of the water surface elevation during the run. The dynamic flow solution is initially ramped down to the calibrated water surface at Q=28k cfs. From this point the flow was stepped up at increasingly faster rates to establish the maximum change in flow per time step of one hour. The current model will allow for flow changes of between 1000 and 1500 cfs per hour.

FUTURE MODELING

During the summer and fall of 2005, USACE Omaha began modeling 2-D flow solutions on another 12 sites along the navigation channel of the Missouri River. These models are designed to aid in compliance with the requirements of the 2003 revised Biological Opinion. The sites include six control and six modified dike fields. A number of new dike modifications are being modeled, including dike notches, sills, and chevron structures within the dike field.

A new model is being completed at DeSoto Bend that includes these new modifications and will be discussed in detail at the presentation during the conference. Please contact the author for additional information on these models.

REFERENCES

2-D Hydrodynamic Modeling and Sediment Transport of Missouri River, Nebraska City Reach. West Consultants, Inc. San Diego, CA. Contract No. DACW45-01-D-0003, Task Order No. 14. March 2003.

Donnell, B. ed. (2002) Users Guide to RMA2 WES Version 4.3. US Army Corps of Engineers Waterways Experimentation Station Research Laboratory, Vicksburg, MS.

Donnell, B. ed. (2000) Users Guide to SED2D WES Version 4.5. US Army Corps of Engineers Waterways Experimentation Station Research Laboratory, Vicksburg, MS.

Missouri River Mitigation Project: Hamburg Bend Flow Split Evaluation. USACE Omaha District. August 2003

Operation and Maintenance Manual – Missouri River: Fish and Wildlife Mitigation Hamburg Bend Project. Otoe County, NE. USACE Omaha District. March 2002

Pratt, Thad C. and Daryl S. Cook. HyPAS User's Manual: A Hydraulic Processes Analysis System, An extension for ArcView GIS, Version 4.3. USACE ERDC – CHL. January 2001.

Suspended Sediment Data Assessment Study, Missouri River at Nebraska City, Nebraska. WEST Consultants, Inc. San Diego, CA. MRR Sediment Series Report No. 39c. January 2001

U.S. Army Corps of Engineers, Omaha District. February 2002. Missouri River Streambank Stabilization and Navigation Project Action Plan for Creating 2000 Acres of Shallow Water Habitat by 2005 (Draft).

U.S. Army Corps of Engineers Omaha District, May 2003. Two-Dimensional Modeling to Evaluate Shallow Water Habitat Creation on the Main Stem of the Missouri River in Nebraska.

U.S. Fish and Wildlife Service, December 2003. 2003 Amendment to the 2000 Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and the Operation of the Kansas Reservoir System.

U.S. Fish and Wildlife Service, November 2000. U.S. Fish and Wildlife Service Biological Opinion on the Operation of the Missouri River Main Stem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System.