STRONG FOUNDATIONS. STRONG FUTURE.

ASH GROVE

A CRH COMPANY

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

Commercial sand dredgers provide most of sand material for the construction industry. The sand goes into concrete and asphalt that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades.

Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

DIRECT 913-451-8900
FAX 913-451-8324

11011 CODY STREET
OVERLAND PARK, KS 66210

ASHGROVE.COM

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Mark Kreiser
Manager of Logistics & Marketing Services
Central Region - Midwest Sales

Ash Grove Cement
A CRH Company
11011 Cody Street
Overland Park, Kansas 66210

mark.kreiser@ashgrove.com

---

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

BOONE QUARRIES

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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Very truly yours,

2604 N. Stadium Blvd. • Columbia, Missouri 65202-1271
573-447-0100 • Fax 573-446-0147

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

CLARKSON
CONSTRUCTION COMPANY

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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Sincerely,

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Columbia READY MIX
2600 NORTH STADIUM BLVD.
COLUMBIA, MISSOURI 65202

TELEPHONE 573-445-3901

The Difference Is In the Service

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

CON ◆ AGG COMPANIES

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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Very truly yours,

2604 North Stadium Blvd. • Columbia, Missouri 65202-1271 • 573-446-0905 • Fax: 573-446-2870

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

CONTINENTAL CEMENT

Corporate Office:
16401 Swingley Ridge Road
Suite 610
Chesterfield, Missouri 63017
636-532-7440
800-625-1144

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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Very truly yours,

Tom Beck

Thomas A. Beck
President

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Franklin County Concrete, LLC

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,
Franklin County Concrete

Mitch Parrish
Chief Operating Officer

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

FRED WEBER INC.

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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2320 Creve Coeur Mill Road • P.O. Box 2501 • Maryland Heights, Missouri 63043-8501
314.344.0070 • 314.344.0970 Fax
www.fredweberinc.com

Fred Weber, Inc. supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Dale C. Hoette
President

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Geiger READY-MIX

4318 Speaker Road
Kansas City, KS 66106
www.geigerreadymix.com

Central Dispatch
913-281-0111
Fax 913-281-1492

Administrative Office
913-772-4010
Fax 913-772-8661

Leavenworth, Kansas

Kansas City, Kansas

Olathe, Kansas

Liberty, Missouri

Lee's Summit, Missouri

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
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Very truly yours,

Todd Geiger

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

MLC READY MIX
816.537.6660

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
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Very truly yours,

Merrill Crose

MLC Ready Mix, President

Murdon Corp
— PRECAST CONCRETE PRODUCTS —
14241 Old Hwy. 66 — St. James, Missouri 65559
573-265-7028 Fax: 573-265-7026

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
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Very truly yours,

Don Murdon PRES

Norris Quarries, L.L.C.

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
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2604 N. Stadium Blvd. • Columbia, Missouri 65202-1271
Toll Free: 866-277-9143 • Phone: 573-447-0100
Fax: 573-446-0147

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil

U.S. Army Corps of Engineers

Kansas City Regulatory Office

601 East 12th Street

Kansas City, MO 64106

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NORTHLAND READY MIX, INC.
8607 Schell Rd. Pleasant Valley, MO 64068 • (816) 781-7113• northland7113@hotmail.com

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Very truly yours,

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PO Box 176

Jefferson City, MO 65102-0176

Kansas Department of Health and Environment

Bureau of Environmental Field Services

Watershed Management Section

1000 SW Jackson Street, Suite 430

Topeka, KS 66612-1367

Ashley Scott
Northland Ready Mix, Inc.

Northland Ready Mix, Inc.
Halley Northland Construction, Inc.
Halley Concrete Pumping, LLC
8607 Schell Rd.
Pleasant Valley, MO 64068
Office: 816-781-7113
Fax: 816-781-6626
Email: northland7113@hotmail.com

April 21, 2020

VIA EMAIL AND U.S. MAIL

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U.S. Army Corps of Engineers
Kansas City Regulatory Office
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Very truly yours,

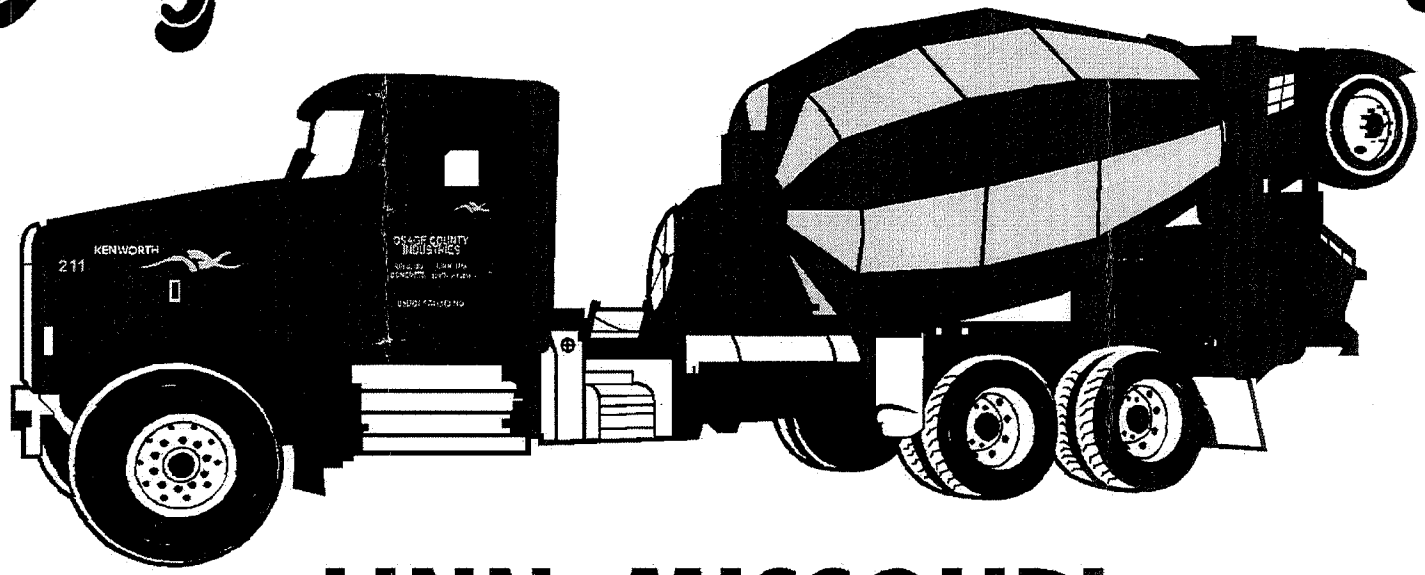
Mike Rachen MGR. Osage county concrete

cc: Missouri Department of Natural Resources
PO Box 176

Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Osage County Concrete



LINN, MISSOURI

428 Highway 50 W • Linn • 573-897-2149

OZARK READY MIX COMPANY, INC.

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Pavestone LLC
601 NE Pavestone Dr.
Lee's Summit, MO 64064
www.pavestone.com

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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At our Pavestone LLC facility in Lee's Summit, MO, commercial sand dredgers on the Missouri River provide all the sand used in our manufacturing operations. Pavestone makes concrete products used in commercial construction and sold retail sales in Kansas City and surrounding areas. Missouri River sand is of high quality and vitally important to our business.

Based on past performance, the commercial sand dredgers along the Kansas City and Waverly sections have worked within established regulations to protect the river and its flora and fauna. I expect this will continue under the new permits through 2025.

Pavestone LLC supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Wade Medlar
General Manager, Pavestone LLC

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

QUIKRETE®-Kansas City
2430 S. 88th Street
Kansas City, KS 66111
(913) 441-6525
(913) 441-8710 Fax

April 21, 2020

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

Commercial sand dredgers provide most of sand material for the construction industry. The sand goes into concrete and asphalt that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades.

Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

_____

Jon A Mitchell
Regional Operations Manager

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
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matthew.s.shively@usace.army.mil

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Very truly yours,

Stephen Christopher Bainer Sr. 1775 Bainer Bldg. Mod. Inc.

cc: Missouri Department of Natural Resources
PO Box 176

Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Jeffrey Viehmann, President

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Ronald Suma

SUMA EQUIPMENT SALES

cc: Missouri Department of Natural Resources
PO Box 176

Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

WHISTLE REDI-MIX INC.

P.O. BOX 230
PLEASANT HILL, MO 64080

518 Walker St.
Pleasant Hill, MO. 64080
(816) 540-3143

1301 N.W. 500
Holden, MO. 64040
(816) 850-4000

701 Linnco Dr.
LaCygne, KS. 66040
(913) 757-4775

501 Locust
Harrisonville, MO 64701
(816)380-3001

April 21, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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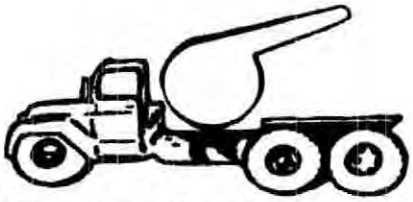

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Very truly yours,

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

AGCMO
MISSOURI CHAPTER
THE CONSTRUCTION ASSOCIATION

Jefferson City
1221 Jefferson Street
Jefferson City, MO 65109
P: 573.636.3188 F: 573.634.3510

St. Louis
6330 Knox Industrial Dr., Ste. 200
St. Louis, MO 63139
P: 314.781.2356 F: 314.781.2874

April 22, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 6 4106

Re: Missouri River Commercial Sand Dredging Permits

Dear Mr. Shively:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Leonard P. Toenjes, CAE
President

cc: Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

AMERICAN WATER

April 22, 2020

Mr. Matt Shively
Regulatory Project Manager
U.S. Army Corps of Engineers – Kansas City Regulatory Office
601 E 12th St
Kansas City, MO 64106

RE: Comments on Renewal of Missouri River Commercial Dredging Permit

Dear Mr. Shively,

Missouri American Water appreciates the opportunity to comment on the renewal of the Missouri River Commercial Dredgers permit. As a water and wastewater utility operating throughout Missouri, we have a deep obligation to maintain healthy watersheds and sources of drinking water for our communities. As dredging has been shown to impact water quality and the recharge of collector wells in addition to actual intake structures, we respectfully request that the minimum protective standards of Special Conditions relating to water utility infrastructure and resources, including but not limited to j., k., l., and u. of the current permit, be retained in the renewed permit.

Sincerely,

Traci Lichtenberg

Traci Lichtenberg
Manager, Water Quality & Environmental Compliance
Missouri American Water

Missouri American Water
901 Hog Hollow Rd
Chesterfield, MO 63017

P 314-469-6050 x6421
F 314-205-1051
Traci.Lichtenberg@amwater.com

amwater.com

GATEWAY DREDGING AND CONTRACTING, LLC.
1777 Highway 79 South
Old Monroe, Missouri 63369
Office # 636-665-5180

April 22, 2020

Mr. Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Mr. Shively:

This letter is in response to the Public Notice issued on March 18, 2020 concerning Commercial River Dredging Permits on the Lower Missouri River. Gateway Dredging and Contracting LLC. is the operating company for Limited Leasing Company and J.T.R. Inc. We would like to offer our support for issuance of the permits. These companies have operated dredging companies on the Missouri River for over 50 years. We have employed many highly skilled Union Operating Engineers through this time. The products produced have provided material for many of the improvements in the St. Louis area. These projects include highway and road construction, warehouses, residential, and airport upgrades. Our operation is an essential part of the St. Louis economy and its ability grow. Issuance of the permits would allow our company to continue its support of the construction industry and numerous projects. Please consider our comments pertaining to the renewal of the permits. Thank you.

Brian J. Viehmann, CEO

Brian J Viehmann

Gateway Dredging and Contracting, LLC.

MISSOURI CONCRETE ASSOCIATION, INC.

101 E. High Street, P.O. Box 392, Jefferson City, Missouri 65102
(573) 635-6271 • FAX: (573) 636-9749 • www.moconcrete.com
RANDY J. SCHERR, Executive Director

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April 22, 2020

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Randy J. Scherr,
MCA Executive Director

cc: Missouri Department of Natural Resources
Kansas Department of Health and Environment

2600 Capitol Avenue, Suite 140 | Sacramento, CA 95816 | 916.371.7400 | www.nhcweb.com

nhc
northwest hydraulic consultants

NHC Ref. No. 5005120

22 April 2020

Lathrop GPM LLP
314 East High Street
Jefferson City, MO
65101

Attention: **David Shorr**
Partner

Via email: dshorr@lathropgage.com

Re: **Expert Peer Review of USACE Lower Missouri River Mobile Bed HEC-RAS Model**

Dear Mr. Shorr:

Northwest Hydraulic Consultants Inc. (NHC) completed a review of the mobile bed HEC-RAS model of the lower 500 miles of the Missouri River (hereinafter Model 500), developed by the Kansas City District of the US Army Corps of Engineers (USACE). Our review is provided in the attached technical report, which includes a copy of the USACE Calibration Report for reference to the USACE's development and calibration of Model 500.

Model 500 attempts to simulate complex, interdependent hydraulic and sedimentation processes over time periods of several years and over distances of several hundred miles using HEC-RAS. HEC-RAS is a state-of-the-art modeling tool that conceptually simulates several of these processes, however our review identified several technical deficiencies in the setup and calibration of Model 500. These deficiencies are significant and indicate multiple shortcomings and uncertainties in the reliability of the model's computational results that preclude its use for any planning or design purposes, including assessment of impacts to Federal navigation or bank protection projects for 408 permitting reviews. Technical issues with Model 500 are described in detail in our attached technical report, and key limitations in the Model 500 setup and application are summarized below:

1. The HEC-RAS code developers released an update of the model (version 5.0.7) which is different from the version used by the USACE in their model setup and calibration (version 5.0.3). According to the HEC-RAS software developers, the new model coding fixed a variety of errors in the version originally used in Model 500. Application of the Model 500 input data in the corrected version of HEC-RAS (version 5.0.7) provides widely different results from those presented in the Calibration Report indicating that the model using version 5.0.3 does not provide realistic simulation results.

2. The USACE specified large sediment outflows to simulate floodplain depositions that are excessive, resulting in computed, unexplained, and physically impossible negative sediment loads in the river channel at several locations during the simulations.

3. The USACE added a large amount of sediment from unknown sources in the lower reach of Model 500 to improve model performance. This additional amount is greater than the average annual sand load in the Missouri River and was applied without justification. In the absence of any observed data the Model 500 results are unrealistic. This unknown sediment loading is an indication of deficiencies in the model setup and boundary conditions.

4. The intra-dike sediment erosion and deposition processes are not fully explained in the Calibration Report. Cross-section comparisons of modeled and surveyed bathymetric data need to be completed to evaluate the locations, timing, flow condition, and magnitude of intra-dike sedimentation processes and to assess if the model is properly accounting for this component of the sediment budget.

These unresolved issues indicate the existing Model 500 has several technical flaws and should not be used in its present setup and configuration to support any ongoing or future permitting, planning, or design efforts on the Missouri River. Please contact us (bhall@nhcweb.com, ashvidchenko@nhcweb.com, 916.371.7400) should you have any questions on our findings.

Sincerely,

Northwest Hydraulic Consultants Inc.

Brad Hall, PE
Principal

Andrey Shvidchenko, PhD
Senior Engineer

cc: Mike Odell – Holliday Sand and Stone, mike.odell@hollidaysand.com

HYDROTECHNICAL ASSISTANCE TO MISSOURI RIVER DREDGERS GROUP

REVIEW OF USACE LOWER MISSOURI RIVER MOVABLE-BED SEDIMENT MODEL

REPORT

Prepared for:

Lathrop GPM LLP

314 East High Street, Jefferson City, MO 65101

Prepared by:

Northwest Hydraulic Consultants Inc.

2600 Capitol Ave, Suite 140, Sacramento, CA 95816

22 April 2020

NHC Ref. No. 5005120

Prepared by:

Andrey Shvidchenko, PhD
Senior Engineer

Reviewed by:

Brad Hall
Principal

DISCLAIMER

This document has been prepared by Northwest Hydraulic Consultants Inc. in accordance with generally accepted engineering practices and is intended for the exclusive use and benefit of Lathrop Gage LLP, Missouri River Dredgers Group, and their authorized representatives for specific application to the Lower Missouri River, MO. The contents of this document are not to be relied upon or used, in whole or in part, by or for the benefit of others without specific written authorization from Northwest Hydraulic Consultants Inc. No other warranty, expressed or implied, is made.

Northwest Hydraulic Consultants Inc. and its officers, directors, employees, and agents assume no responsibility for the reliance upon this document or any of its contents by any parties other than the client for whom the document was prepared.

EXECUTIVE SUMMARY

Northwest Hydraulic Consultants Inc. (NHC) was requested to review the "calibrated" one-dimensional (1-d) HEC-RAS movable-bed model of the lower 500 miles of the Missouri River recently prepared by the Kansas City District of the US Army Corps of Engineers (USACE). The main goal of the review was to evaluate the model technical adequacy and it's suitability for planning future dredging quantities and locations on the lower Missouri River. The review included the examination of the model setup and calibration, model calibration report, and measured data utilized in the model development. The model performance was tested using HEC-RAS 5.0.3 (originally used by the USACE to develop and calibrate the model) and the latest HEC-RAS 5.0.7 (in which several serious sediment-related software bugs found in the previous versions were fixed).

The following are the main findings of this review:

(1) The model geometry and roughness reasonably represents the existing channel conditions. However, in the absence of the actual surveyed cross-section data, the correctness of the model sections could not be evaluated by NHC.

(2) The intra-dike sediment erosion and deposition processes are not fully explained in the calibration report. Cross-section comparisons of modeled and surveyed bathymetric data need to be completed to evaluate the locations, timing, flow condition, and magnitude of intra-dike sedimentation processes and to assess if the model is properly accounting for this component of the sediment budget.

(3) Bed gradations specified in the model reasonably agree with the measured data. However, the rationale behind the bed gradation smoothing method is not clearly described in the accompanying calibration report. Given the relatively similar bed material composition along the study reach, a simple reach-average approach should be used or tested.

(4) Some sediment input parameters in the model seems to be overcomplicated and not very well justified. For example, the reduction of sediment loads during the 2011 flood event was not observed along the entire study reach and may not need to be represented by a separate flow-load rating curve at the model upstream boundary. Some of the tributary sediment load rating curves could be improved to better fit the measured data. The unmeasured sediment loads specified in the model as lateral inflows could be introduced as part of the tributary sediment loads. The modeled floodplain sediment outflow seems excessive, which actually results in computed, unexplained, and physically impossible negative sediment loads in the river channel at several locations during the 2011 flood event.

(5) The calibration report states that the loads for the tributary rating curves in the model were divided by two to compensate for a HEC-RAS 5.0.3 code error that apparently doubles tributary loads. However, it is not clear if the same correction is required, and if so, was done for the other lateral sediment inflow sources (unmeasured loads and floodplain deposits). The updated

version HEC-RAS 5.0.7 presumably does not have this error in the model coding, according to the software developers.

(6) The model uses the combination of the Toffaleti and Meyer-Peter and Muller (MPM) sediment transport functions. While the Toffaleti function is suitable for large sand-bed rivers, the MPM is mostly applicable to gravel bed materials and is not a good choice for predominantly sand-bed channels. Testing the model with solely Toffaleti, or possibly a different function, should be investigated.

(7) To provide for better agreement with observed post-2011 bed aggradation, the USACE added a large amount of sediment from unknown sources in the lower reach in the model. This additional amount is greater than the average annual sand load in the Missouri River. Such an approach is difficult to justify and, in the absence of any observed data, is unrealistic. This unknown sediment loading is an indication of deficiencies in the model setup and boundary conditions.

(8) The model reasonably reproduce sediment loads and bed changes observed in the prototype only for the HEC-RAS 5.0.3 version originally used by the USACE to develop and calibrate the model. However, running the model with the latest HEC-RAS 5.0.7 version produces reasonable results only in the most upstream reach between Rulo and Kansas City and shows unrealistic bed changes downstream of Kansas City. The release notes for HEC-RAS 5.0.7 indicates that several bug fixes to the active layer calculations were made in the model update between the two versions. The implications of this model version update indicates any modeling using the previous version may be unreliable based on guidance provided by the model's developers.

(9) NHC's test runs indicate that a recalibration of the entire model is needed to enable its application using the most recent, improved, and corrected version of the HEC-RAS software. The previous versions of HEC-RAS include serious computational bugs/errors and, therefore, their application for predicting future morphological changes and dredging strategies in the Missouri River is unreliable and should not be used in support of any planning and design decisions.

(10) Because of the large size of the movable-bed model, the model simulations can not provide more detailed levels of sediment data output for a more in-depth analysis. To reduce the model complexity and simplify model calibration, NHC recommends that the model be discretized into a few segments between relatively stable channel locations.

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LIST OF ABBREVIATIONS

1-d	one-dimensional
CRP	Construction Reference Plane
DSS	Hydrologic Engineering Center's Data Storage System
HEC-RAS	Hydrologic Engineering Center's River Analysis System
LiDAR	Light Detection and Ranging
Model 155	USACE's HEC-RAS movable-bed model of the 155 mile reach of the Missouri River between St. Joseph and Waverly
Model 500	USACE's HEC-RAS movable-bed model of the lower 500 miles of the Missouri River between Rulo and confluence with the Mississippi River
MRRP	Missouri River Recovery Program
NHC	Northwest Hydraulic Consultants Inc.
RM	River Mile
USACE	US Army Corps of Engineers
USGS	US Geological Survey

1 INTRODUCTION

Northwest Hydraulic Consultants Inc. (NHC) was requested to review the "calibrated" one-dimensional (1-d) HEC-RAS movable-bed model of the lower 500 miles of the Missouri River (hereinafter Model 500) recently prepared by the Kansas City District of the US Army Corps of Engineers (USACE). The river reach included in the model is shown in Figure 1. The model was obtained from the USACE through the Freedom of Information Act as HEC-RAS input files together with the associated model calibration report (USACE 2018, attached in Appendix A).

The main goal of the review was to evaluate the technical adequacy and applicability of the model, to identify model shortcomings or apparent errors, and to provide recommendations for any future analysis or model modifications and applications that may support upcoming dredge permit applications. The review included the examination of the model setup and calibration, model calibration report, and measured data utilized in the model development. The model was tested using HEC-RAS 5.0.3 (originally used by the USACE to develop and calibrate the model) and the latest HEC-RAS 5.0.7 (in which several serious sediment-related software bugs found in the previous versions were fixed).

The information extracted from the model runs was compared to the results presented in the calibration report, to the previous USACE movable-bed model developed for the 155 mile reach between St. Joseph and Waverly (hereinafter Model 155), and to the sediment transport data collected by the US Geological Survey (USGS). Results from these cross-comparisons were used to evaluate the model performance and it's suitability for planning future dredging quantities and locations.

2 SEDIMENT TRANSPORT DEFINITIONS

2.1 Suspended Load and Bed Load

The total sediment load in a river can be divided based on the mode of transport, into suspended load and bed load. Suspended load consists of the fine sediment maintained in suspension by turbulent currents. Bed load consists of the coarse sediment that is transported along the river bottom and creates bed forms such as dunes and bars.

Movement of sediment as suspended or bed load depends on the nature of the sediment and the hydraulic characteristics of the flow. Generally, smaller particles such as silts and clays move in suspension, larger sand-size particles move both in suspension and as bed load, and gravel-sized particles predominantly move as bed load. The boundary between the size of particles moved in suspension or as bed load is not precise and varies with flow strength; the greater the flow, the coarser the sediment that can be suspended by turbulence.

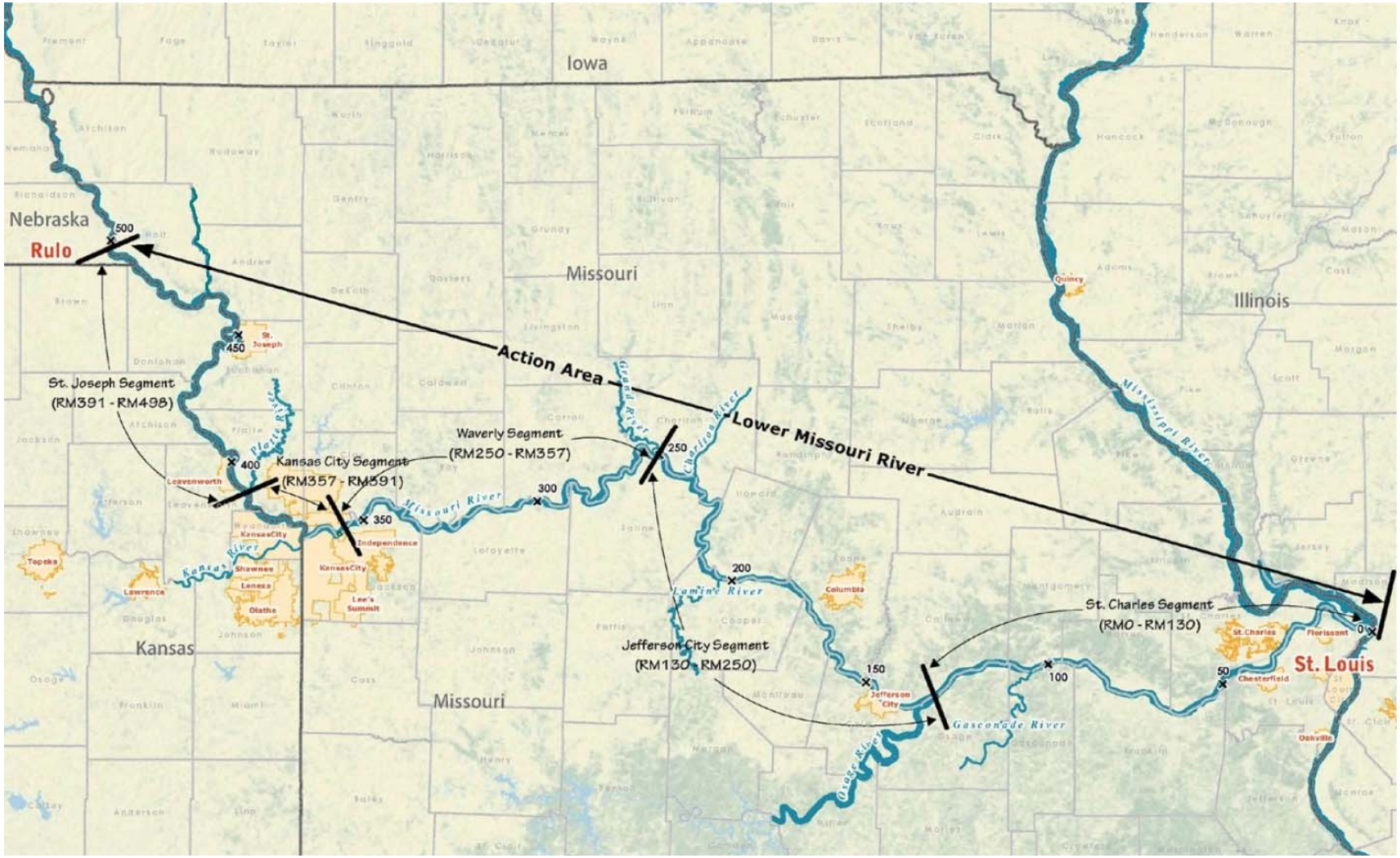

Figure 1 Lower Missouri River (from USACE 2011).

2.2 Bed Material Load and Wash Load

The total sediment load can also be divided by its presence in the streambed, into bed material and wash load. Particles that are found in significant quantities in the bed and are exchanged with the bed material during transport in suspension or as bed load are part of the bed material load. Wash load consists of the finest particles (usually silt and clay) that are continuously maintained in suspension by the flow turbulence and, thus, are not found in the bed in significant quantities. Under this division, the total sediment load is bed material load plus wash load.

Bed material transport depends on hydraulic variables, which are closely related to water discharge, and consequently can often be calculated from knowledge of the bed material and the hydraulic characteristics of a particular site. Wash load is mostly determined by its supply from upstream sources and it may be partly independent of water discharge. Typically, wash load is measured as part of a suspended-sediment gaging program.

3 DATA SOURCES

Readily available flow and sediment data collected by the USGS, USACE, and others were used to verify the information presented in the USACE (2018) model calibration report and to evaluate the setup and calibration of Model 500. The following sources and data were used in this review:

(1) USGS (2020) – Annual peak and mean flows measured at selected USGS gages on the Lower Missouri River.
(2) USGS (2019) – Discrete total suspended sediment and suspended sand data measured at selected USGS gages on the Lower Missouri River.
(3) Heimann et al. (2010) – Annual total suspended sediment loads (which include wash loads) and suspended sand loads for selected USGS gages on the Lower Missouri River for Water Years (WYs) 1976-2008.
(4) Heimann (2016) – Annual total suspended sediment loads (which include wash loads) for selected USGS gages on the Lower Missouri River for WYs 1968-2014.
(5) Abraham et al. (2017) – Bed load and bed material data collected for the Lower Missouri River by the USACE in 2014. Bed load was measured by comparing successive multi-beam bathymetric surveys.
(6) Cardno ENTRIX (2011) – Bed material data collected by the USGS and USACE for the Lower Missouri River.

4 USACE MOVABLE-BED MODELS

4.1 Model 155

The USACE previously developed a HEC-RAS 5.0 movable-bed sediment model of the 155 mile reach of the Missouri River between St. Joseph and Waverly (USACE 2017). This model is referred in this review as Model 155. The model geometry was synthesized using bed bathymetry from the 1994 hydrographic survey data and bank and overbank data from 1998/1999. Bed sediments in the model were based on the bed material samples collected at 5-mile increments in 1994. Model bed gradations were computed as a weighted average of 95% of the measured individual gradation and 5% of a reach-average gradation. The upstream and lateral sediment inflows were specified using suspended sand data measured at the USGS gages on the Missouri River at St. Joseph, Platte River at Sharps Station, and Kansas River at Desoto and bed load sand transport measured in the Missouri River at Kansas City. The model included historical dredging tonnages and locations. The observed floodplain deposition of sand through the levee breaches during the historic flood of 2011 was modeled as a negative lateral load distributed proportional to the areal extent of deposition. Sediment transport capacity was computed using the Toffaleti transport formula.

The model was calibrated to replicate measured water surface profiles, velocities, sediment loads, bed elevation changes, and volume of bed degradation from 1994 to 2014 (with the principal calibration period from 1994 to 2009 and a verification period from 2009 to 2014). The calibrated model was then used to compute long-term bed change trends over a 50-year period (from 2015 to 2065) for several alternative structural modifications and dredging conditions.

NHC reviewed the earlier version of Model 155 and the associated calibration report and provided recommendations for the model improvement (NHC 2014). The modified model was then used to test several conceptual dredging approaches that do not lead to significant river bed degradation (NHC 2018).

4.2 Model 500

Recently, the USACE developed a HEC-RAS 5.0.3 movable-bed sediment model for the lower 500 miles of the Missouri River between Rulo and the confluence with the Mississippi River (USACE 2018). This model is referred in this review as Model 500. Model 500 includes the river reach contained in Model 155, but the model parameters for this reach were substantially revised. The model development and calibration followed the basic principles outlined in HEC (1982) and USACE (1989), with some adaptation. The stated purpose of this planning level model is to assess the reach and river scale effects and future bed elevations under alternative management scenarios. The review of Model 500 input parameters and calibration is provided in the following sections.

5 REVIEW OF MODEL 500 INPUT PARAMETERS

5.1 Model Geometry

The model geometry was synthesized using bed bathymetry from the 1994 hydrographic survey data and bank and overbank data from 2013 Light Detection and Ranging (LiDAR). Comparing to Model 155, Model 500 includes significantly wider overbank areas, which provides a more realistic modeling of high flows and overbank flooding. Model 500 contains 801 cross-sections which span approximately 500 river miles of the Missouri River. The spacing ranges from about 670 to 6,920 ft, with the typical spacing around 3,000-5,000 ft. This spacing is generally adequate for reproducing reach-scale, long-term morphological changes.

Cross-section geometries were adjusted to account for the dike and sill structures and inter-dike regions located within the control volume associated with each cross-section. Conceptually, the ineffective flow areas along the banks within each control volume were summed and then divided by the control volume length in order to compute the equivalent blocked areas in the control volume to be entered into each cross-section. The ineffective flow area associated with each dike was assumed to extend at 1:1 (contraction zone) upstream and 4:1 (expansion zone) downstream of the dike. The methodology is described in detail on p.15-18 in the USACE (2018) report (attached to the present report in Appendix A). Thus, model cross-sections include effective, averaged channel widths within the control volumes bounded by surrogate dikes and sills, rather than modeling the actual dike and sill structures. Such methodology allows computing of average conveyance areas and average bed elevation changes within each control volume, as constrained by the moveable bed limits described in section 5.3 below. Therefore, bed changes computed at each cross-section in the 1-d mobile-bed model should be viewed as representing the combined effect of bed erosion or deposition on the channel bed and erosion or deposition in the inter-dike regions.

The 1982 Construction Reference Plane (CRP), which was the official CRP in 1994, was used to set the structure elevations in the calibrated model. Dike configurations have changed since 2008 or 2009 through lowering and notching of dikes withing the project area, but dike geometry was not changed for the model calibration period (1994-2014). Dike geometry and configurations needs to be accounted for in the model verification time period of 2009 through 2014, and in any future condition model simulations. Surveyed cross-section data has not been made available to or reviewed by NHC to verify dike and intra-dike geometry with model geometry as specified in HEC-RAS. Variable roughness coefficients were specified in the model and calibrated (adjusted) to reproduce the measured water surface elevations.

NHC reviewed the Model 500 geometry setup and did not find any significant technical flaws or errors. However, in the absence of reviewing the actual surveyed cross-sections, the correctness of the model sections compared to the actual river bathymetry and dike conditions could not be evaluated.

5.2 Flow

The total calibration period used in Model 500 is 20 years, from 1994 to 2014. This time period includes a drought period from 2000 to 2006 and the historic flood of 2011, which provided a wide range of flow conditions for the mobile-bed model testing and calibration. This period also includes years of most significant bed degradation along the lower Missouri River in the early 2000s (USACE 2017, 2018).

Annual peak flows and annual mean flows recorded at the USGS gages on the Missouri River at St. Joseph and at Kansas City are shown in Figure 2. Also shown on this figure are the period of construction of the major dams on the Missouri River and the calibration period used in the USACE's movable-bed models. The annual peak flow records indicate a general reduction of peak flows on the Missouri River in the second half of the 1900s, which was related to the construction and operation of the upstream dams (USACE 2017). It is seen that the calibration period reasonably represents the historic flow pattern since the 1960s (after the completion of the major dams).

Daily flow values from 1 August 1994 to 29 July 2014, computed from seven mainstem Missouri River and seven tributary USGS gaging stations, were used as the flow inputs to Model 500. The model upstream boundary was set to the daily flow reported by USGS for the Missouri River at Rulo. Each tributary was entered as a lateral flow. The difference between the mainstem Missouri River gages that could not be explained by the tributary flows were entered as uniform lateral flows. The downstream model boundary was based on the stage series computed by the Missouri River Recovery Program (MRRP) unsteady flow model which includes the backwater effect from the Mississippi River. NHC reviewed the overall setup of the hydraulic boundaries and did not find any significant errors.

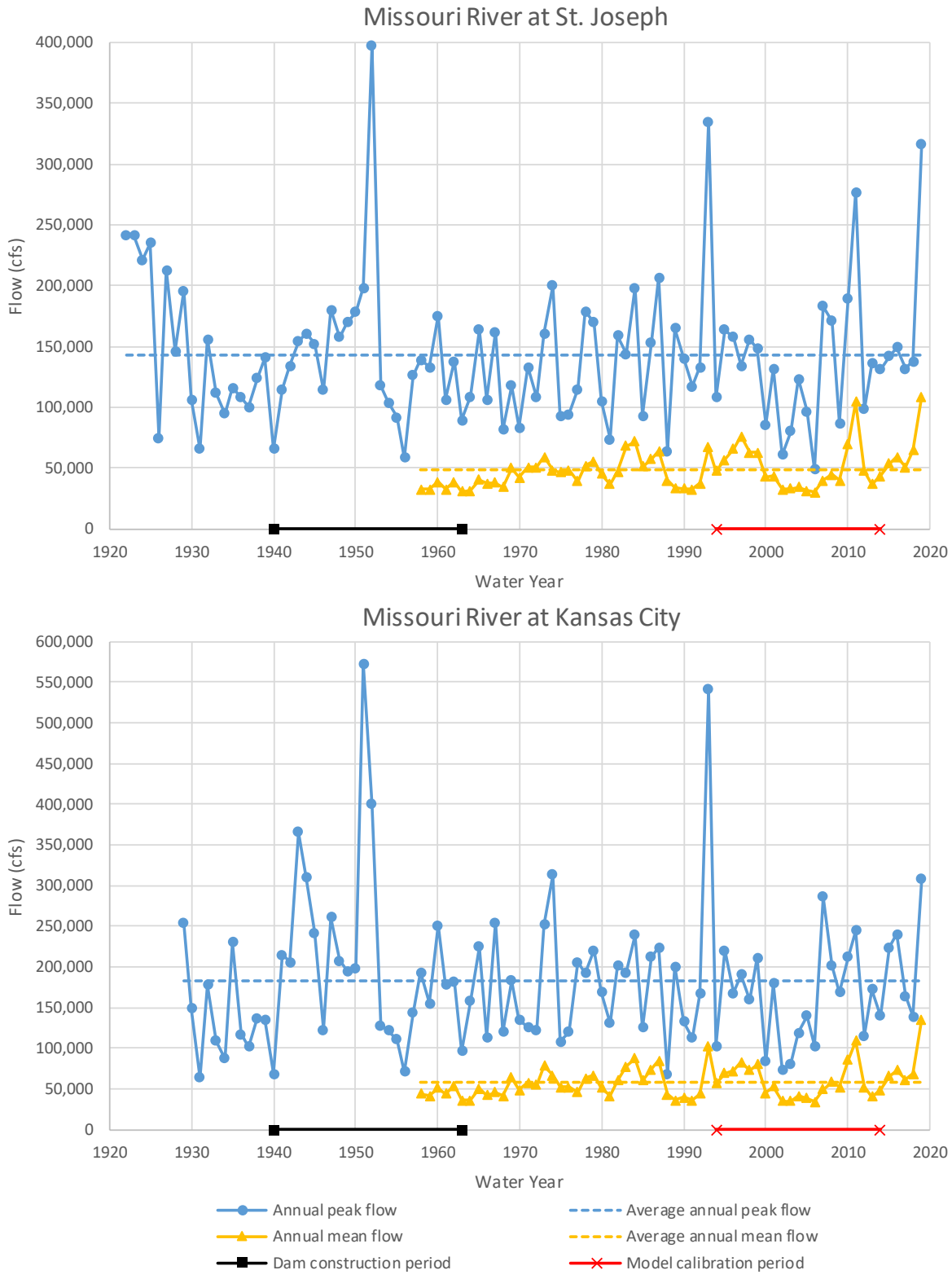

Figure 2 Annual peak flows and annual mean flows at USGS gages on Missouri River.

5.3 Bed Sediment Extent

The moveable bed limits in the model were initially set at the toe of the training structures and then adjusted as needed for model stability and to match prototype behavior. Moveable bed width used in the previous Model 155 and present Model 500 are compared in Figure 3. It is seen that the moveable bed width between St. Joseph and Waverly in Model 500 is noticeably greater and also more variable compared to Model 155. The reason for such a difference is not clear, but may be related to different methods used to represent ineffective flow areas between training dikes in the models.

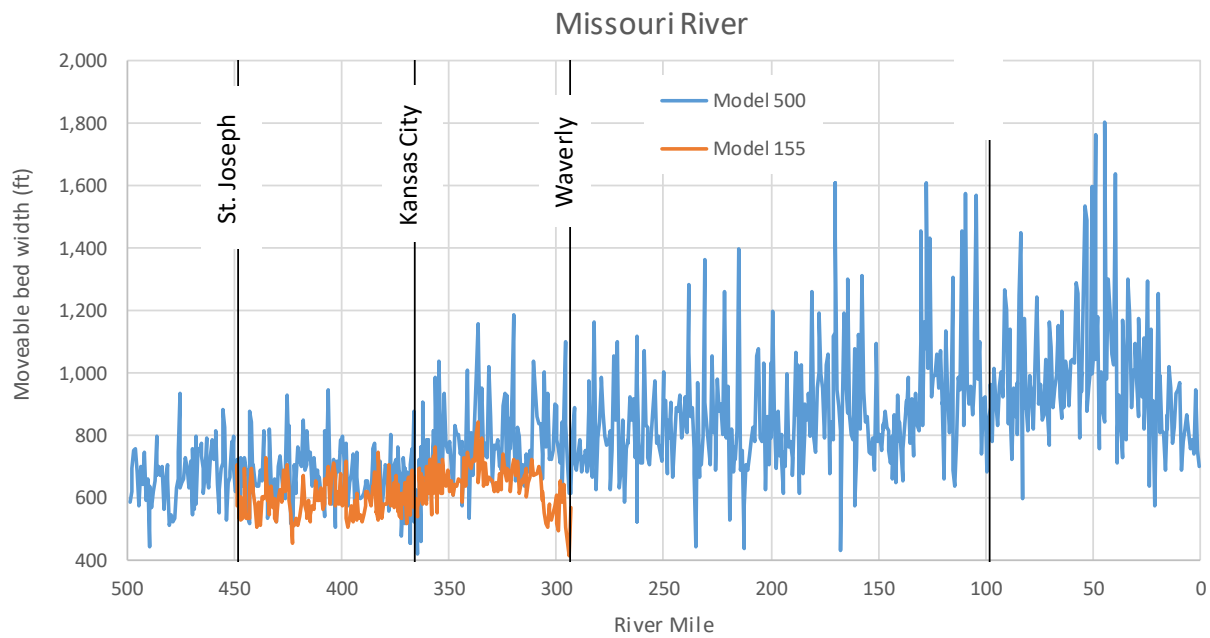

Figure 3 Modeled moveable bed width.

No bed change is allowed outside of the moveable bed limits, similar to Model 155. The USACE (2018) calibration report states that the depth of the erodible bed was set to 40 ft, while 20 ft was specified in the actual model. This, however, did not affect the modeling results as the computed bed degradation was less than 20 ft.

HEC-RAS has the ability to simulate sediment deposition outside of the moveable bed limits if the water surface extends beyond that portion of the channel. That feature may emulate the deposition of bed material sediments in the ineffective flow areas between dikes, although subsequent erosion of these intra-dike sediment deposits can not be simulated. Also, a comparison of intra-dike sediment erosion or deposition should be reviewed by comparing repeat cross-section or bathymetric surveys of the intra-dike regions. These comparisons are not provided in either the Model 155 or Model 500 calibration reports.

5.4 Bed Material

Bed sediments in the model are based on the bed material samples collected at 5-mile increments in 1994. The location of the individual samples at a given cross-section is not known (i.e. channel thalweg, centerline, etc.). To smooth individual samples, the model bed gradation was calculated as a weighted average of 50% of the individual gradation and 50% of the reach-average gradation. The average reaches were River Mile (RM) 500-391 (Rulo to Platte River), RM 391-250 (Platte River to Grand River), RM 250-130 (Grand River to Osage River), and RM 130-0 (Osage River to the mouth). The percentages of the individual versus reach-average gradations used in Model 500 (50% individual and 50% reach-average) differ from Model 155 (95% individual and 5% reach-average).

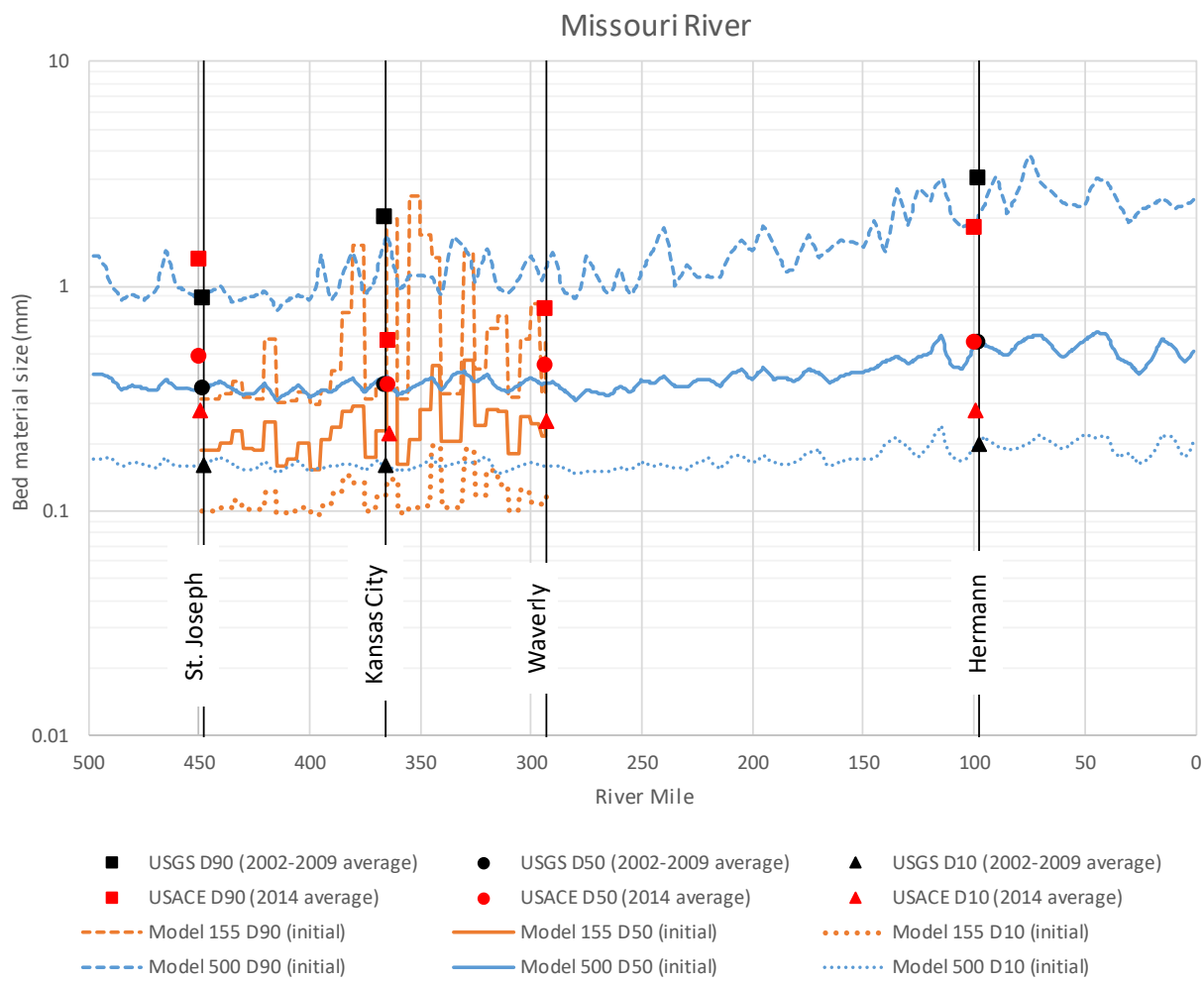

Figure 4 Comparison of modeled and measured bed material sizes.

Figure 4 compares characteristic sediment sizes (D_{50}, D_{90}, and D_{10}) in Model 500 and Model 155 with the average sizes measured by the USGS and USACE (from Cardno ENTRIX (2011) and Abraham et al. (2017)). Bed material in Model 500 is somewhat coarser and less variable along the modeled reach than

in Model 155. In general, the approach used to specify bed gradations in Model 500 seems to more reasonably account for natural variability of bed sediment and the limited number of samples than Model 155. However, the rationale behind the bed gradation smoothing method is not clearly described in the USACE (2018) calibration report. Given the relatively similar bed material composition along the study reach, a simple reach-average approach should be tested.

Interestingly, the bed material data in Figure 4 show a slight coarsening trend between St. Joseph and Hermann. The reason for such a non-typical behavior (natural rivers usually show a fining trend from upstream to downstream) deserves an explanation.

5.5 Upstream Sediment Inflow

The incoming sediment load and gradation was computed and entered into the model as a Data Storage System (DSS) time series for each grain class. Only sands and gravels were included in the model; silts and clays were assumed to represent wash load and were not included. The incoming sediment included both the suspended load and bed load.

The long-term average flow-load relationship and gradation for the suspended load was developed using (rather scattered) USGS suspended sediment data measured at St. Joseph. The upstream sediment inflow in Model 500 was specified for 9 grain classes (from very fine sand to coarse gravel), comparing to 6 grain classes (from very fine sand to very fine gravel) in Model 155. In Model 500, the suspended loads computed for St. Joseph were reduced by the Nodaway River sediment load in order to create the model upstream boundary condition.

A separate flow-load relationship was developed for the 2011 flood when, as is stated in the USACE (2018) calibration report, high volumes of relatively clear water released from the upstream dams resulted in reduced sediment loads in the Missouri River at St. Joseph during this event. In support of this statement, the calibration report presents the measured total suspended load data (including wash load) which show a noticeable downward shift in the flow-load relationship at St. Joseph during 2011. However, the measured suspended sand data (without wash load) show somewhat less drastic decrease in sediment loads. Suspended sand loads measured at the USGS gages on the Missouri River at St. Joseph, Kansas City, and Hermann (published in USGS 2019) are plotted in Figure 5. It is seen that while there was some decrease in suspended sand loads measured at high flows during 2011 at St. Joseph, the suspended sand loads measured at Kansas City and Hermann were within the overall data scatter. This suggests that the temporary reduction in sand loads during the 2011 event at St. Joseph was likely a local phenomenon (such as sediment supply from tributaries) rather than a system-wide response to the release of clear water from the dams located hundred miles upstream of the study reach.

The bed load portion of the inflowing sediment load in the model was computed from the bed load rating curve for St. Joseph presented in Abraham et al. (2017). The method used to account for bed load seems reasonable.

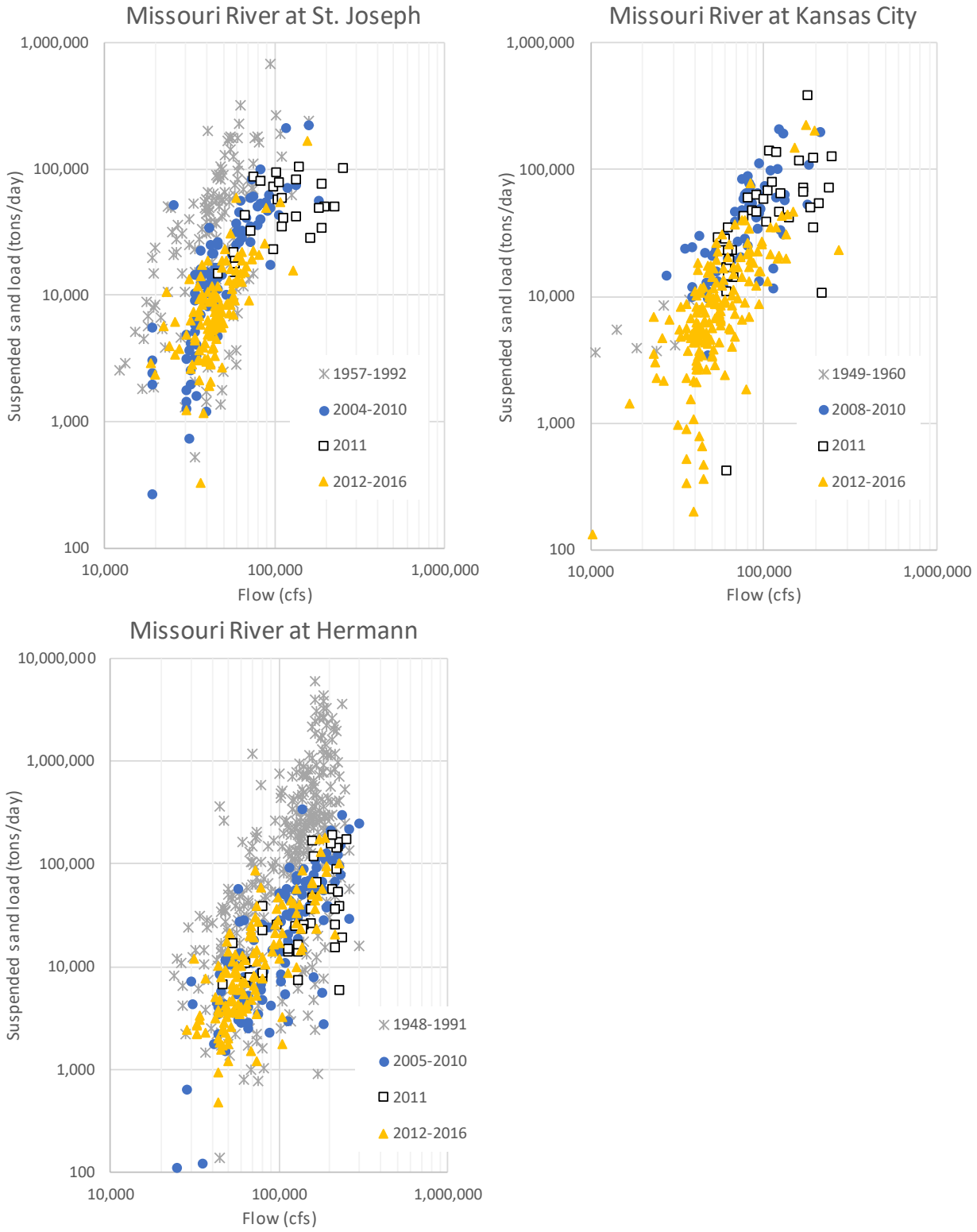

Figure 5 Measured suspended sand loads at USGS gages on Missouri River.

5.6 Lateral Sediment Inflow from Tributaries

Seven major tributaries enter the Missouri River in the model reach: Nodaway River (RM 463.2), Platte River (RM 391.3), Kansas River (RM 367.6), Grand River (RM 250.2), Chariton River (RM 239.2), Osage River (RM 130.4), and Gasconade River (RM 104.5). Sediment rating curves at these tributaries were included in the model as lateral flow-load boundary conditions. The flow-load curves were developed using USGS suspended sediment data for the Nodaway River at Clarinda, Platte River at Sharps Station, Kansas River at Desoto, Grand River near Summer, Chariton River near Prairie Hill, Osage River below St. Thomas, and Gasconade River at Jerome. The USGS data for the Gasconade River at Jerome yielded total suspended loads only. The wash load percentage was taken from the Osage River. Actually, there is a gage on the Gasconade River above Jerome, which includes suspended sand load data and which is better suited for developing the bed material rating curve for this tributary. Bed load was assumed to be 1% of suspended load for the Nodaway River and 5% of suspended load for the other tributaries. The calculated rating curves are presented in the calibration report. The model itself includes these rating curves with the loads divided by two to compensate for a HEC-RAS 5.0.3 bug that doubles tributary loads.

The USACE (2018) calibration report compares the developed flow-load rating curves with the measured total suspended loads, which is not very informative as the total load includes both suspended bed material and wash load while the model calculates bed material transport only. To assess the reasonableness of the developed tributary sediment inflow data, the flow-load rating curves were extracted from Model 500 and multiplied by two to provide the actual loads. The actual flow-load rating curves are compared with the suspended sand loads measured at the USGS gages (published in USGS 2019) in Figure 6. The developed rating curves generally follow the rather scattered measured data, but some of the curves could be improved (for example, for the Chariton River at high flows and the Osage River at low flows).

The flow-load rating curves used in Model 500 somewhat differ from the curves presented in the calibration report and also differ quite significantly from Model 155. The loads in Model 155 were not reduced by a factor of two as it was done in Model 500 to compensate for the software bug.

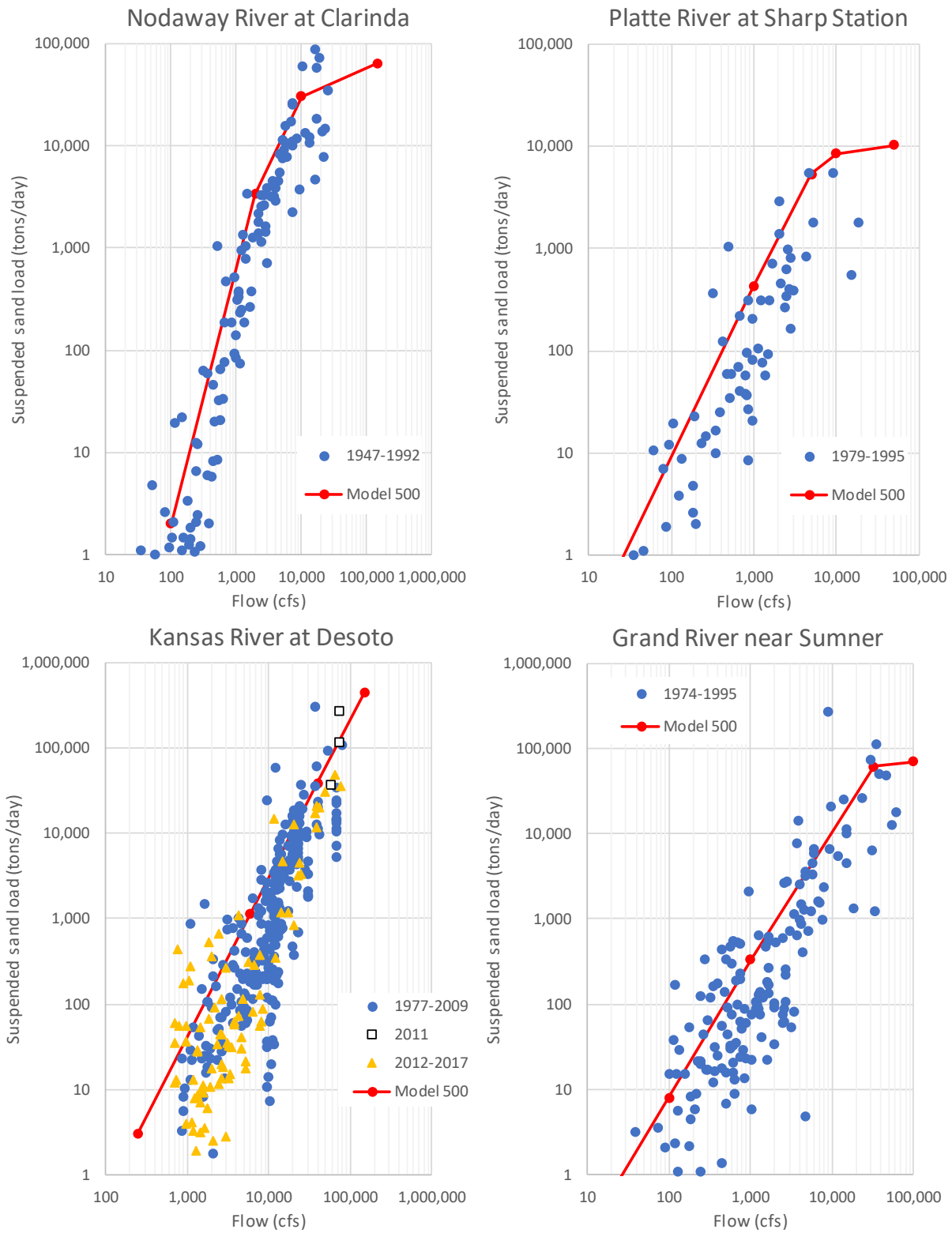

Figure 6 Measured suspended sand loads at USGS gages on tributaries to Missouri River.

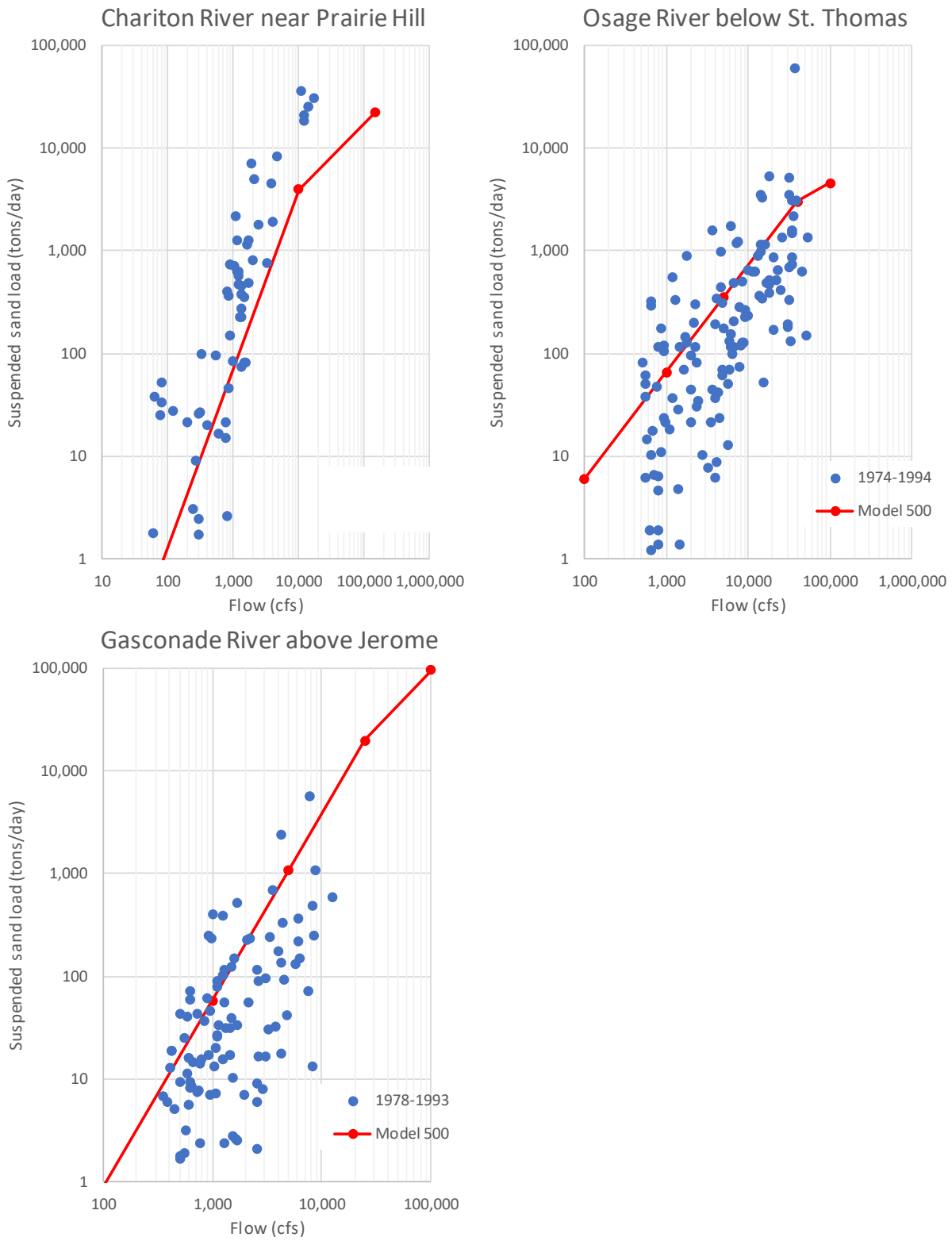

Figure 6 – Continued.

5.7 Dredging

The model includes the actual dredging tonnages and locations reported to USACE's regulatory branch. Dredging was specified as monthly totals at each cross-section and uniformly distributed over the duration of each month. Location and total dredging tonnages specified in Model 155 and Model 500 are compared in Figure 7. The site-specific dredging tonnages between St. Joseph and Waverly somewhat differs between Model 500 and Model 155, but the total dredging distributions and amounts for the 1994-2014 calibration period are quite similar (the difference is about 200,000 tons or less than 1%).

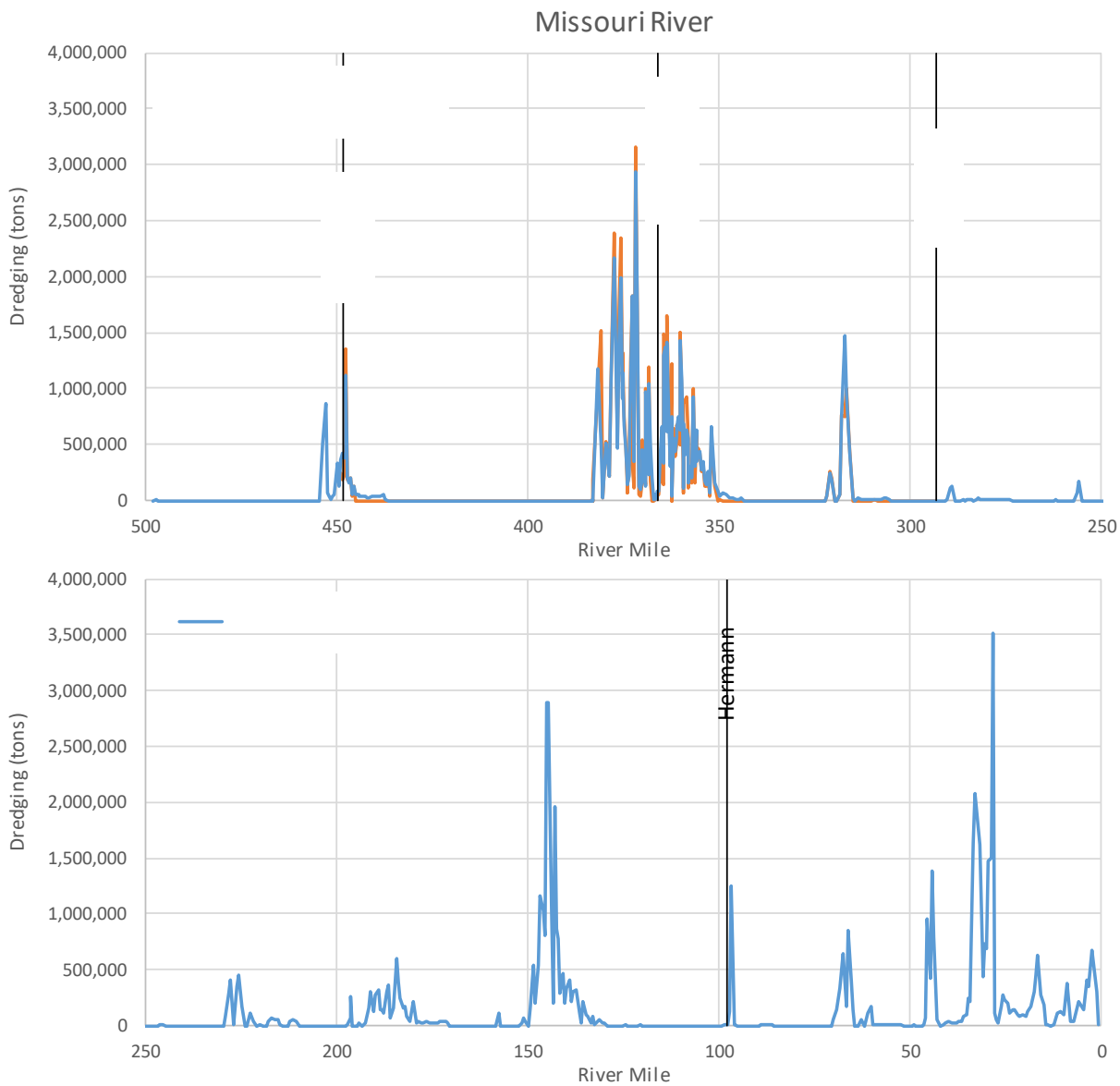

Figure 7 Modeled dredging.

5.8 Unmeasured Sediment Inflow

Sediment budgeting was used to estimate unmeasured sediment inflows for inclusion in the model. The USACE states that the unmeasured sediment load incorporates all non-specific sediment sources needed for the sediment budget to balance, including bank erosion, gullies, shallow water habitat constriction activities, as well as errors in the upstream, downstream, and tributary rating curves. Sediment budget analysis was conducted for the reaches from St. Joseph to Kansas City and from Kansas City to Herman for 1994 to 2005. The calculated average annual unmeasured sediment inflow was about 980,000 and 5,520,000 tons/year, respectively. For comparison, the average annual suspended sand load during this period was about 9,560,000 tons/year at St. Joseph, 11,700,000 tons/year at Kansas City, and 15,620,000 tons/year at Hermann (Heimann et al. 2010). The calculated unmeasured loads were entered into the model using flow-load rating curves tied to the flow boundary conditions representing ungaged water lateral inflows. To avoid problems with negative uniform lateral inflows, separate flow boundary conditions that are always positive were created for use with the unmeasured sediment rating curves. It is not clear from the calibration report or review of the model input data if the unmeasured loads in the model itself were divided by two (as was done for the tributary sediment inflows) to compensate for the HEC-RAS 5.0.3 bug that doubles lateral sediment loads.

The above procedure used in Model 500 to account for sediment disbalances seems somewhat complicated and cumbersome, and not well justified through any technical analysis or field measurements. A more straightforward and simpler approach would be to adjust the upstream and tributary flow-load rating curves, which are drawn through the cloud of measured data and which obviously could be improved (see Figure 6 above).

5.9 Floodplain Deposition and Sediment Budgets

The floodplain deposition outside of the levees (which line most of the Missouri River) was estimated for the 1993 historic flood using a sediment budget analysis and for the 2011 flood using the aerial extend of sand deposition from Alexander at al. (2013). The calculated total floodplain deposition along the modeled reach is about 225,500,000 tons for the 1993 flood and 45,700,000 tons for the 2011 flood. These data were used to develop site-specific relationships between the daily flows and floodplain deposition amounts, which were then used to estimate bed material outflow from the river channel into floodplains for the other flood events within the calibration period. The calculated floodplain depositions were modeled as a negative sediment outflow time series at discrete locations which correspond to the observed locations of the 2011 floodplain deposition. The USACE (2018) calibration report does not indicate if the loads in these time series were divided by two to compensate for the HEC-RAS 5.0.3 bug that doubles tributary loads.

The total amount of floodplain sediment outflows included in the model itself is about 88,200,000 tons for the period 1994-2014. If the model includes a reduced sediment outflow to compensate for the software bug, the actual total amount of the floodplain sediment outflow during 1994-2014 is then 176,400,000 tons. For comparison, the total upstream sediment inflow in the model during 1994-2014 is about 198,200,000 tons. The modeled floodplain sediment outflow seems excessive, which actually

results in computed negative sediment loads in the river channel at several locations during 2011 (see review of model calibration below).

It should be noted that Alexander et al. (2013) describes the sediment deposited on the floodplain during the 2011 flood as sand deposits. However, according to the USGS (2019) suspended sediment data for the Missouri River, during high flows sand constitutes around 10-30% of suspended load, the rest being silt and clay (see Figure 8). Therefore, the floodplain deposits may include significant amounts of silt and clay (which are not simulated in Model 500).

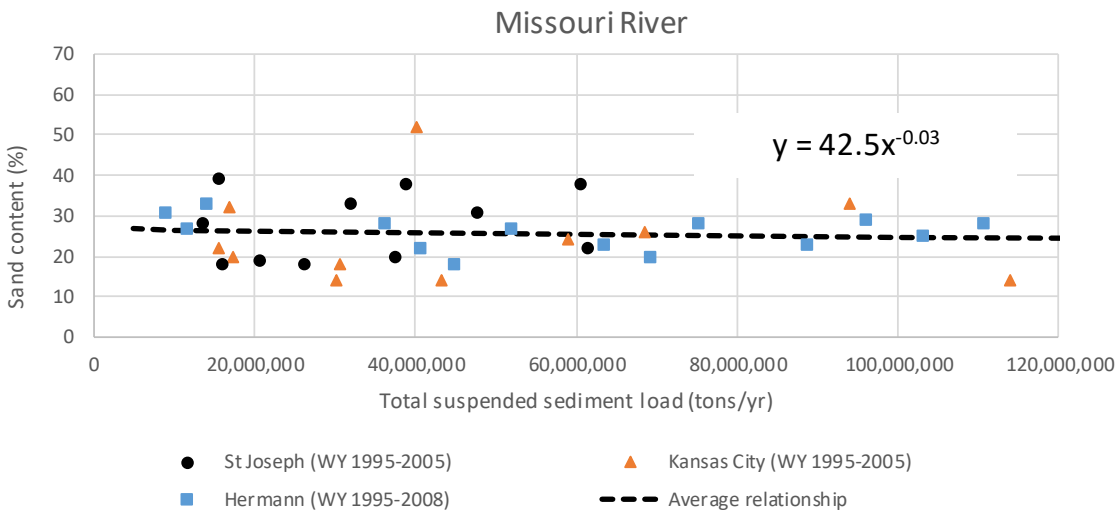

Figure 8 Sand content in annual suspended sediment load (USGS data).

Because Model 500 includes wide overbank areas, sediment outflow into the floodplain could be modeled by allowing sediment deposition outside of the moveable bed limits instead of the direct withdrawal of sediment from the channel implemented in Model 500. The viability of this option has not been tested.

5.10 Sediment Transport Computations

The Toffaleti total load function was used in Model 155 and was also initially selected to compute the sediment transport capacity in Model 500. The Toffaleti method was developed primarily for sand sizes particles and is usually applied to large sand-bed rivers. During calibration performed by the USACE, it was found that the Toffaleti function produced insufficient transport during the flood of 2011. To increase the transport capacity at high flows, the combined Toffaleti/Meyer-Peter and Muller (MPM) function (with a coefficient of 1 and an exponent of 1.5 in the MPM transport function) was eventually selected in Model 500. The Toffaleti fall velocity method was also used. Exner 5 sorting method was employed in both Model 155 and Model 500.

It should be noted that the MPM function is mostly applicable to calculating bed load transport in gravel systems. The bed in the study reach of the Missouri River is primarily composed of sand, so the

applicability of the MPM function to the Missouri River is questionable. It is not clear why the MPM function was modified with the coefficient and exponent stated in the USACE (2018) report.

6 REVIEW OF MODEL 500 CALIBRATION

6.1 Calibration Procedure

Calibration is the process of selecting model parameters and sediment transport functions that allow the model to reconstitute measured hydraulic and sediment transport characteristics and bed elevation changes. The total calibration periods used by the USACE for Model 500 is from 1 August 1994 to 29 July 2014. The principle calibration period runs from 1 August 1994 to 1 October 2009. This time period includes a range of high and low flows and is assumed to be most representative for future prediction (USACE 2018). Measured water surface profiles, flow velocities, sediment loads, and repeat cross-section surveys represent extensive calibration data over this period. A second time period from 1 October 2009 to 29 July 2014 was also used in calibration. However, because this time period includes the historic flood of 2011 which exhibited unique boundary conditions, this time period serves more as a verification of reasonableness of the model performance.

The principal parameters which were varied by the USACE to achieve calibration were the roughness coefficient values, flow-based roughness adjustment factors, sediment transport function, bed gradation data, sediment loading from tributaries, and moveable bed extents. The calibration procedure was based on the generally accepted methodology and included fixed-bed and movable-bed tests.

According to USACE (2018), the calibrated model showed reasonable agreement with the measured water surface elevations, velocities, and sediment loads. The calibrated model closely approximated the observed bed changes from 1994 to 2009, reasonably reproduced the bed degradation observed in the upstream part of the study reach from 2009 to 2014, but did not reproduce the bed aggradation observed after the 2011 flood event in the lower part of the study reach. To provide a better estimate for the post-2011 bed aggradation, the USACE added 23 million tons of sediment load from unknown sources into the lower reach in the model. This additional sediment load is greater than the average annual sand load in the study reach of the Missouri River (Heimann et al. 2010).

While the overall calibration procedure used by the USACE appears to be reasonable, the addition of the large amount of sediment to improve the model performance is difficult to justify and may be an indication of deficiencies in the model sediment boundary conditions.

6.2 Model Testing

NHC re-ran the calibration of Model 500 using HEC-RAS 5.0.3 and HEC-RAS 5.0.7 to verify the model performance. As mentioned previously, HEC-RAS 5.0.3 was originally used by the USACE to develop and calibrate the model. HEC-RAS 5.0.7 it the latest version released by the software developer, in which the following serious software bugs were fixed (from the HEC-RAS 5.0.7 release notes):

- **Sediment Transport Active Layer Issue:** Version 5.0.6 changed the active layer approach (including a significant bug fix) that changed its behavior substantially.

- **Uniform Lateral Inflow with Sediment Time Series**: Pairing Uniform Lateral Inflow with a sediment time series brought the total sediment in at each cross-section from the upstream cross-section to the downstream cross-section. The program was corrected to uniformly distribute the sediment between cross-sections.

- **Double Counting Quasi-Unsteady Lateral Sediment Loads**: All HEC-RAS 5.0.x versions, including Version 5.0.3 introduced lateral sediment loads (from rating curves or time series) twice, once upstream and once downstream of the specified cross-section, double counting these loads. HEC-RAS Version 5.0.4 only brings the load in downstream of the cross-section (making it more like unsteady flow), while previous versions brought the sediment load in upstream of the cross-section.

Per the USACE (2018) calibration report, lateral sediment loads in Model 500 were divided by two to compensate for the HEC-RAS 5.0.3 bug that doubles lateral loads. Therefore, to run Model 500 in HEC-RAS 5.0.7, all the lateral sediment loads (rating curves and time series) in the model were doubled to provide the actual loads. NHC also extracted results from the Model 155 output files, which were originally created in HEC-RAS 5.0. The main results from these comparative test runs are discussed below.

6.3 Sediment Load

Sediment loads measured at the USGS gages were used to verify the performance of the sediment models. Heimann et al. (2010) provided estimates of annual total suspended sediment loads (which include wash load) and suspended sand loads for the Missouri River at St. Joseph and Kansas City through WY 2005 and at Hermann through WY 2008. The relationship between the suspended sand loads and total suspended load from Heimann et al. (2010) is shown in Figure 9. This relationship was used to convert annual total suspended sediment loads at these locations from Heimann (2016) to suspended sand loads through WY 2014. Per the USACE (2017) calibration report, the bed load contributes around 5% of the total bed material load in the Missouri River, with 95% of the bed material load carried in suspension.

The annual total bed material loads (suspended sand loads plus bed loads) based on the USGS measured data and loads computed by the HEC-RAS models are compared in Tables 1-3. Graphical comparisons of the HEC-RAS and USGS annual bed material loads are provided in Figure 10. For Model 500, sediment loads are shown without the additional post-2011 sediment applied by the USACE to improve the model performance in the lower reach. The addition of post-2011 sediment does not change significantly the computed sediment loads at the locations of the gages, but it does change the bed aggradation in the lower reach after 2011 (this is discussed in the following section).

Given the complexity and variability of the natural sediment transport process, potential sediment load measurement errors, and difficulty of accurate sediment transport modeling, the overall agreement

between the measured and computed loads is quite reasonable for most of the simulation time period. However, Model 500 shows negative loads in the river for WY 2011 for both HEC-RAS 5.0.3 and HEC-RAS 5.0.7, which is apparently related to the excessive floodplain sediment outflow in the model during the 2011 flood event. In the context of 1-d HEC-RAS modeling a negative sediment load at a given cross section would indicate a net upstream movement of sediment. This is fundamentally in disagreement with 1-d sediment budget calculations so further explanation of this computational result is required.

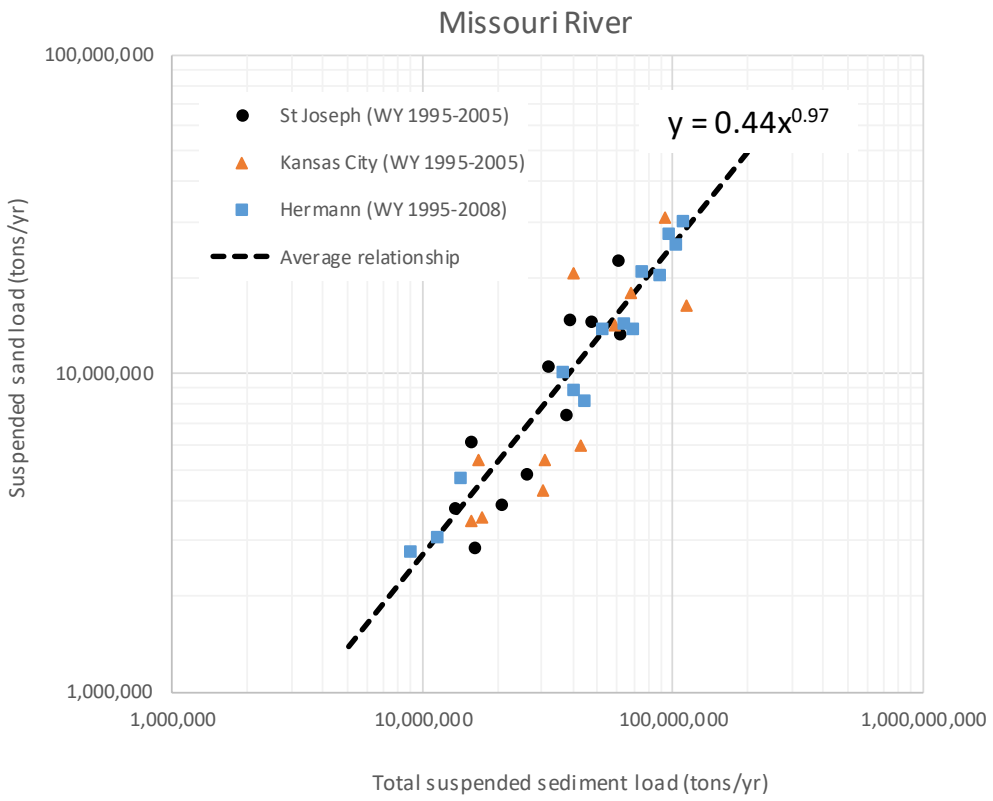

Figure 9 Relationship between suspended sand load and total suspended load (USGS data).

Table 1 Comparison of HEC-RAS to USGS bed material loads for Missouri River at St. Joseph.

Water Year	Total bed material load[1] (tons)			
	USGS	Model 155 HEC-RAS 5.0	Model 500[2] HEC-RAS 5.0.3	Model 500[2] HEC-RAS 5.0.7
1995	11,160,000	13,370,000	14,810,000	14,550,000
1996	15,580,000	16,750,000	17,520,000	17,370,000
1997	24,000,000	20,780,000	23,590,000	23,580,000
1998	15,470,000	15,460,000	16,210,000	16,380,000
1999	14,000,000	15,080,000	15,710,000	15,730,000
2000	6,440,000	7,920,000	6,590,000	6,630,000
2001	7,790,000	8,590,000	8,050,000	8,090,000
2002	3,990,000	5,060,000	3,570,000	3,600,000
2003	4,120,000	5,350,000	4,200,000	4,210,000
2004	5,090,000	5,860,000	4,710,000	4,710,000
2005	3,010,000	4,870,000	3,770,000	3,760,000
2006	2,750,000	4,440,000	2,910,000	2,890,000
2007	11,040,000	7,700,000	7,050,000	6,970,000
2008	11,280,000	9,510,000	8,600,000	8,550,000
2009	7,540,000	7,280,000	6,736,000	6,680,000
2010	9,650,000	18,610,000	16,860,000	14,390,000
2011	9,010,000	17,230,000	-160,000[3]	-20,050,000[3]
2012	5,030,000	7,720,000	7,410,000	7,120,000
2013	5,830,000	6,300,000	5,550,000	5,680,000
2014	9,970,000	7,620,000	6,870,000	7,090,000
Total	**182,740,000**	**205,520,000**	**180,540,000**	**157,930,000**
Average annual	**9,140,000**	**10,280,000**	**9,030,000**	**7,900,000**
Average difference	**---**	**12%**	**-1%**	**-14%**

Notes: [1]Includes suspended load and bed load; [2]Without extra post-2011 sediment; [3]Negative load due to modeled floodplain sediment outflow.

Table 2 Comparison of HEC-RAS to USGS bed material loads for Missouri River at Kansas City.

Water Year	Total bed material load[1] (tons)			
	USGS	Model 155 HEC-RAS 5.0	Model 500[2] HEC-RAS 5.0.3	Model 500[2] HEC-RAS 5.0.7
1995	14,950,000	19,950,000	20,520,000	20,490,000
1996	21,790,000	19,620,000	21,390,000	21,680,000
1997	32,840,000	21,920,000	25,550,000	25,520,000
1998	18,950,000	16,690,000	20,830,000	21,010,000
1999	17,370,000	19,280,000	21,620,000	22,430,000
2000	5,660,000	7,990,000	8,650,000	8,680,000
2001	6,320,000	9,310,000	11,250,000	11,870,000
2002	3,660,00	4,800,000	4,650,000	5,230,000
2003	3,740,000	5,600,000	4,930,000	5,500,000
2004	5,680,000	6,400,000	6,840,000	7,760,000
2005	4,530,000	5,620,000	6,690,000	7,730,000
2006	4,240,000	4,630,000	5,000,000	6,020,000
2007	15,260,000	9,390,000	10,580,000	11,660,000
2008	16,020,000	9,670,000	12,820,000	14,500,000
2009	10,130,000	8,290,000	10,960,000	12,710,000
2010	18,510,000	20,280,000	21,440,000	20,110,000
2011	17,180,000	9,380,000	-3,800,000[3]	-33,220,000[3]
2012	4,640,000	11,400,000	10,020,000	11,370,000
2013	4,880,000	6,870,000	7,640,000	8,600,000
2014	8,200,000	8,790,000	9,130,000	10,830,000
Total	**234,560,000**	**225,880,000**	**236,720,000**	**220,500,000**
Average annual	**11,730,000**	**11,290,000**	**11,840,000**	**11,030,000**
Average difference	**---**	**-4%**	**1%**	**-6%**

Notes: [1]Includes suspended load and bed load; [2]Without extra post-2011 sediment; [3]Negative load due to modeled floodplain sediment outflow.

Table 3 Comparison of HEC-RAS to USGS bed material loads for Missouri River at Hermann.

Water Year	Total bed material load[1] (tons)			
	USGS	Model 155 HEC-RAS 5.0	Model 500[2] HEC-RAS 5.0.3	Model 500[2] HEC-RAS 5.0.7
1995	26,950,000	---	17,040,000	14,940,000
1996	15,160,000	---	22,280,000	22,080,000
1997	29,050,000	---	31,690,000	33,690,000
1998	22,110,000	---	28,310,000	30,390,000
1999	32,000,000	---	31,430,000	34,150,000
2000	4,950,000	---	7,900,000	8,430,000
2001	14,630,000	---	18,810,000	20,380,000
2002	8,730,000	---	8,700,000	9,360,000
2003	3,230,000	---	5,700,000	6,360,000
2004	9,390,000	---	11,440,000	13,160,000
2005	14,630,000	---	11,680,000	13,780,000
2006	2,920,000	---	4,870,000	5,350,000
2007	10,740,000	---	10,600,000	8,690,000
2008	21,470,000	---	20,290,000	22,430,000
2009	16,510,000	---	18,630,000	20,930,000
2010	26,400,000	---	33,590,000	37,060,000
2011	15,440,000	---	1,710,000[3]	-28,600,000[3]
2012	5,130,000	---	8,160,000	8,870,000
2013	10,640,000	---	11,510,000	13,070,000
2014	11,440,000	---	9,530,000	12,140,000
Total	**301,520,000**	**---**	**313,880,000**	**306,660,000**
Average annual	**15,080,000**	**---**	**15,690,000**	**15,330,000**
Average difference	**---**	---	**4%**	**2%**

Notes: [1]Includes suspended load and bed load; [2]Without extra post-2011 sediment; [3]Small or negative load due to modeled floodplain sediment outflow.

Figure 10 Comparison of HEC-RAS to USGS annual bed material loads.

6.4 Bed Changes

Longitudinal cumulative bed changes computed by the models from 1994 to 2009 are shown in Figure 11. Measured data for accumulated bed changes for 1994 through 2009 were approximately digitized from the USACE (2018) calibration report and are also shown as "Measured (USACE 2018)" on this figure for comparison. Bed changes computed by Model 155 (HEC-RAS 5.0) and Model 500 (HEC-RAS 5.0.3) are identical to those provided in the USACE (2017) and USACE (2018) calibration reports, respectively. These two models reasonably approximate the magnitude and locations of mass change from 1994 to 2009 (the vertical shift for Model 155 is due to the different starting upstream location for the graph). However, bed changes computed by Model 500 (HEC-RAS 5.0.7) reasonably agree with the measured data only upstream of Kansas City and show unrealistic bed aggradation downstream of Kansas City.

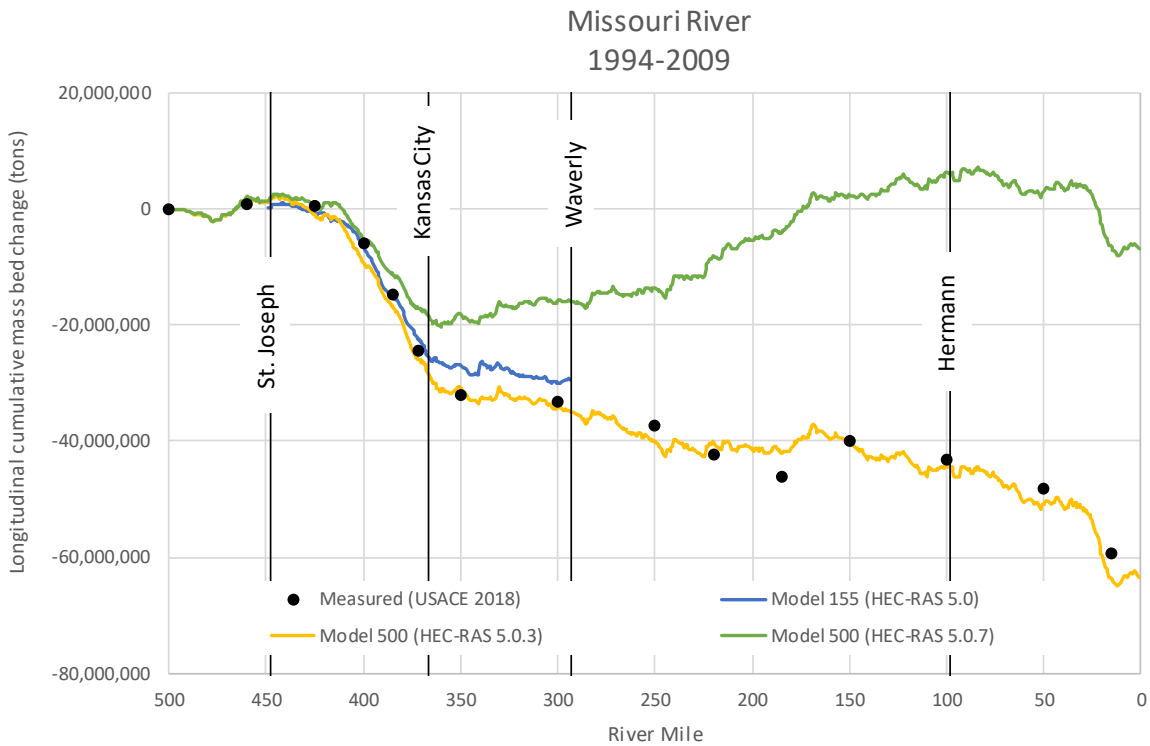

Figure 11 Longitudinal cumulative mass bed change (1994-2009).

Longitudinal cumulative bed changes computed by the models from 2009 to 2014 are compared with the measured data (digitized from USACE 2018 and labeled "Measured (USACE 2018)") in Figure 12. The results shown on this figure for Model 500 include the extra 23,000,000 tons of sediment applied by the USACE to improve the model performance in the lower reach after 2011. Model 155 (HEC-RAS 5.0) shows satisfactory agreement with the measured bed changes for this time period (the vertical shift for this model is due to the different starting upstream location for the graph). Model 500 (HEC-RAS 5.0.3) shows reasonable agreement with the measured bed changes upstream of Waverly and underestimates bed aggradation downstream of Waverly. Model 500 (HEC-RAS 5.0.3) with the extra post-2011 sediment shows satisfactory results for the entire study reach. Model 500 (HEC-RAS 5.0.7) reasonably

approximates the bed changes upstream of Waverly, but produces poor results downstream of Waverly either without or with the extra post-2011 sediment.

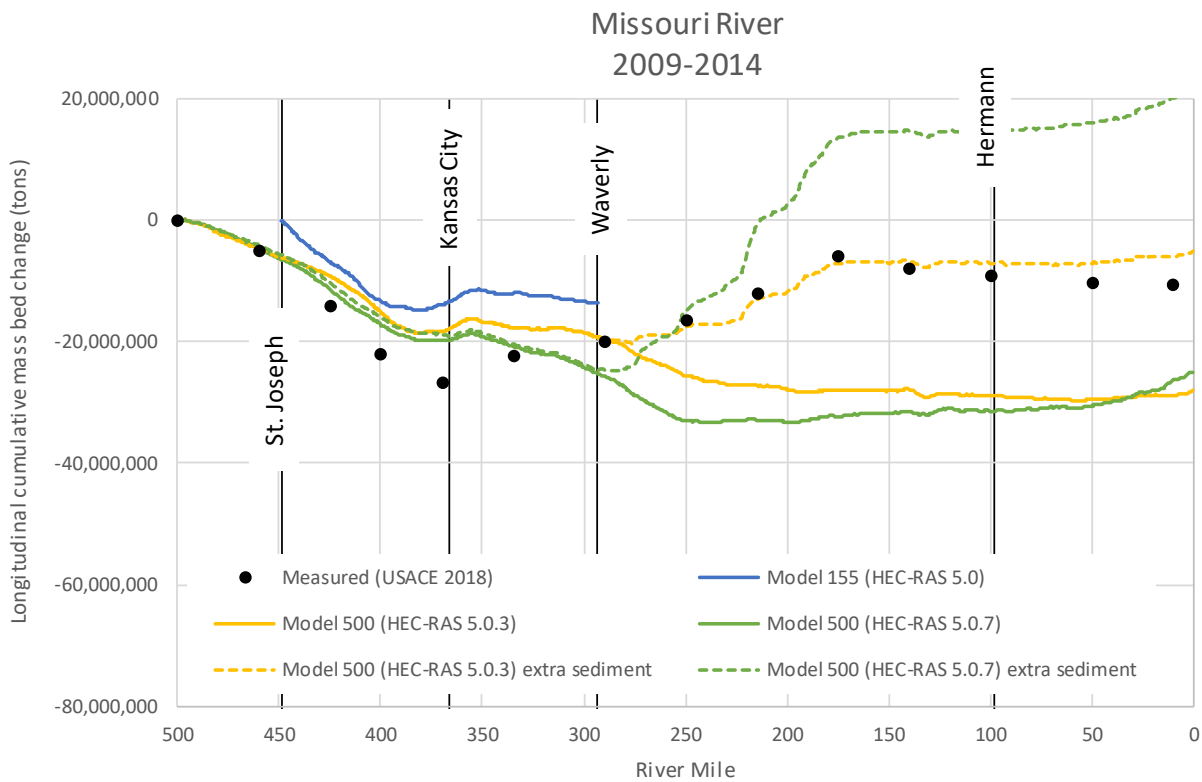

Figure 12 Longitudinal cumulative mass bed change (2009-2014).

Several additional test runs were conducted for Model 500 (HEC-RAS 5.0.7) with and without various lateral sediment sources originally developed by the USACE, which did not improve the model performance. This indicates that a recalibration of the entire model is needed to enable its application using the most recent, improved, and corrected version of the HEC-RAS software.

The previous HEC-RAS versions showed reasonable calibration results for Model 150 and Model 500. However, because the previous versions included some serious computational bugs/errors identified by the software developer, their application for predicting future morphological changes and dredging strategies in the Missouri River should not be relied upon until further model calibration and verification using HEC-RAS 5.0.7. Model applications completed to date are unreliable and should not be used in support of any planning and design decisions.

Because of the large size of Model 500, it was barely manageable and would only provide a default level of sediment data output. Model output limitations would not allow NHC to query critical sediment output, so the model's verity can not be assured. It is recommended to consider splitting Model 500 into a few segments between relatively stable channel locations (e.g. Rulo to Waverly and Waverly to the

mouth). This would reduce the complexity of individual models and would probably simplify model calibration for shorter reaches.

7 CONCLUSIONS

NHC reviewed the setup and calibration of the movable-bed model of the lower 500 miles of the Missouri River recently prepared by the USACE. NHC evaluated the model performance using HEC-RAS 5.0.3 (originally used by the USACE to develop and calibrate the model) and the latest HEC-RAS 5.0.7 (in which several serious sediment-related software bugs found in the previous versions were fixed). The following is a summary of the main findings:

(1) The model geometry and roughness reasonably represents the existing channel conditions. However, in the absence of the actual surveyed cross-section data, the correctness of the model sections could not be evaluated by NHC.

(2) The intra-dike sediment erosion and deposition processes are not fully explained in the calibration report. Cross-section comparisons of modeled and surveyed bathymetric data need to be completed to evaluate the locations, timing, flow condition, and magnitude of intra-dike sedimentation processes and to assess if the HEC-RAS model is properly accounting for this component of the sediment budget.

(3) Bed gradations specified in the model reasonably agree with the measured data. However, the rationale behind the bed gradation smoothing method (% of individual gradations versus % of reach-average gradations) is not clearly described in the accompanying calibration report. Given the relatively similar bed material composition along the study reach, a simple reach-average approach should be used or tested.

(4) Some sediment input parameters in the model seems to be overcomplicated and not very well justified. For example, the reduction of sediment loads during the 2011 flood event was not observed along the entire study reach and may not need to be represented by a separate flow-load rating curve at the model upstream boundary. Some of the tributary sediment load rating curves could be improved to better fit the measured data. The unmeasured sediment loads specified in the model as lateral inflows could be introduced as part of the tributary sediment loads. The modeled floodplain sediment outflow seems excessive, which actually results in computed and unexplained negative sediment loads in the river channel at several locations during the 2011 flood event.

(5) The calibration report states that the loads for the tributary rating curves in the model were divided by two to compensate for a HEC-RAS 5.0.3 code error that apparently doubles tributary loads. However, it is not clear if the same correction was done for the other lateral sediment inflow sources (unmeasured loads and floodplain deposits). The updated version HEC-RAS 5.0.7 presumably does not have this error in the model coding, according to the model code developers.

(6) The model uses the combination of the Toffaleti and Meyer-Peter and Muller (MPM) sediment transport functions. While the Toffaleti function is suitable for large sand-bed rivers, the MPM is mostly applicable to gravel bed materials and is not a good choice for predominantly sand-bed channels. Testing the model with solely Toffaleti, or possibly a different function, should be investigated.

(7) To provide a better estimate for the post-2011 bed aggradation, the USACE added a large amount of sediment from unknown sources in the lower reach in the model. This additional amount is greater than the average annual sand load in the Missouri River. Such an approach is difficult to justify and may be an indication of deficiencies in the model sediment boundary conditions.

(8) The model reasonably reproduce sediment loads and bed changes observed in the prototype only for the HEC-RAS 5.0.3 version originally used by the USACE to develop and calibrate the model. However, running the model with the latest HEC-RAS 5.0.7 version produces reasonable results only in the most upstream reach between Rulo and Kansas City and shows unrealistic bed changes downstream of Kansas City. The release notes for HEC-RAS 5.0.7 indicates that several bug fixes to the active layer calculations were made in the model update. Active layer calculations are an important component of the sediment transport routines within HEC-RAS, so the Model 500 results need to reviewed in greater detail. The implications of this model update on this and previous mobile bed USACE model results needs to be investigated and identified.

(9) NHC's test runs indicate that a recalibration of the entire model is needed to enable its application using the most recent and corrected version of the HEC-RAS software. The previous versions of HEC-RAS include serious computational bugs/errors and, therefore, their application for predicting future morphological changes and dredging strategies in the Missouri River is unreliable and should not be used in support of any planning and design decisions.

(10) Because of the large size of the movable-bed model, the model simulations can not provide more detailed levels of sediment data output for a more in-depth analysis. To reduce the model complexity and simplify model calibration, NHC recommends that the model be discretized into a few segments between relatively stable channel locations.

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APPENDIX A

USACE's Lower Missouri River Sediment Model Calibration Report (dated July 2018)

US Army Corps of Engineers
Kansas City District

Lower Missouri River Sediment Model Calibration Report

JULY 2018

1.0 Introduction

The bed of the Missouri River experiences both short-term fluctuations, episodic responses to major floods, and long-term trends (USACE 2017a). Effective long-term management of the river should acknowledge and incorporate the effects of these bed elevation changes. This document serves as an initial orientation to development of a mobile-bed sediment model for the lower 500 miles of the Missouri River. Hereafter this model is referred to as the Lower Missouri River Sediment Model (LMRSM). The model creation and calibration followed the basic principles outlined in the HEC-6 Calibration Guide (HEC 1982) and EM 1110-2-4000, with some adaptation. This document summarizes river behavior and provides information on the model set up and calibration.

The purpose of the LMRSM is to compare future bed elevations under alternative management scenarios. The immediate purpose is to provide a 2033 bed elevation projection for use in the Missouri River Recovery Program under the various proposed alternatives. This is a planning level model to assess the reach and river scale effects of proposed alternatives. Final design of habitat projects will require additional calculations or modeling beyond the output of this mobile-bed model.

This report covers model development and calibration. A subsequent report will document alternatives testing.

2.0 River Behavior

2.1 River History and Modifications

The Missouri River in its current form is a highly regulated, highly stabilized river that drains approximately 529,350 square miles (USACE 2006). Major tributaries include the Yellowstone River, the Platte River, and the Kansas River, each of which drains more than 60,000 square miles. Prior to channel modification, the Missouri River was a wide, braided channel which occupied approximately 300,000 acres downstream of Sioux City, IA. Through the construction of a series of river training structures (dikes and revetments), the river was transformed into a single-thread channel with projected surface area of 112,000 acres (USACE 1981) downstream of Sioux City, IA. The current river is significantly narrower than the original, pre-modified river.

The system of river training structures is called the Bank Stabilization and Navigation Project (BSNP). Structures that run parallel to the river are called revetments, while those that protrude into the river are commonly called dikes. The dikes are generally several hundred feet to over a half mile long, but many of the dikes have most of their length buried in accreted land so that only a small portion of each dike is actually exposed to flow. Most dike structures downstream of Rulo, Nebraska are extended by a low sill which protrudes further into the channel. In common usage, the entire structure, both dike and sill, is

referred to as a dike. Figure 1 illustrates a dike structure with a low sill with typical dimensions in reference to the CRP (Construction Reference Plane). The CRP is a sloping datum mirroring the water surface profile exceeded 75% of the time during navigation season, and is used to set structure heights to overtop at consistent frequencies based on design criteria from December 1973. A more detailed history of BSNP structure design standards, modifications, and current condition is included in the Missouri River Bed Degradation Feasibility Study report.

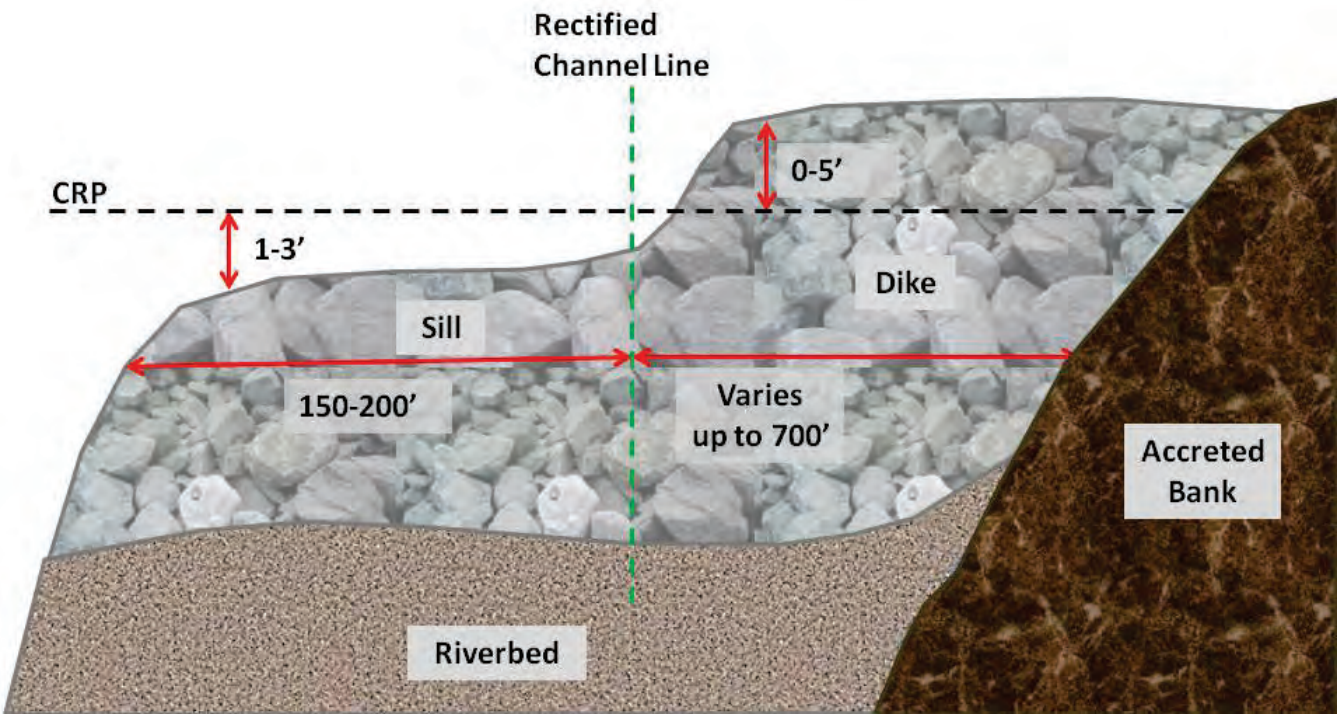

Figure 1. BSNP Dike and Sill with Typical Dimensions, not to scale

In conjunction with the BSNP, a series of six mainstem dams were constructed. These dams store a significant volume of water, reducing downstream flooding and supplying water to support navigation on the lower Missouri River eight months out of the year. The authorized purposes for the Missouri River Mainstem Reservoir System as outlined in the Section 9 of the 1944 Flood Control Act include: flood control, navigation, irrigation, hydropower, water supply, water quality control, recreation, and fish and wildlife (USACE 2006).

The channel stabilization accomplished through the BSNP has allowed the construction of miles of federally operated and maintained levees and floodwalls and additional privately owned levees generally located on both banks of the Missouri River downstream of Omaha, Nebraska. Portions of these levees, particularly in the more urbanized areas, as well as smaller privately owned agricultural levees, are located immediately adjacent to the river bank. At many locations, these small, privately-owned levees contain flows with a 5 to 10-year return interval at top width only slightly larger than the channel. Larger floods exceeding a 50-year return period are generally only contained by the federally

constructed levees and only a few private levee systems. Due to the varying levels of protection of these levees, channel widths for major floods vary considerably from location to location (see Figure 2.)

Figure 2 graphically depicts the level of confinement imposed on the river corridor by levees vs. the natural floodplain width. The widths shown in Figure 2 were developed using existing models not the ManPlan study model. The "Valley Width" line in Figure 2 indicates the floodplain width for the 1% AEP profile if there were no levees and is provided as a reasonable approximation for the valley width. Figure 2 is not used in the sediment modeling, but is provided for context to differentiate geologic constrictions from levee-induced constrictions. The LMSM includes the levees at the actual locations.

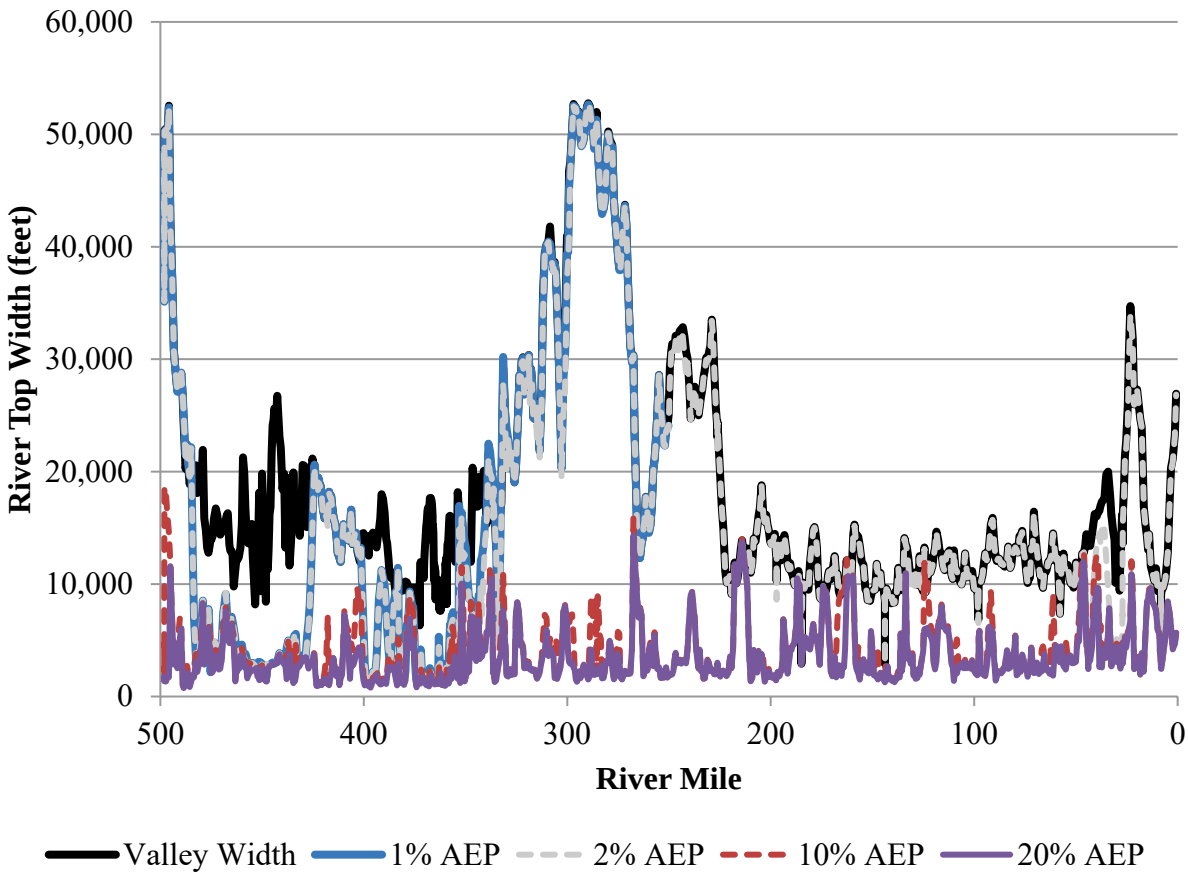

Figure 2. Valley Width and River Top Width at Different Flood Levels

There are no man-made grade controls on the lower Missouri River downstream of Gavin's Point Dam which is located at RM 811. Riprap placed at bridge piers does not armor the entire bed and has not stabilized the river. There are no known natural grade controls in the active channel, though this has not been the subject of a thorough investigation. There are some natural bedrock outcroppings on the river banks (Laustrup et al. 2007). The stability of the river near Waverly may be due to natural rock outcropping at that location, but may be caused by other factors. Borings at bridge locations indicate 40 to 100 ft of sand to bedrock in the Kansas City Reach (MoDOT 2008).

2.2 Sediment Loads

The sediment load in the Missouri River is quite variable, with high flows typically carrying exponentially more sediment than low flows. USACE (2017a) notes that the historic flood of 1993 brought about a downward shift in the flow-sediment relationship at the St. Joseph gage. The exact cause of this phenomenon is not known, but may be due to the deposition of bed material on the floodplains leading to less in-channel sediments available for transport (Horowitz 2006). This was a temporary phenomenon, however, and not a trend. As seen in Figure 3, sediment loads after 1993 were within the scatter of the sediment loads from 1952 – 1992. During the 2011 flood, the flow-load relationship temporarily decreased, which can be explained by the high volumes of clear water which came from the upstream reservoirs. It appears that for low flows, the post-2011 sediment levels are lower than pre-flood (but within the pre-1993 scatter), but for moderate flows, the flow-load relationship has returned to pre-2011 levels.

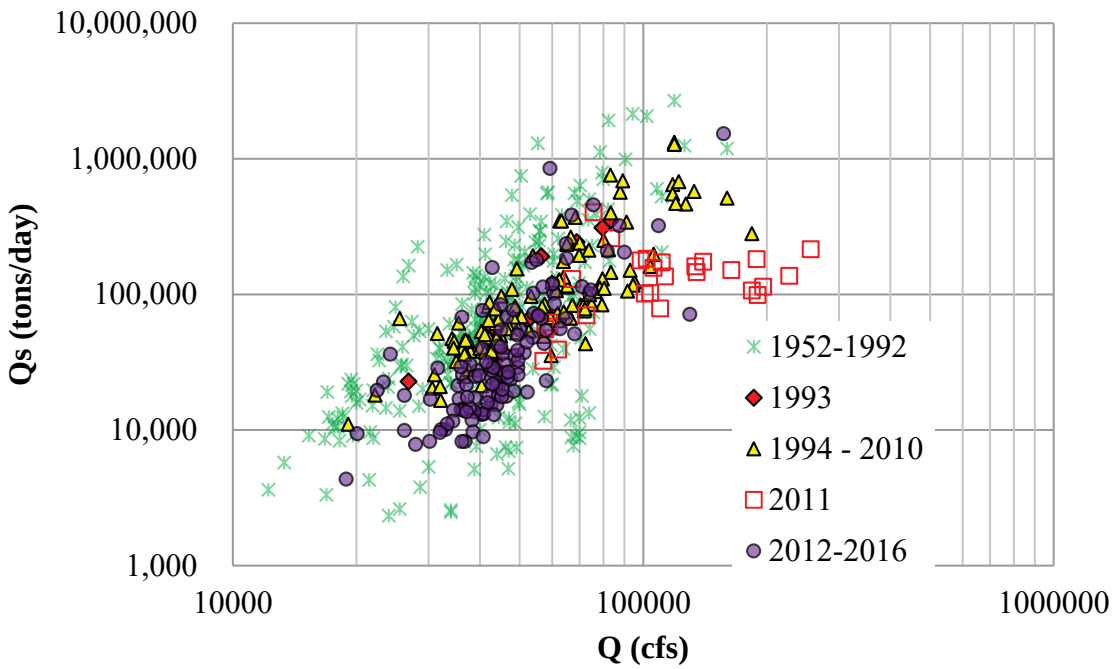

Figure 3. Sediment load at the St. Joseph, MO gage.

2.3 Commercial Dredging

The bed of the Missouri River is dredged (mined) downstream of Rulo, Nebraska as a source of sand and gravel. Commercial dredging on the Missouri River has taken place for many years to varying amounts. Historically, most of the extraction from the bed of the Missouri River took place in the Kansas City metro area, with additional operations in St. Joseph, Waverly, Jefferson City, and St.

Charles. Figure 4 shows the extracted quantities for the Missouri River from 1935 to 2016. As seen, the total dredging take began increasing in the 1950s. It increased sharply in the early 90s and remained high through the 2000s. This sharp increase was a result of regulatory restrictions on dredging on the Kansas River and increased local demand for construction materials. The level of dredging in 2002 includes USACE dredging for the construction of the L-385 unit of the Federal Missouri River Levee System. The annual extraction began falling in the late 2000s and is now around 4 million tons per year. Commercial sand and gravel dredging removed a total of approximately 247 million tons (181 million yd^3) from the bed of the lower 500 miles of Missouri River from 1935 to 2016. USACE (2017a) concludes that commercial sand and gravel dredging was the dominant cause of bed degradation from St. Joseph to Waverly, MO from 1994 to 2014.

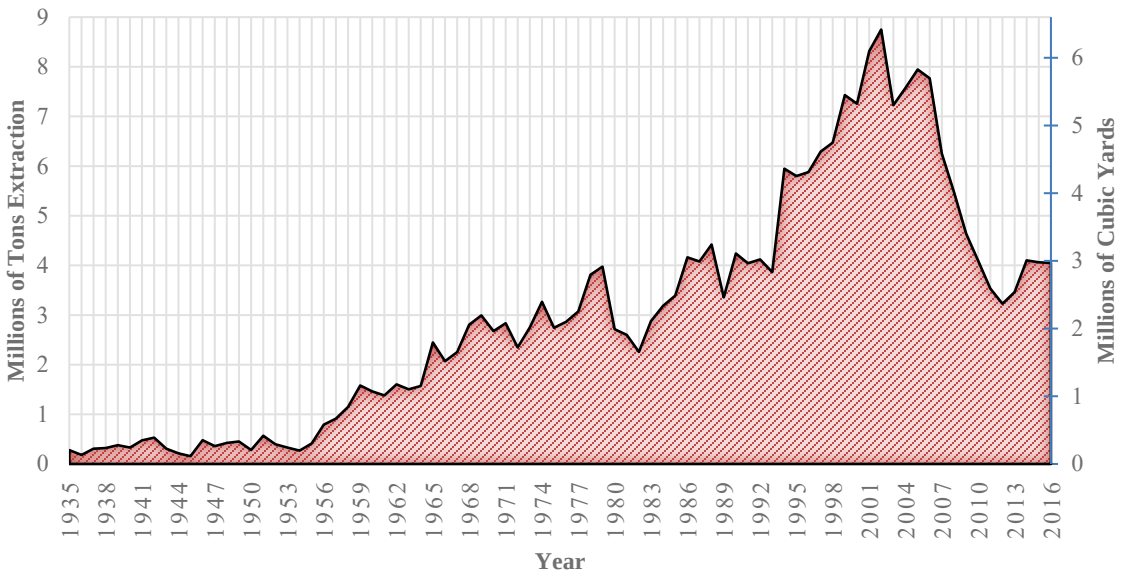

Figure 4. Extracted Dredging Quantities for the Missouri River in Kansas City

2.4 Stage and Low Water Surface Profile Degradation

The lower Missouri River has experienced significant bed degradation – persistent lowering of the river bed (USACE 2017a, 2011, 2009). Bed degradation of the Missouri River has caused a corresponding though not necessarily equivalent drop in the water surface elevations for low discharges. Figures 5, 6, 8, and 9 demonstrate that the stage of low discharges has been dropping at St. Joseph, Kansas City, Boonville, and Hermann gages, respectively (USACE 2017b). At the Waverly gage (Figure 7) the low stages have been relatively stable.

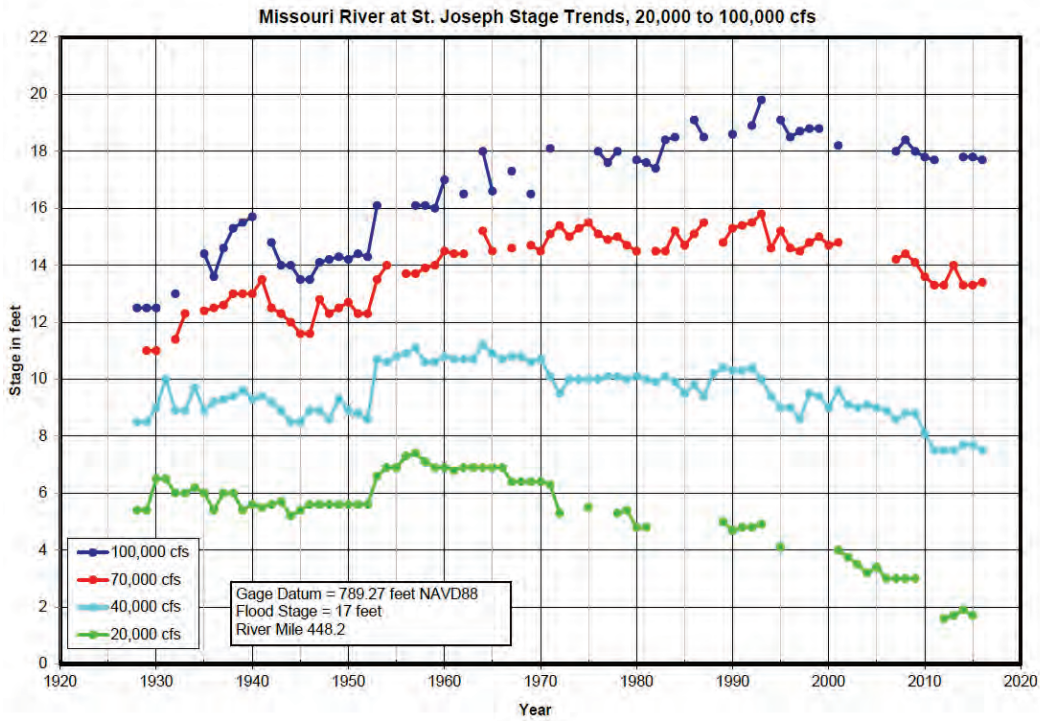

Figure 5. Missouri River Stage Trends- Missouri River at St. Joseph, MO

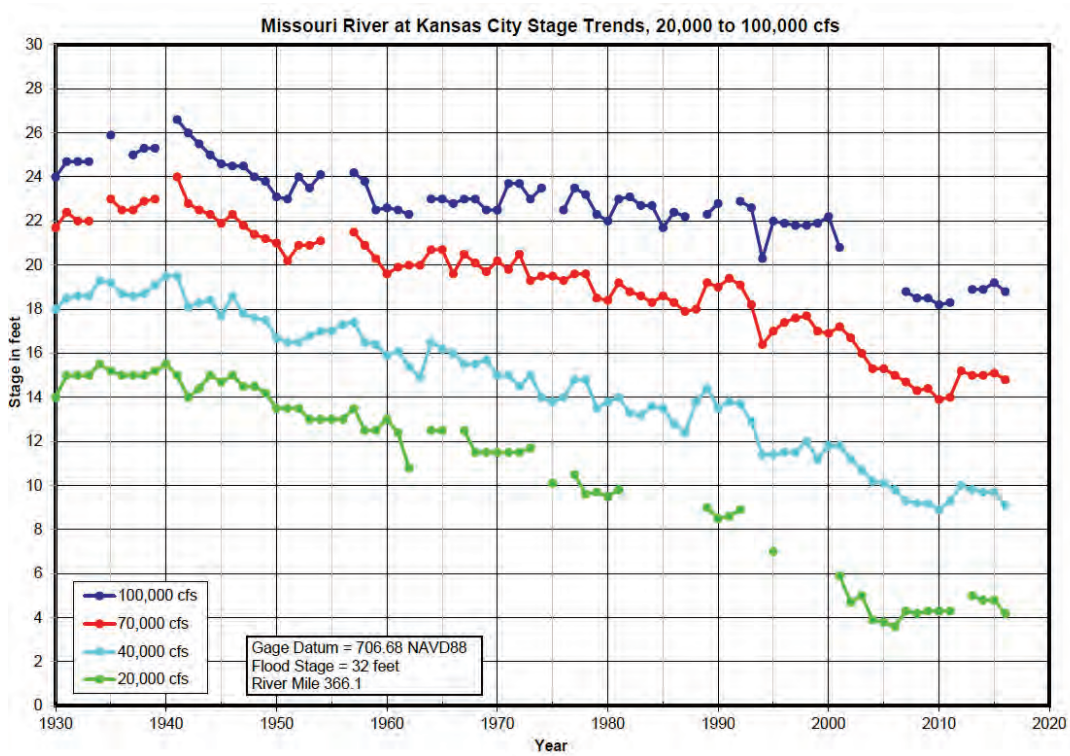

Figure 6. Missouri River Stage Trends- Missouri River at Kansas City, MO

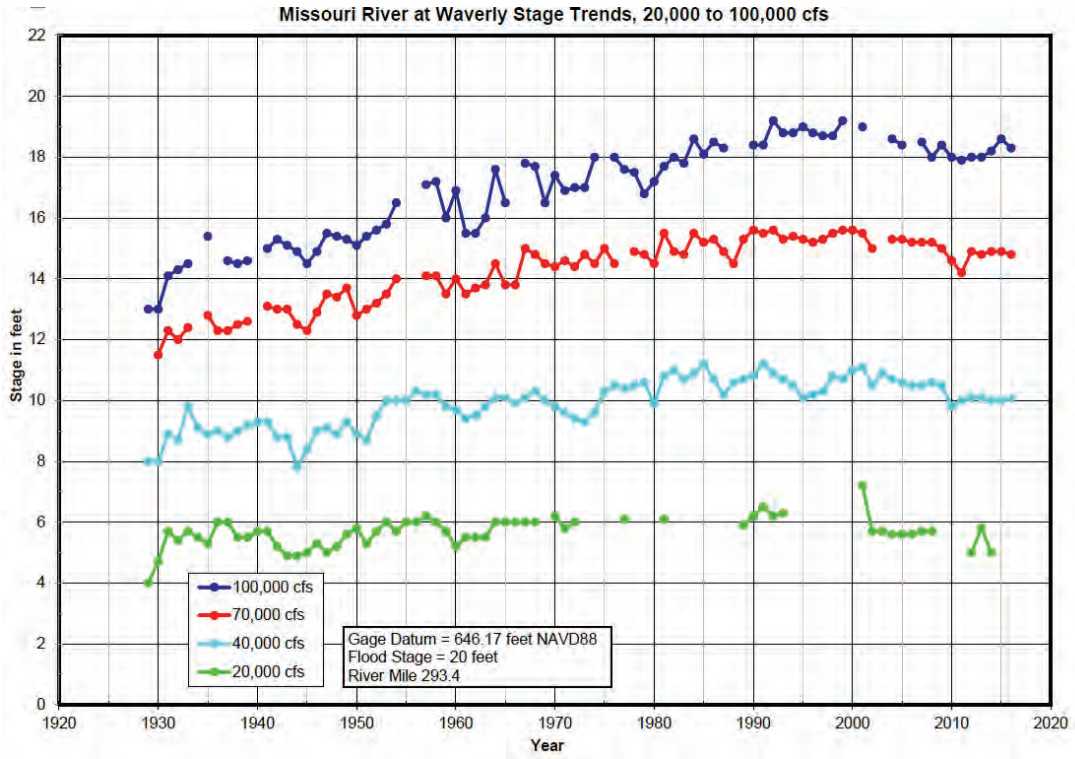

Figure 7. Missouri River Stage Trends- Missouri River at Waverly, MO

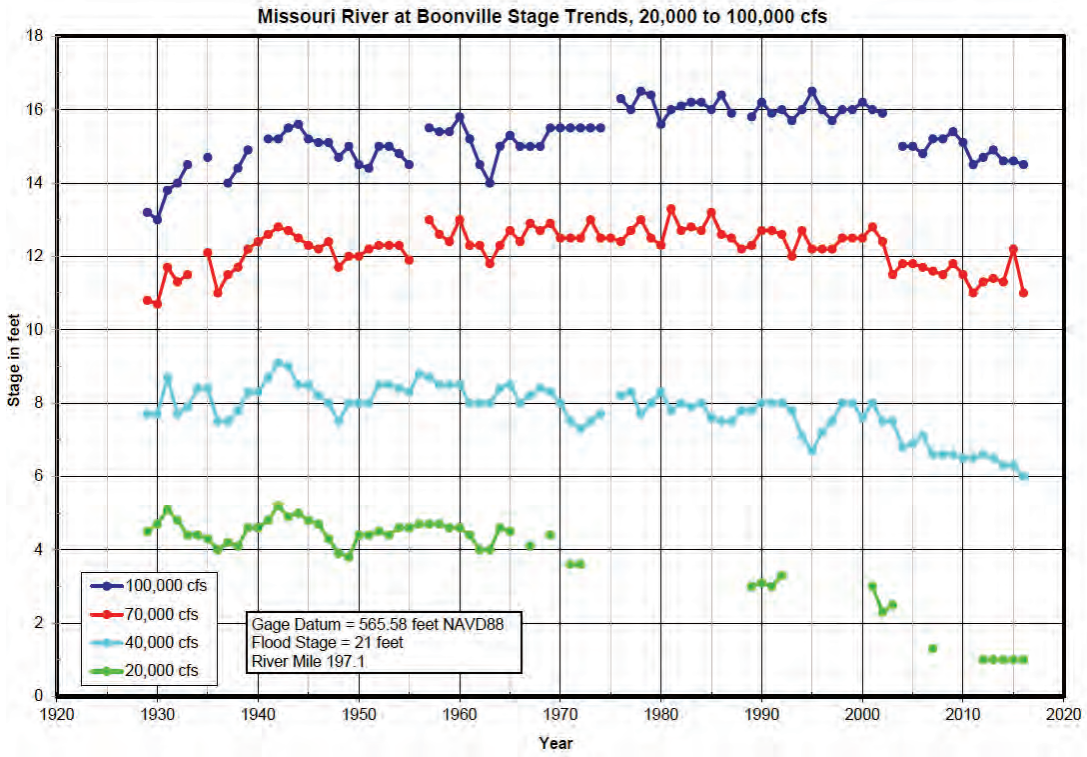

Figure 8. Missouri River Stage Trends- Missouri River at Boonville, MO

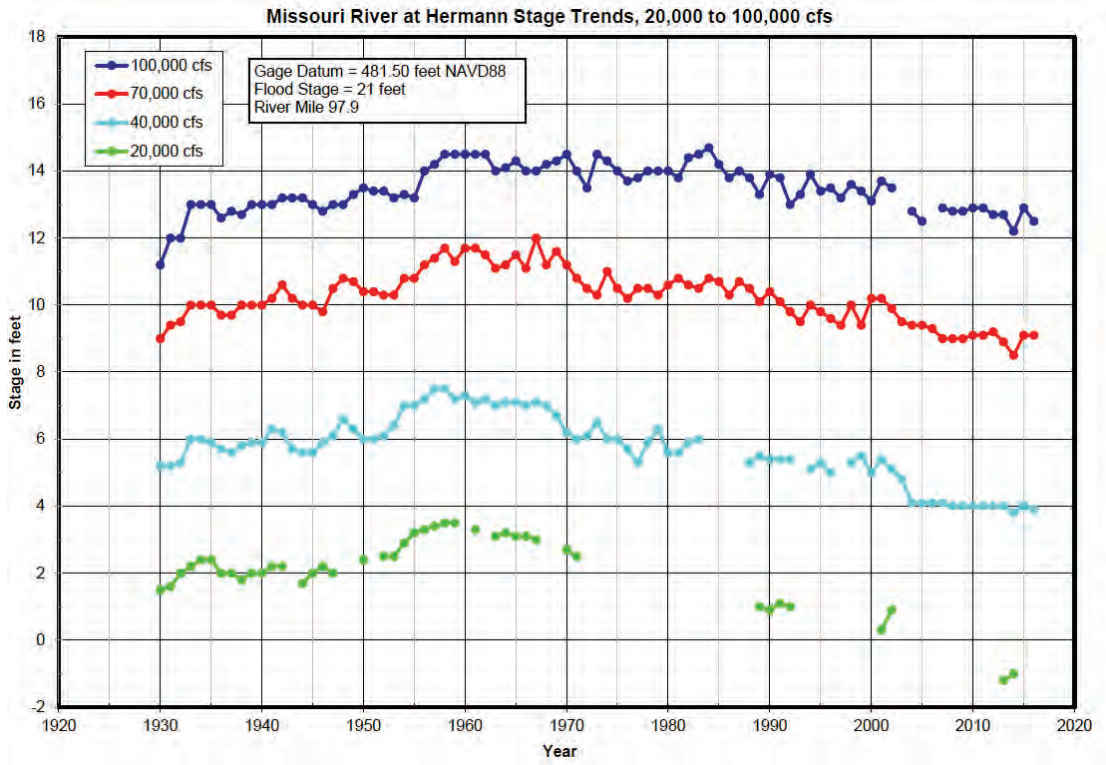

Figure 9. Missouri River Stage Trends- Missouri River at Hermann, MO

On the lower Missouri River, water surface elevations at dozens of locations have been measured on an annual or biannual basis for decades, which provided a way to track stage trends over time for the full lower 500 miles. These low water profiles were measured when flow rates were within a tight range, and then were adjusted to a consistent discharge based on rating curves at nearby gages to allow valid comparison (USACE 2010). Figure 10 plots selected profiles from 1974 to 2017 as a change compared to the average slope of the river. The average slope is defined by the starting and ending elevations of the 2010 Construction Reference Plane.

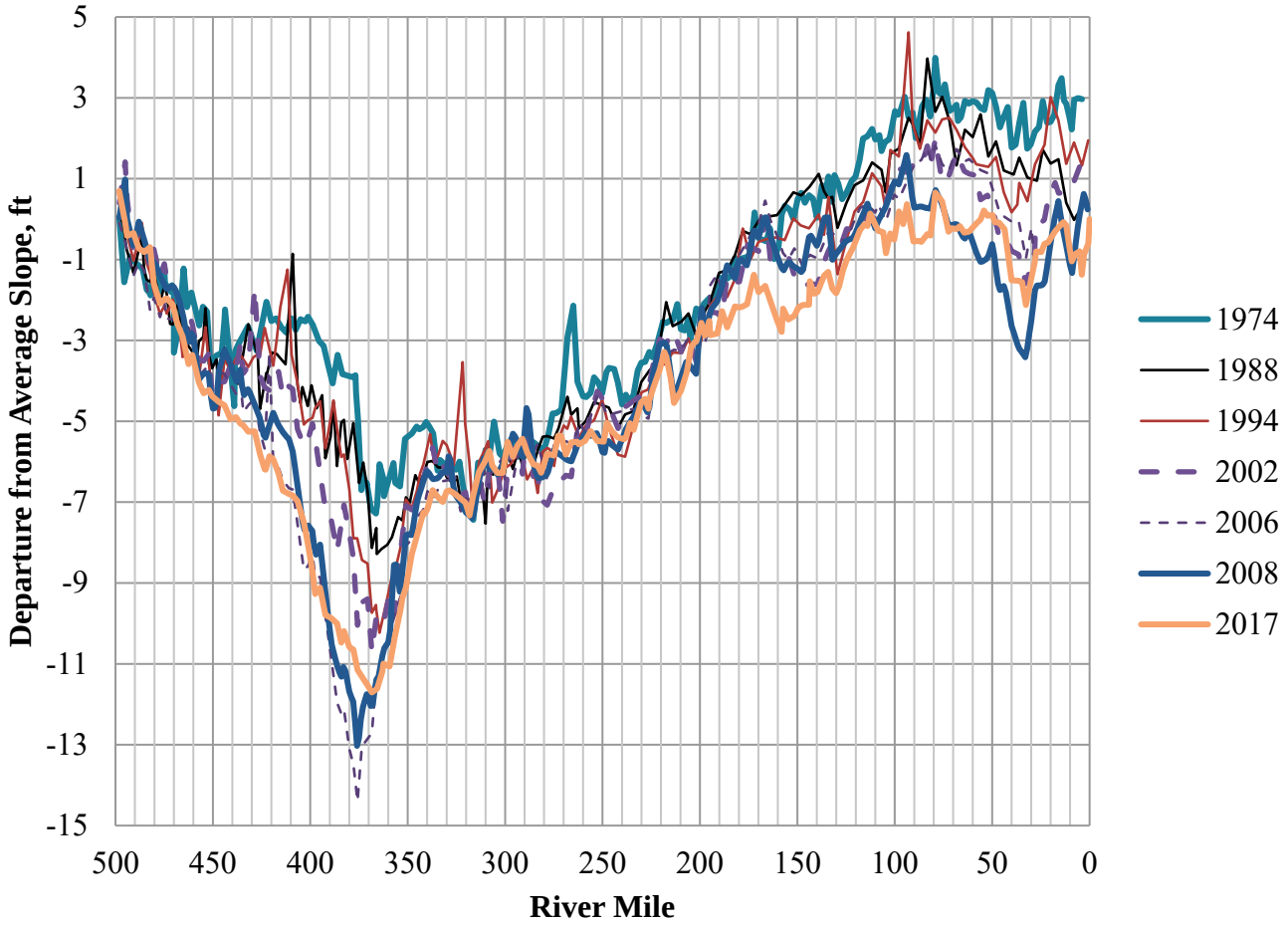

Figure 10. Low Water Surface Profiles—Departure from Average Slope

The rates of low water surface degradation vary considerably over the 500 miles. In some stretches of the river, degradation is insignificant, while in other areas, degradation has already induced damage to the BSNP and federal levee system, and necessitated expensive repairs and retrofits of other public and private infrastructure (USACE 2017a). As seen in Figure 10, areas of localized depression existed as of 1974 in the Kansas City metro area (RM 350 to 380). Very significant degradation has occurred since 1974, especially RM 450 to 320 and 200 to 0.

2.5 Bed Elevation and Volume Changes

Figure 11 presents the average bed elevations for key survey years, averaged over 5-mile reaches. As in Figure 10, the elevations are spatially de-trended (i.e. what is plotted is the departure from the average river slope) to allow easier visual comparison among years. The average river slope is computed by drawing a linear trend line from the average elevation in the most upstream 5 miles to the average elevation in the most downstream 5 miles.

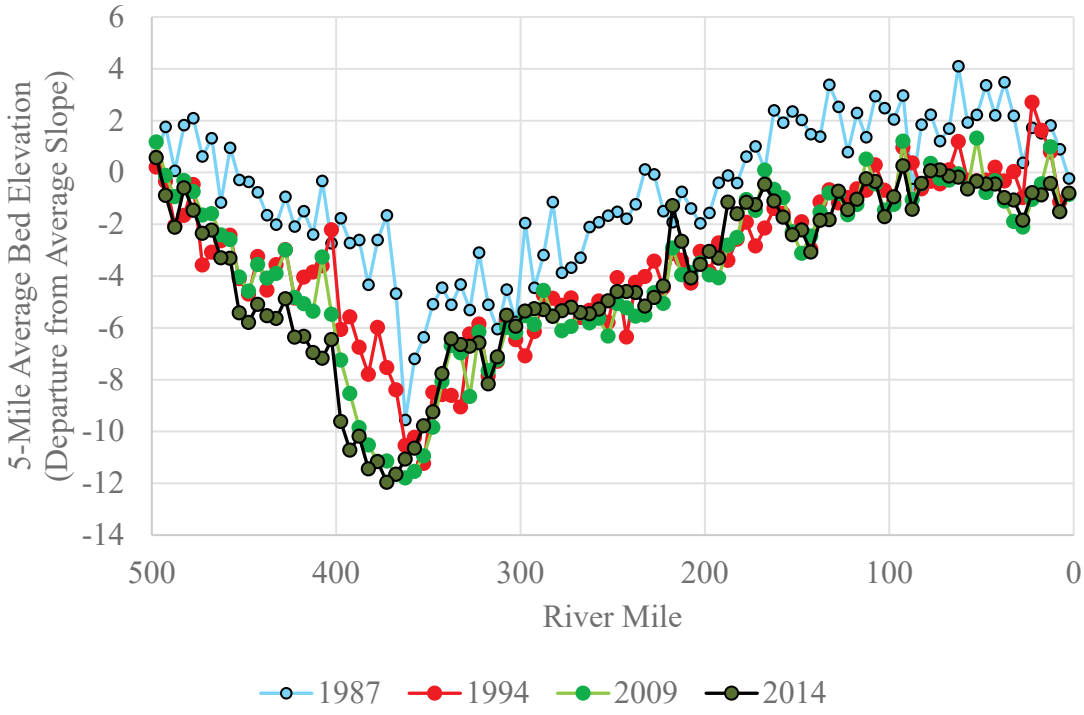

Figure 11. Spatially De-trended Average Bed Elevations (5-Mile-Average Departure from Average Slope)

As seen in Figure 11, very significant bed lowering occurred between the 1987 and 1994 surveys, which can be attributed predominantly to the effects off the 1993 flood. After 1994, the bed continued to degrade from aprox. RM 360 to 450. Numerical modeling in USACE (2017a) indicates that further degradation after 1994 from RM 360 to 390 was induced by commercial dredging and that this degradation migrated upstream as a result of the 2011 flood. The scatter precludes visual identification of trends downstream of RM 360 using Figure 11. These trends can be seen in the longitudinal cumulative volume change curves between each consecutive set of surveys, as presented in Figure 12. On longitudinal cumulative volume change curves, a downward slope indicates degradation, while an upward slope indicates recovery.

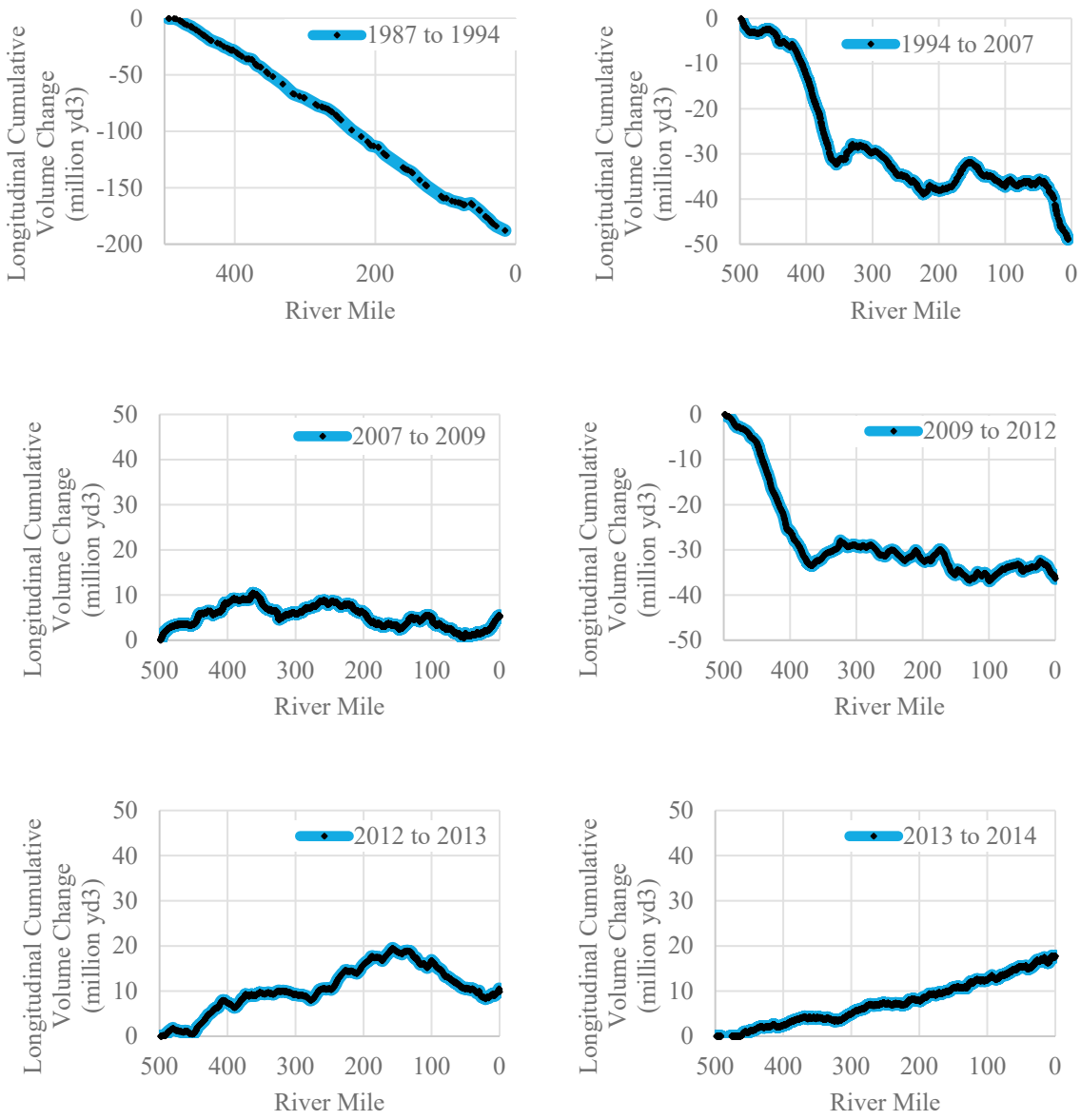

Figure 12. Longitudinal Cumulative Volume Change Between Successive River-Wide Surveys. Note the different scale for the 1987 to 1994 change.

The 1993 flood, which produced discharges of over 540,000 cfs in Kansas City (RM 366.2) caused tremendous degradation on the lower Missouri River. As seen in Figure 12, the Missouri River degraded 187.9 M yd^3 from 1987 to 1994. Commercial dredging over the same time period totaled 22.8 M yd^3, indicating that 165.1 M yd^3 was caused by an imbalance in sedimentation processes (i.e. the sediment leaving the lower Missouri River exceeded the sediment entering). As discussed later in this report, this sediment most likely deposited on the floodplain.

Following the 1993 flood, from 1994 to 2007 the river degraded an additional 48.9 million yd^3. Channel mining during this time period totaled 69.5 million yd^3, indicating that the channel mining prevented what would have been a bed recovery trend of 1.6 million yd^3 / year. The 2007 to 2009 analysis indicates localized degradation and aggradation with overall aggradation of 5.1 million yd^3.

From 2009 to 2012, the river degraded an additional 36.4 million yd^3, principally as a result of the 2011 flood. In Kansas City during the 2011 flood, the flow remained above 142,000 cfs (a 2-year flow) for over 100 days, which was approximately 40 days longer than the record flood of 1993. Upstream of RM 367, the degradation profile from the 2011 flood closely matches that of the 1993 flood. Downstream of RM 367, the bed degraded during the 2011 flood, but not nearly as much as in 1993.

Following the 2011 flood, from 2012 to 2013 the river recovered from RM 500 to 160 but continued to degrade from RKM 160 to 0, with a river-wide net recovery of 9.8 million yd^3. From 2013 to 2014 the river responded much more uniformly, recovering 17.8 million yd^3.

Overall, from 1987 to 2014, the bed of the river for the lower 500 miles of Missouri River degraded approximately 240 M yd^3, computed as the sum of the volume change between each successive set of surveys. Figure 13 indicates the components that sum to this quantity of total bed degradation. The "1993 Flood" component is the bed change seen from 1987 to 1994 minus the dredging over the same time period. The "2011 Flood" component is the bed change from 2009 to 2012 minus the dredging over the same time period. The dredging component is the sum of reported dredging tonnages from 1987 to 2014, converted to a volume. The "Natural Recovery Rate" component was found by subtraction and represents the level of rebound that could have occurred over this time period without direct removal of bed sediment via dredging. These volumes are specific to the 1987 to 2014 time period, which are not necessarily reflective of future bed change or average natural sediment recovery rates.

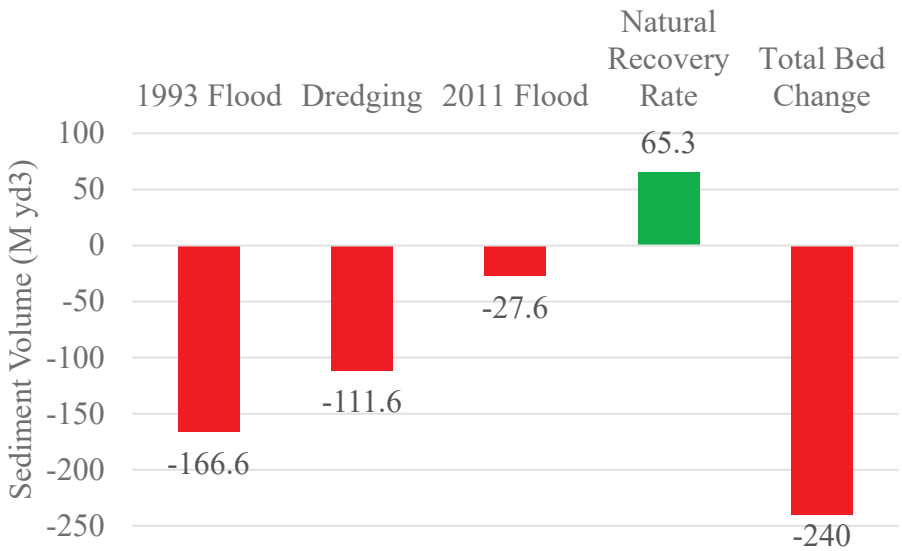

Figure 13. Components of Bed Change from 1987 to 2014

3.0 Model

3.1 Model Introduction

A HEC-RAS 5.0.3 sediment model was developed to predict differences in future bed elevation trends among alternatives. The model runs from RM 498.1, near Rulo, NE to RM 0.74 near the confluence with the Mississippi River. There are 801 cross sections with median spacing of 3354 ft (ranging from 671 ft to 6921 ft.) This resolution allows testing of reach-scale effects.

3.2 Model Schematic

Figure 14 provides a schematic of the model network with river miles, major tributaries, channel cross-sections, and USGS gages located. Due to the length of the river modeled, a detailed mapping of all pertinent features including levees, floodwalls, and river training structures for the full 500 river miles is not provided here. The reader is advised to review the Missouri River Hydrographic Survey Mapbook (USACE 2004).

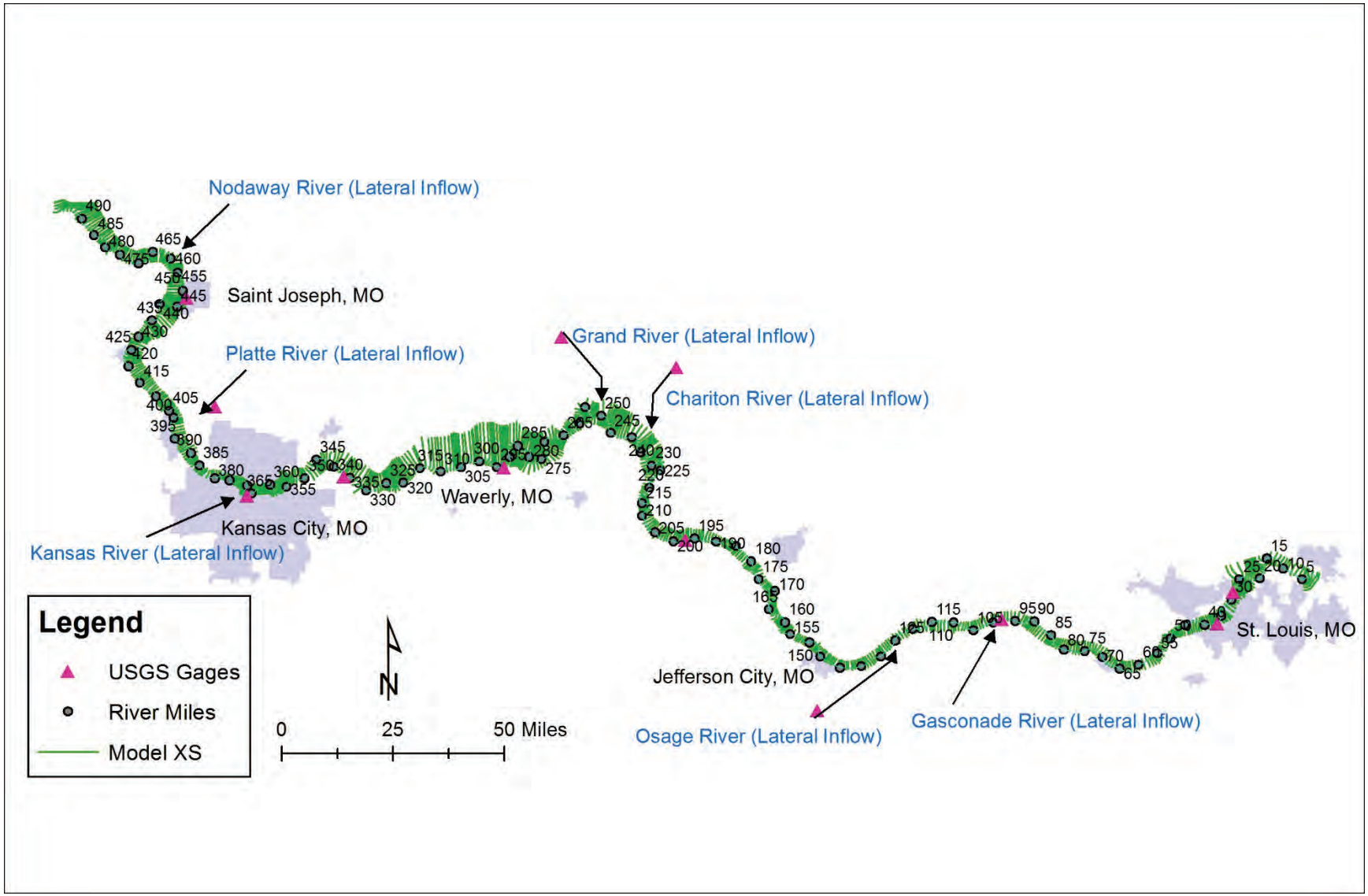

Figure 14. Model Schematic

3.3 Initial Conditions

Initial channel conditions consist of cross-sections, roughness values, and lateral extent, depth, and gradation of the bed. These initial conditions are described in the following paragraphs.

Cross-Sections

The starting geometry was synthesized using bed bathymetry from the 1994 hydrographic survey data (USACE 1994) and bank and overbank data from 2013 LIDAR. The model cross sections were chosen to generally match the locations of the floodway model, with consideration for the locations of the 1994 data. The cross-sections utilize the Missouri River 1960 river mile nomenclature. However, reach lengths are based on the actual channel distance between cross-sections along the sailing line, which varies slightly from using a difference in river miles to compute lengths. The starting year of 1994 was chosen due to data availability; a full hydrographic survey was conducted in 1994 which documented bed elevations as well as dike and revetment geometry. Not all cross-sections present in the 2007 floodway model were retained in the degradation model. Cross-sections with unrealistically small or large cross-sectional areas, cross-sections that were too tightly spaced and bridge cross-sections were removed to achieve model stability.

Dike, sill, and revetment structures were entered into the cross-sections as station/elevation points to account for the blocked flow area between dike structures. The methodology is similar, but more robust, to that used on the Missouri River by Teal and Remus (2001) and in USACE (2017a). Conceptually, the ineffective flow areas within each control volume are summed, then divided by the control volume length in order to compute the blocked area to be entered into each cross section. Figure 15 conceptually displays the process. Figure 16 displays actual computed data for the same river location.

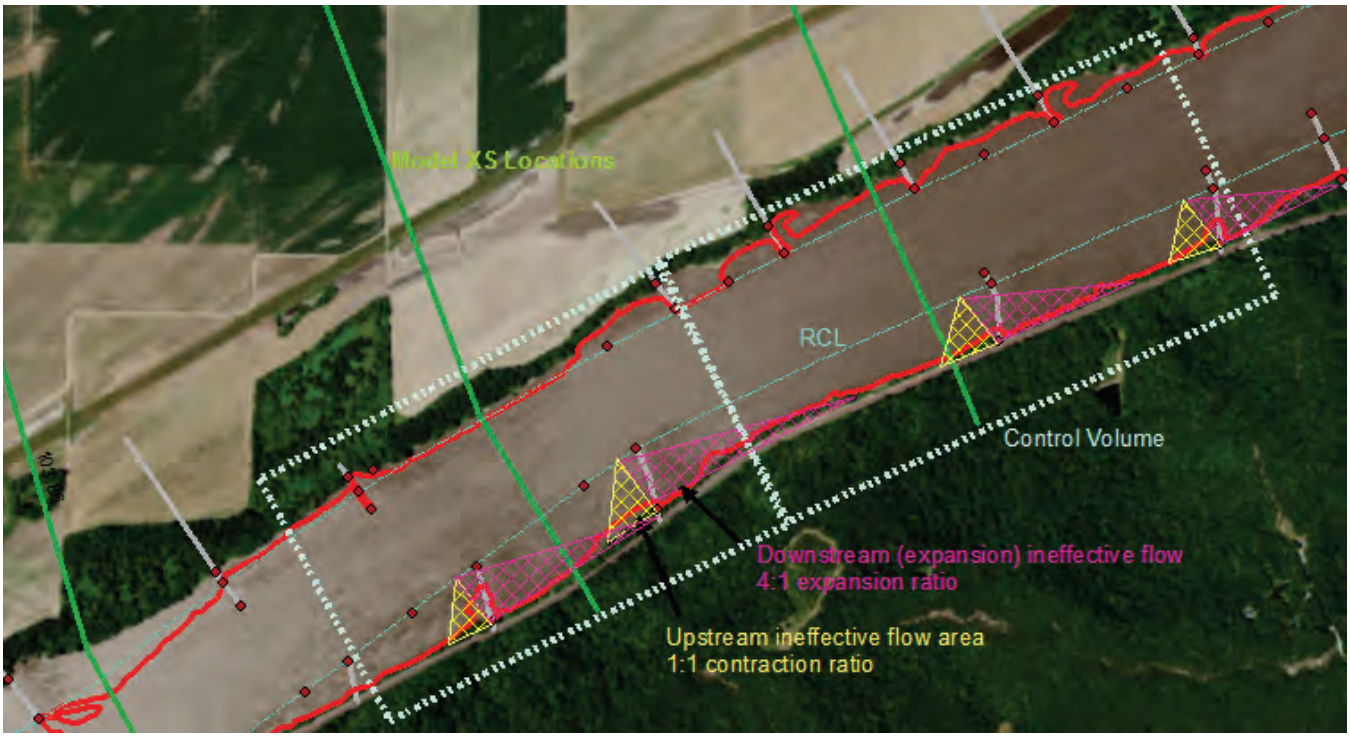

Figure 15. Conceptual depiction of ineffective flow areas from dike structures

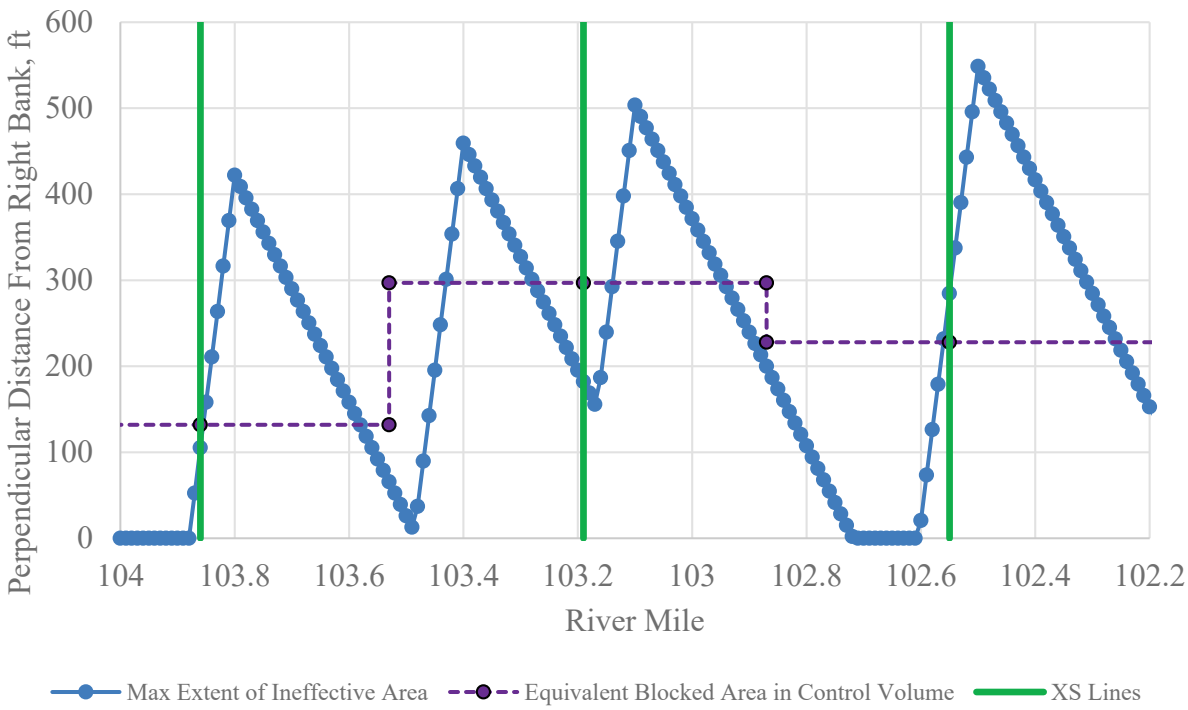

Figure 16. Computation for effective dike length

The following steps summarize the process:

1. Structures in the GIS layer representing dikes and sills were assigned to either the right or left bank.
2. The perpendicular length of each dike structure was found using GIS. This was accomplished by computing the intersection point of each dike structure with a GIS layer representing the low bank, then finding the shortest distance between that intersection point and the Rectified Channel Line. Distances for locations where a dike intersected a bank more than once and other anomalies were manually measured in ArcMap or GoogleEarth.
3. The perpendicular length of each sill structure was assumed equal to the GIS line distance for the portion of structure riverward of the Rectified Channel Lines.
4. The remaining steps were executed four times. Once for the dike structures (structure length as described in step 2) and once for the sill structure (structure length = dike length as in step 2 + the sill length as in step 3). Then repeated twice more for the dikes and sills on the opposite bank.
5. For each hundredth-mile increment from RM 497.7 to RM 0.49, the maximum riverward extent of the ineffective flow area of the bounding dikes was calculated. The zone of expansion was assumed to be 4:1 on the downstream end of each dike. The zone of contraction was assumed to be 1:1 on the upstream and of each dike. The closest bounding dikes did not necessarily generated the most riverward extent of ineffective flow; closer, shorter dikes were at times in the shadow of slightly more distant, longer dikes. To remedy, the ineffective flow expansion/contraction line for four dikes upstream and two dikes downstream of each increment were considered and the maximum length of ineffective flow selected. See Figure 16.
6. The total ineffective flow area was computed for each control volume, then divided by the length of the control volume to yield an effective dike length.
7. This effective dike length was entered into the HEC-RAS model as a blocked obstruction then converted to sta/elev points.

Structures extending from the channel bank to the Rectified Channel Line were assigned the elevation criteria for a dike (the average of the concave and convex design elevations). Structures from the rectified channel line and further into the channel were assigned the design criteria for a sill. These criteria are provided in Table 1. The 1982 CRP, which was the official CRP in use in 1994, was used to set the structure elevations. L-head revetment heights were read individually from the 1994 Missouri River Hydrographic Survey Mapbook (USACE 1994).

Table 1. Dike and Sill Elevations in Model

River Mile Range	Offset from 1982 CRP (ft)			
	Concave Dike Criteria	Convex Dike Criteria	Model Dike Elevation	Sill (Criteria and Model)
498 to 367	+3	+1	+2	-2
367 to 250	+3	+1	+2	-2
250 to 130	+4	+2	+3	-2
130 to 0	+5	+3	+4	-1

As this is a quasi-unsteady, not truly unsteady flow model, levee breaches were not modeled. As RAS allows only one levee point in each overbank, smaller levees were typically included as ineffective flow areas and larger levees as levee points. The levees were placed to maintain an accurate distance between the river bank and the levee, as measured in GIS from the National Levee Database shapefile. The simplified treatment of levees inherent to a quasi-unsteady flow model limits the ability of this model to predict flood heights or floodplain deposition during extreme (levee overtopping) events.

In quasi-unsteady flow modeling, a levee that is overtopped instantly and fully contributes to the flow (i.e. there is no time factor for filling and draining). Where this was problematic, additional permanent ineffective flows were added. Ineffective flows were also included to bridge over chutes present in the LIDAR that were not constructed until later in the calibration period and to fill in the area behind L-head revetments.

Roughness

Channel roughness was assigned as Manning ‘n’ values in four horizontally-varied regions: the active channel (n = 0.028), the channel with sill influence (n = 0.041), the channel with dike influence (n = 0.0413), and the floodplain (n = 0.07). These regions are delineated in Figure 17. Variations in roughness among large reaches were included in the flow-roughness change factors, listed in Table 2, rather than in the base level ‘n’ values. Lisbon chute began flowing in 1996 and was assigned an ‘n’ value of 0.05. Cranberry bend was present prior to 1994 and was assigned an n value of 0.029. The remainder of the chutes were not constructed until late in the calibration period and were assigned the floodplain ‘n’ value of 0.07.

Measured water surfaces at the Kansas City gage indicate that at very high flows, the roughness for the active bed decreases as the bed transitions from dunes to plane bed. This was physically verified using multi-beam bathymetric surveys, as documented in USACE (2017a). Table 2 presents the flow-roughness values used in the model.

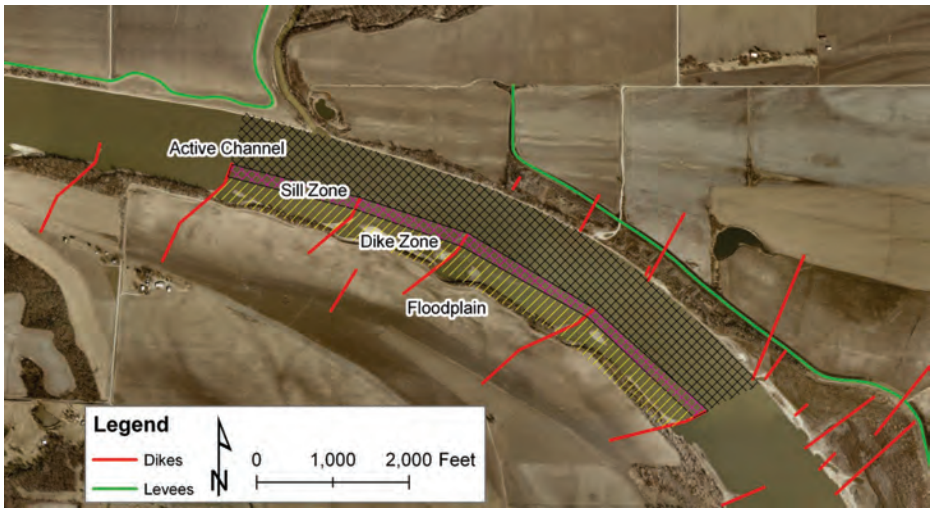

Figure 17. Active Channel and Inter-dike Regions

Table 2. Flow-Roughness Change Factors

RM 498.1 to 463.97	
Q (cfs)	Roughness Factor
0	1.05
70000	1.05
120000	1
150000	0.95
200000	0.92

RM 463.17 to 393.18	
Q (cfs)	Roughness Factor
0	1.09
50000	1.09
70000	1.05
120000	1
150000	0.95
200000	0.9

RM 392.59 to 367.89	
Q (cfs)	Roughness Factor
0	0.95
70000	0.95
120000	0.85
200000	0.8

RM 367.57 to 321.11	
Q (cfs)	Roughness Factor
0	1
50000	1
70000	0.98
120000	0.98
150000	0.95
200000	0.9

RM 320.42 to 250.85	
Q (cfs)	Roughness Factor
0	1.02
50000	1.03
120000	1.03
150000	1.02

RM 250.23 to 169.13	
Q (cfs)	Roughness Factor
0	0.9
70000	0.9
120000	0.9
150000	0.85

RM 62.92 to 0.774	
Q (cfs)	Roughness Factor
0	1
70000	1
120000	0.95
150000	0.95

Tributaries

Seven major tributaries enter the Missouri River in the model reach: the Nodaway River (RM 463.17), Platte River (RM 391.29), Kansas River (RM 367.57), Grand River (RM 250.23), Chariton River (239.32), Osage River (RM 130.37), and Gasconade River (104.49). Over the calibration period (1994 – 2014) the combined flow inputs from these tributaries totals aprx. 31% of the flow in the Missouri River at St. Charles, MO. These tributaries were included as flow and sediment boundary conditions. As explained later, the differences in flow and sediment at the mainstem gages beyond those explicitly specified are included as uniform lateral flows. Thus the flow and sediment inputs from other tributaries such as the Big Nemaha, Lamine / Blackwater, etc. are included in these uniform lateral flow and sediment inputs.

Bed Sediment Extent

The moveable bed limits were initially set at the toe of the most riverward structure (dike or sill). These limits were adjusted as needed for model stability or calibration. The depth of the erodible bed was set to 40 ft, which is beyond the limits of degradation expected to occur over the next 50 years. A river-wide sub-surface investigation has not been performed to accurately locate bedrock in the active channel, but specific borings near bridges indicate 40 to 100 ft of sand in Kansas City.

Bed Sediment Gradation

Bed sediments were sampled at 5-mile increments in 1994 over the entire model reach. The model bed sediment was a weighted average of 50% of the individual sediment sample and 50% of the reach-average sediment sample. The average reaches were defined as follows: RM 500 to 391 (Rulo to Platte River), RM 391 to 250 (Platte River to Grand River), RM 250 to 130 (Grand River to Osage River), and RM 130 to 0 (Osage River to the mouth). Table 3 presents the original, 1994 data (interpolated to standard sizes) compared to the model bed gradations.

Table 3. Initial and Final Model Gradations, Percent Finer (Rounded to Whole Numbers)

RM	Original Data									Model Data								
	Diameter (mm)									Diameter (mm)								
	0.125	0.25	0.5	1	2	4	8	16	32	0.125	0.25	0.5	1	2	4	8	16	32
1	1	12	49	77	89	94	98	100	100	1	12	49	77	89	94	98	100	100
5	0	25	59	79	90	96	99	100	100	0	25	58	79	90	96	99	100	100
10	1	9	46	76	90	97	99	100	100	1	10	46	76	90	96	99	100	100
15	1	9	38	71	88	95	98	100	100	1	9	39	71	88	95	98	100	100
20	1	22	57	78	90	96	99	100	100	1	22	56	78	90	96	99	100	100
25	2	31	74	84	91	96	99	100	100	2	30	72	84	91	96	99	100	100
30	1	20	61	83	94	98	99	100	100	1	20	61	83	93	98	99	100	100
35	1	24	54	74	89	97	99	100	100	1	23	54	74	89	97	99	100	100
40	0	9	37	62	82	94	98	100	100	0	9	37	63	82	94	98	100	100
45	1	10	35	60	80	93	98	100	100	1	10	36	61	81	93	98	100	100

RM	Original Data									Model Data								
	Diameter (mm)									Diameter (mm)								
	0.125	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**	**0.125**	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**
50	0	8	39	72	90	97	99	100	100	0	8	40	72	90	97	99	100	100
55	1	9	36	63	80	91	97	100	100	1	9	37	63	81	92	97	100	100
60	0	17	55	74	89	97	99	100	100	0	17	54	74	89	97	99	100	100
65	1	23	53	75	89	94	96	99	100	1	23	53	75	88	94	97	99	100
70	0	8	36	65	84	93	97	99	100	0	9	36	65	84	93	97	100	100
75	1	12	40	61	75	86	95	99	100	1	12	40	61	76	87	95	99	100
80	1	15	42	71	87	92	96	98	100	1	15	42	71	87	93	96	98	100
85	1	18	52	77	92	98	100	100	100	1	17	52	77	91	98	100	100	100
90	1	14	49	66	81	92	98	100	100	1	14	49	66	81	92	98	100	100
95	1	9	44	72	89	97	100	100	100	1	9	44	72	89	97	100	100	100
100	1	14	45	79	94	98	100	100	100	1	14	45	78	94	98	100	100	100
105	1	29	66	86	95	99	100	100	100	1	29	66	85	95	99	100	100	100
110	3	22	64	84	92	97	99	100	100	3	22	64	83	92	97	99	100	100
115	0	5	36	65	81	93	98	100	100	0	6	37	65	81	93	98	100	100
120	0	12	50	77	89	95	98	100	100	1	12	50	76	89	95	98	100	100
125	1	24	54	72	85	94	99	100	100	1	24	54	72	85	94	99	100	100
130	1	16	62	86	95	98	99	100	100	1	16	62	86	94	98	99	100	100
135	1	12	48	67	79	91	98	100	100	1	12	49	68	80	92	98	100	100
140	1	15	54	85	96	99	100	100	100	1	15	55	85	96	99	100	100	100
145	3	26	62	77	87	94	98	100	100	3	26	62	78	87	94	98	100	100
150	1	28	67	84	94	97	98	100	100	1	28	67	84	94	97	98	100	100
155	6	47	70	82	92	98	100	100	100	5	46	70	83	93	98	100	100	100
160	1	31	74	85	91	95	98	100	100	1	30	73	85	91	95	98	100	100
165	2	31	70	86	93	97	99	100	100	2	31	69	86	93	97	99	100	100
170	1	9	62	88	96	99	100	100	100	1	10	62	88	96	99	100	100	100
175	1	12	54	79	91	97	99	100	100	1	13	55	79	91	97	99	100	100
180	1	23	74	91	97	99	100	100	100	1	23	73	91	97	99	100	100	100
185	2	27	62	91	99	100	100	100	100	2	27	62	91	99	100	100	100	100
190	1	24	66	85	93	98	100	100	100	1	24	66	85	93	98	100	100	100
195	1	14	51	75	88	95	99	100	100	1	15	52	76	89	96	99	100	100
196.6	0	13	43	76	92	97	99	100	100	0	14	44	76	92	97	99	100	100
200	1	25	67	85	95	99	100	100	100	1	25	67	85	95	99	100	100	100
205	0	14	55	81	93	97	99	100	100	0	15	55	81	93	97	99	100	100
210	1	15	61	85	96	99	100	100	100	1	16	62	85	96	99	100	100	100
215	2	35	75	93	99	100	100	100	100	2	34	74	93	98	100	100	100	100
220	1	17	70	93	98	99	100	100	100	1	17	70	93	98	99	100	100	100
225	1	25	69	93	99	99	99	100	100	1	25	69	93	98	99	99	100	100
230	2	36	75	90	97	99	100	100	100	2	35	74	90	96	99	100	100	100
235	1	33	76	95	100	100	100	100	100	1	33	76	95	99	100	100	100	100
240	1	28	59	76	89	96	99	100	100	1	28	59	76	89	97	99	100	100
245	1	29	72	87	94	98	99	100	100	1	29	72	87	94	98	99	100	100
250	1	22	70	92	98	99	100	100	100	1	22	70	91	97	99	100	100	100
255	1	35	80	96	99	100	100	100	100	1	34	79	95	99	100	100	100	100
260	1	29	71	88	94	97	99	100	100	1	29	71	88	94	97	99	100	100

RM	Original Data									Model Data								
	Diameter (mm)									Diameter (mm)								
	0.125	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**	**0.125**	**0.25**	**0.5**	**1**	**2**	**4**	**8**	**16**	**32**
265	2	39	83	95	98	100	100	100	100	2	38	83	94	98	99	100	100	100
270	1	37	87	96	98	98	99	100	100	1	36	86	95	98	98	99	100	100
275	2	38	69	85	93	97	98	100	100	2	37	69	85	93	97	98	100	100
280	2	47	85	97	99	100	100	100	100	2	46	85	97	99	100	100	100	100
285	1	30	80	95	98	99	100	100	100	1	30	79	94	98	99	100	100	100
290	1	28	62	81	95	99	100	100	100	1	28	62	82	95	99	100	100	100
295	1	25	69	90	98	100	100	100	100	1	25	69	90	98	100	100	100	100
300	1	19	59	83	94	98	99	100	100	1	19	60	84	94	98	99	100	100
305	1	21	52	76	91	97	99	100	100	1	21	53	77	92	97	99	100	100
310	1	36	78	95	99	100	100	100	100	1	36	77	95	99	100	100	100	100
315	9	28	76	92	97	99	100	100	100	8	28	76	92	97	99	100	100	100
320	1	12	57	83	91	93	95	95	99	1	12	58	83	91	94	95	95	100
325	1	19	68	91	97	99	100	100	100	1	19	68	91	97	99	100	100	100
330	1	20	49	79	93	97	98	100	100	1	20	50	79	93	97	98	100	100
335	1	20	53	76	90	97	100	100	100	1	20	53	77	90	97	100	100	100
340	2	27	81	96	99	100	100	100	100	2	27	81	95	99	100	100	100	100
345	1	13	63	89	96	98	99	100	100	1	13	63	89	96	98	99	100	100
355	2	36	71	89	94	96	98	100	100	2	36	71	89	95	96	98	100	100
360	1	39	82	93	97	99	100	100	100	1	38	81	93	97	99	100	100	100
365	2	26	53	75	89	96	99	100	100	2	26	54	76	90	96	99	100	100
370	0	17	68	89	96	98	99	100	100	1	17	68	89	96	98	99	100	100
375	1	36	78	95	99	100	100	100	100	1	35	78	95	99	100	100	100	100
380	1	21	60	82	93	98	99	100	100	1	22	60	82	93	98	99	100	100
385	1	22	68	89	95	97	99	100	100	1	22	68	89	95	97	99	100	100
390	1	28	86	98	99	99	99	100	100	1	28	85	97	99	99	99	100	100
395	1	32	74	83	89	95	98	99	100	1	32	74	84	90	95	98	99	100
400	1	42	84	95	98	99	99	100	100	1	41	83	94	98	99	100	100	100
405	0	20	72	94	99	99	100	100	100	0	20	72	94	98	99	100	100	100
410	1	31	85	94	98	99	100	100	100	1	31	85	94	98	99	100	100	100
415	3	45	89	98	100	100	100	100	100	3	44	88	98	100	100	100	100	100
420	1	18	70	92	97	99	100	100	100	1	18	70	92	97	99	100	100	100
425	1	36	80	93	98	99	100	100	100	1	36	79	93	98	99	100	100	100
430	2	37	82	94	98	99	100	100	100	2	36	82	94	98	99	100	100	100
435	1	23	80	97	100	100	100	100	100	1	24	80	97	99	100	100	100	100
440	0	14	66	89	95	97	99	100	100	0	15	67	89	95	97	99	100	100
450	1	26	80	94	98	99	100	100	100	1	26	79	94	98	99	100	100	100
460	0	29	72	89	96	99	100	100	100	1	29	72	89	97	99	100	100	100
465	1	15	61	80	91	97	99	100	100	1	16	62	80	91	97	99	100	100
470	1	33	75	91	97	99	100	100	100	1	33	75	91	97	99	100	100	100
475	1	24	77	96	99	100	100	100	100	1	25	77	96	99	100	100	100	100
480	0	21	72	94	99	100	100	100	100	0	21	72	94	99	100	100	100	100
485	1	29	77	96	99	100	100	100	100	1	28	77	95	99	100	100	100	100
490	1	14	57	87	96	98	100	100	100	1	15	58	88	96	98	100	100	100
495	1	17	50	80	93	98	99	100	100	1	18	51	81	93	98	99	100	100

3.4 Boundary Conditions

Boundary conditions include flow, water temperature, downstream water surface elevation, incoming sediment load and gradation, floodplain deposition amounts, and dredging amounts, locations, and timing. These boundary conditions are described in the following paragraphs.

Flows

Daily flow values from Aug 1, 1994 – 29 July 2014, computed from seven mainstem Missouri River and seven tributary USGS gaging stations, were used as the flow inputs to the model.

Daily flow values were compiled for the following USGS gage stations listed in Table 4. The model upstream boundary was set to the daily flow reported by USGS for the Missouri River at Rulo, Nebraska. Each tributary was entered as a lateral flow. The difference between the mainstem Missouri River gages that could not be explained by the tributary flows were entered as uniform lateral flows. These uniform lateral flows account for ungagged inflows, totaling 19% of the total flow volume at St. Charles, MO. They also approximate the longitudinal change in the flow profile due to timing effects which are not modeled in quasi-unsteady flow modeling. This same approximation was utilized in USACE (2017a). Additional details regarding drainage area delineations for the watershed are included in the Unsteady HEC-RAS Model Calibration Report, Appendix E.

Scaled down versions (1/10,000) of these uniform lateral flows were entered in order to trigger the floodplain deposition rating curves at the appropriate times. The scaled-down uniform flows are very small and have negligible effect on actual model flows.

The flows from the downstream gage are used in the model as lateral flows and as input to the rating curves. At two gages, insufficient sediment data exists at the downstream gage, so the flow/load relationship was developed from a more upstream gage. These relationships were then used with flows from the downstream gages.

Table 4. USGS Gage Stations Used in the Model

USGS Gage #	Name	USGS Drainage Area (sq mi)
06813500	Missouri River at Rulo, NE	414,900
06818000	Missouri River at St. Joseph, MO	426,500
06893000	Missouri River at Kansas City, MO	484,100
06895500	Missouri River at Waverly, MO	485,900
06909000	Missouri River at Boonville, MO	500,700
06934500	Missouri River at Hermann, MO	522,500
06935965	Missouri River at St. Charles, MO	542,000
06817700	Nodaway River Near Graham, MO	1,520
06817000	Nodaway River at Clarinda, IA*	762

USGS Gage #	Name	USGS Drainage Area (sq mi)
06821190	Platte River at Sharps Station, MO	2,380
06892350	Kansas River at Desoto, KS	59,756
06902000	Grand River Near Sumner, MO	6,880
06905500	Chariton River Near Praire Hill, MO	1,870
06926510	Osage River below St. Thomas, MO	14,584
06934000	Gasconade River Near Rich Fountain, MO	3,180
06933500	Gasconade River Near Jerome, MO*	2,840

* Denotes a gage used for development of the flow/sediment rating curve but not used as the flow input.

Water Temperature

The HEC-RAS sediment model requires a water temperature for each day of the simulation to calculate fall velocity. The annual time series of water temperatures based on measurements at the Kansas City gage, as developed in USACE (2017a), was used in this model.

Downstream Water Surface Boundary Condition

The downstream water surface elevation was originally set to the water surface elevation computed by the Missouri River Recovery Program (MRRP) unsteady flow model which includes the backwater effect from the Mississippi River. However, on inspection, the model water surface output at this location would occasionally drop below the normal depth solution, which produced unreasonably high velocities and excessive scour. To decrease this unrealistic effect, a floor of 1 ft below the normal depth solution (computed from the initial geometry) was imposed. This maintains the backwater effects from the Mississippi River included in the MRRP unsteady flow model. Figure 18 indicates the downstream boundary as a function of the flow in the MRRP unsteady flow model at RS 0.73.

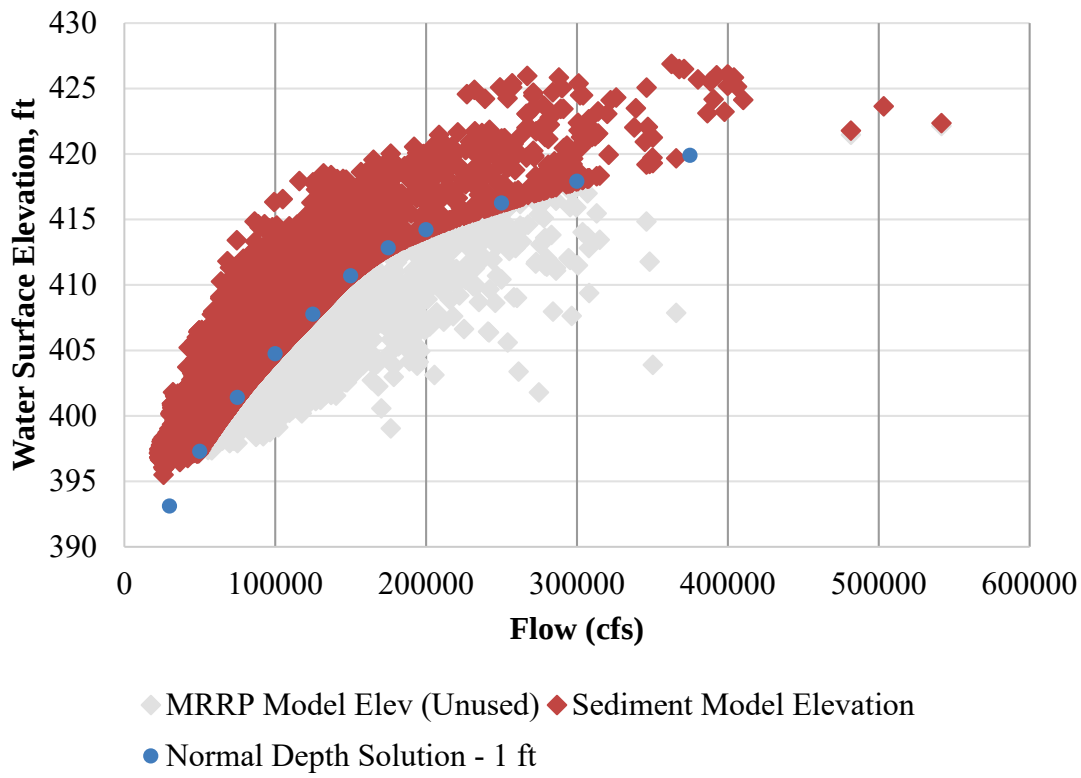

Figure 18. Downstream Boundary Condition

Sediment Load

The incoming sediment load and gradation was computed and entered into the model as a DSS time series for each grain class. The sediment load for a given grain class was computed as the total suspended sediment load multiplied by the percent of the suspended load corresponding to the grain class plus the total bed load multiplied by the percent of the bed load corresponding to that grain class.

Only sands and gravels were included in the model. Finer sediments are wash load in this system; they are not found in appreciably quantities on the bed and do not play a significant role in the physical bed change processes. Wash load causes a numerical artifact in HEC-RAS 5.0.3 and so was not included.

USGS Water Quality data at Saint Joseph, MO were used to develop the flow/load relationship and gradational breakdown of the suspended load. Overall, the suspended sediment load fines considerably with increasing discharge. Figure 17 demonstrates the average, calibrated total load relationships at Saint Joseph compared to USGS measurements for suspended load. (Note that the USGS report many suspended sediment samples that had no coarse sand, which could not be

plotted in log space on Figure 19.) These loads computed for St. Joseph were reduced by the Nodaway sediment load in order to create the model upstream boundary condition.

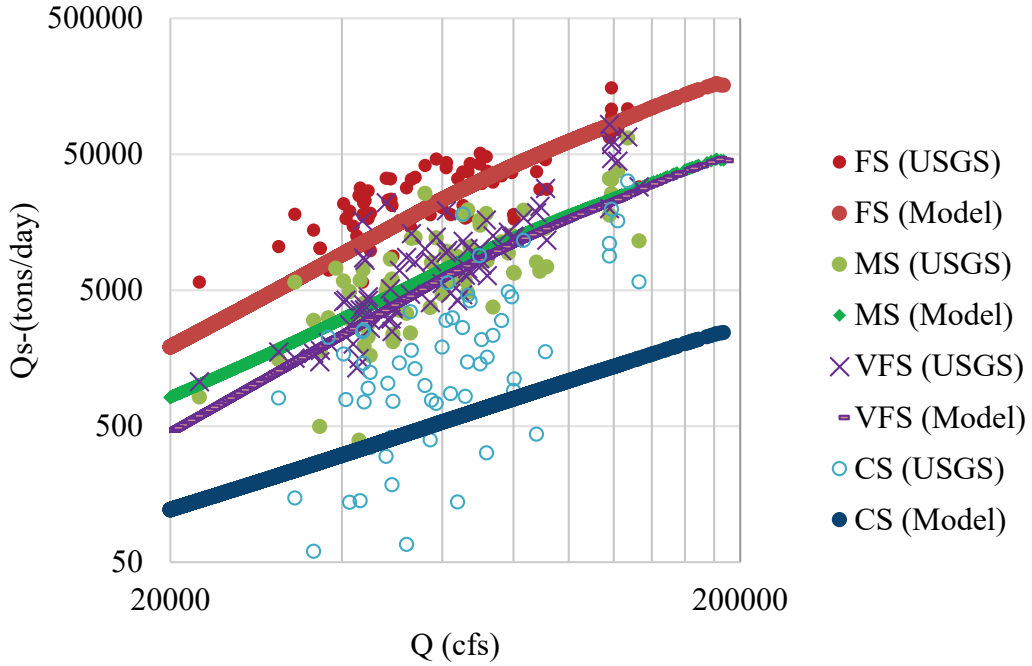

Figure 19. Average relationships at Saint Joseph used to develop upstream rating curve vs. measured suspended sand by grain class

During the 2011 flood, the high volumes of relatively clear water released from the dams resulted in a markedly different suspended sediment relationship. The suspended loads during the 2011 event was based on USGS measurements during the event rather than the long-term relationship shown above.

The bedload portion of the sediment load was computed from the bedload rating curve for St. Joseph presented in Abraham et al. (2017). This bedload rating curve was computed by using successive multi-beam bathymetric surveys (Abraham et al. 2011) with the time correction suggested in Shelley et al. (2013). This rating curve is provided in Figure 20.

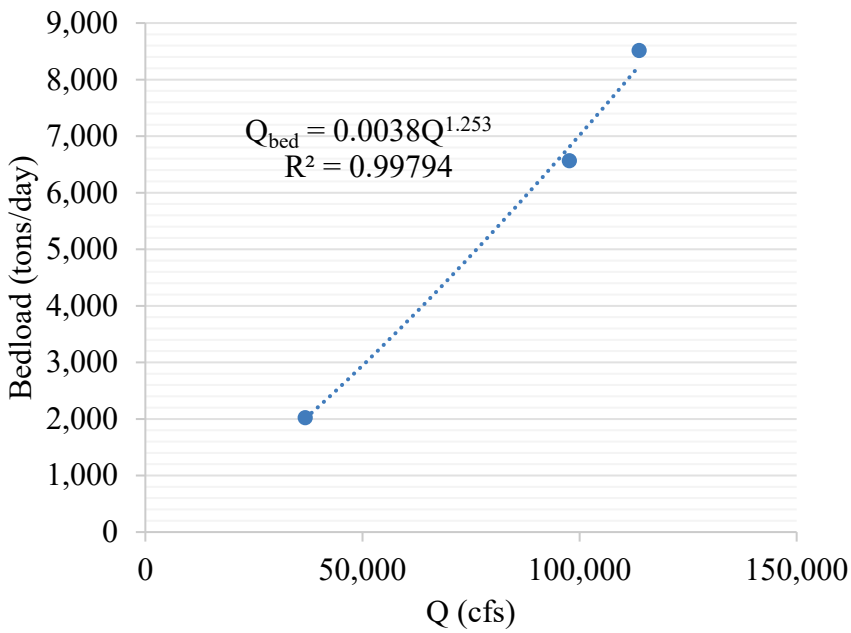

Figure 20. Missouri River Bedload Rating Curve at St. Joseph (from Abraham et al. 2017)

The gradation of the incoming total sediment load is a function of the relative contributions from bed load and suspended load, which varies by flow and by whether the 1994 – 2010 or 2011 flow-load curve is used for the suspended sediment contribution.

Sediment rating curves at seven major tributaries were included in the model as flow-load boundary conditions. This report presents the calculated rating curves—the model itself includes these rating cures with the loads divided by two to compensate for a RAS 5.0.3 bug that doubles tributary loads.

The flow-load curve for the Nodaway River was based on USGS gage data for the Nodaway River at Clarinda, MO. USGS data yielded the gradational breakout of the suspended fines and sands, with over 93% of the suspended sediment load composed of silts and clays. Bed load data was assumed to be 1% of suspended with predominantly fine and medium sand. Table 5 and Figure 21 provide the rating curve for the Nodaway River.

Table 5. Nodaway River Model Bed Material Rating Curve

Q (cfs)	100	2,000	10,000	150,000
Qs (tons/day)	2	1,333	31,200	67,002
VFS	1	436	10,200	21,905
FS	1	556	13,200	28,347
MS	0	205	4,800	10,308
CS	0	77	1,600	3,436
VCS	0	60	1,400	3,007

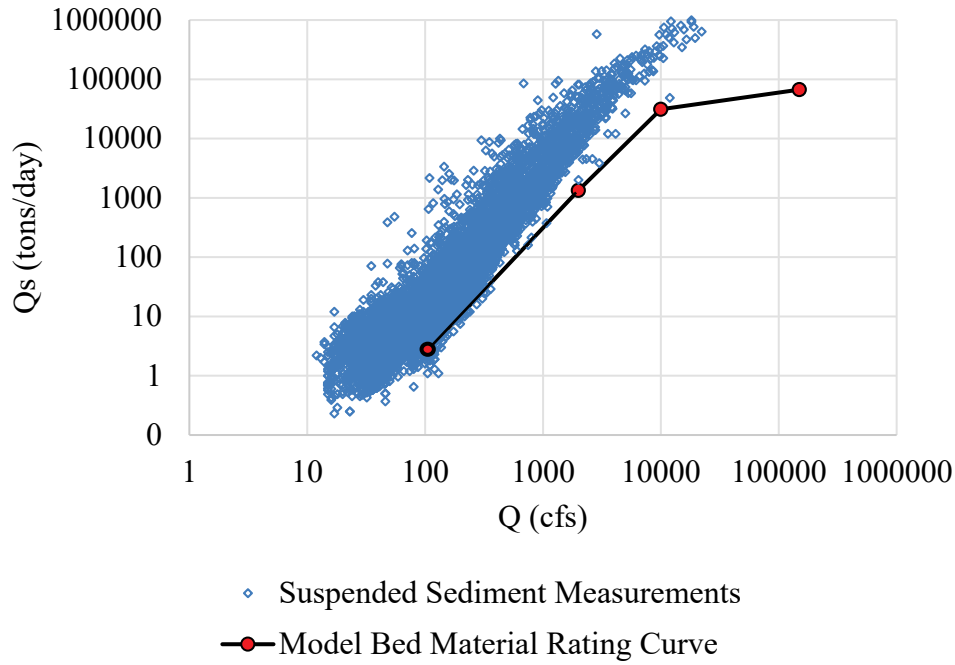

Figure 21. Nodaway River Sediment Loads

The flow-load curve for the Platte River was based on USGS gage data for the Platte River at Sharps Station. A bed material load was developed by subtracting the percent fines recorded in USGS measurements (which increases with increasing flow) and adding 5% as an estimate for bed load. In the absence of measurements, the bed load was assumed composed of very fine, fine, and medium sand. Table 6 and Figure 22 provide the loads and gradations used in the model.

Table 6. Platte River Bed Material Load Rating Curve and Gradation

Q (cfs)	1	1000	5000	10000	50000
Qs (tons/day)	0.004	426	5337	8454	10305
VFS	0.002	265	3149	4763	5504
FS	0.001	151	2004	3322	4247
MS	0.0000	10	184	369	554

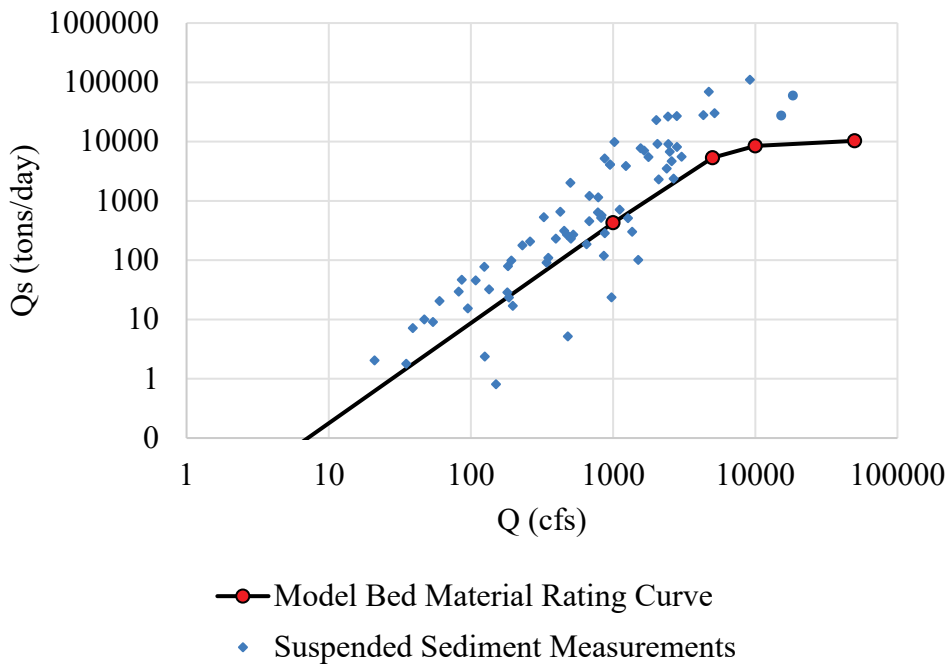

Figure 22. Platte River Sediment Loads

The sediment load and gradation for the Kansas River was based on USGS gage data for the Kansas River at Desoto, Kansas. Bed load data was assumed to be 5% of suspended with predominantly fine, medium, and coarse sand. The Kansas River experiences multiple anthropogenic influences on the sediment load in between the sediment gaging station and the confluence with the Missouri River, including multiple channel mining operations and multiple weirs. Table 7 and Figure 23 provide the rating curve for the Kansas River.

Table 7. Kansas River Bed Material Load Rating Curve and Gradation

Q (cfs)	250	6000	40000	100000	150000
Qs (tons/day)	4	1544	51736	240000	404168
VFS	0.4	160	5278	53418	53418
FS	0.8	568	25922	337534	337534
MS	2.4	738	18236	163036	163036
CS	0	56	1532	20120	20120
VCS	0	20	768	10060	10060

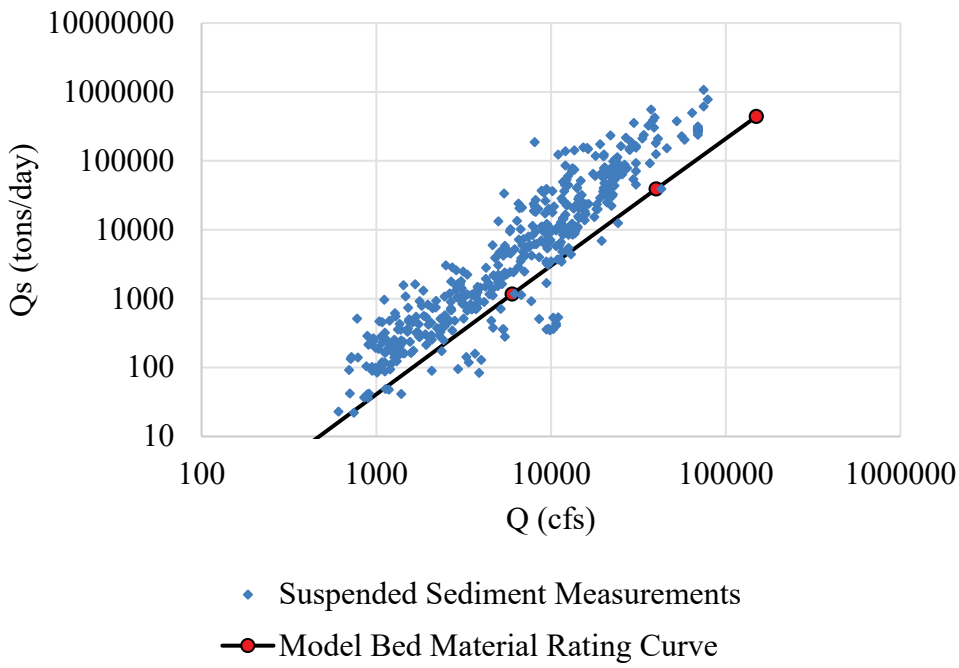

Figure 23. Kansas River Sediment Loads

The sediment load and gradation for the Grand River was based on USGS gage data for the Grand River at Sumner, Missouri. USGS data yielded overall concentrations and % fines. The gradational breakout of the suspended sands was assumed to be predominantly very fine and fine sand. Bed load data was assumed to be 5% of suspended with predominantly fine and medium sand. Table 8 and Figure 24 provide the rating curve for the Grand River.

Table 8. Grand River Bed Material Load Rating Curve and Gradation

Q (cfs)	100	1000	33000	100000
Qs (tons/day)	9	337	61540	70028
VFS	3	128	19361	21181
FS	4	139	25258	28701
MS	2	74	14648	16914
CS	0	10	4279	5387

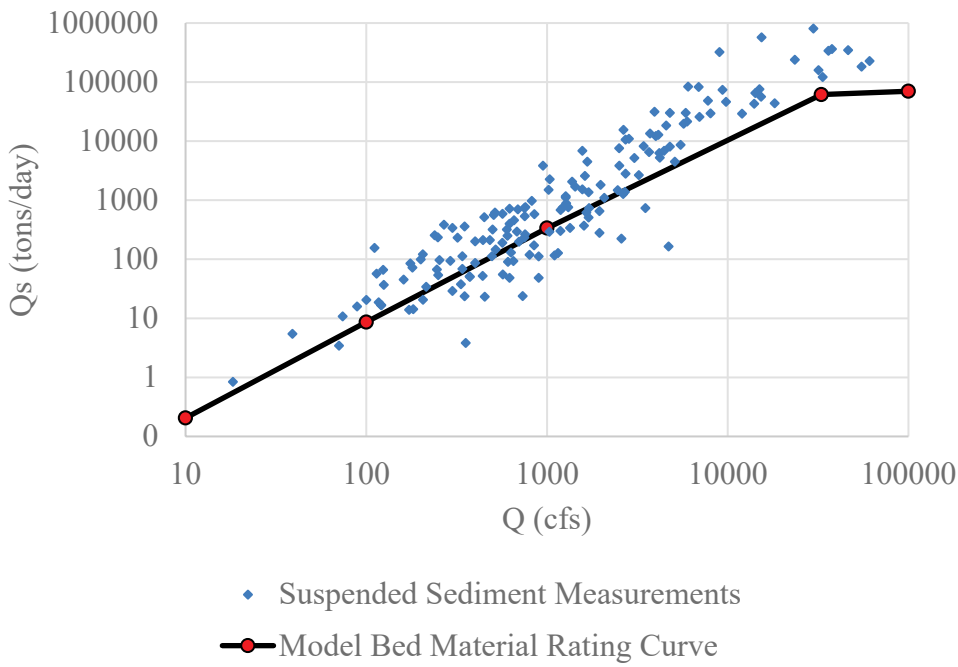

Figure 24. Grand River Sediment Loads

The sediment load and gradation for the Chariton River was based on USGS gage data for the Chariton River near Prairie Hill, MO. USGS data yielded the gradational breakout of the suspended fines and sands. Bed load data was assumed to be 5% of suspended with predominantly fine and medium sand. Table 9 and Figure 25 provide the rating curve for the Chariton River.

Table 9. Chariton River Bed Material Load Rating Curve and Gradation

Q (cfs)	20	10000	150000
Qs (tons/day)	0.1	3927	22305
VFS	0.00	222	1188
FS	0.05	2536	14505
MS	0.01	588	3311
CS	0.01	390	2201
VCS	0.00	191	1100

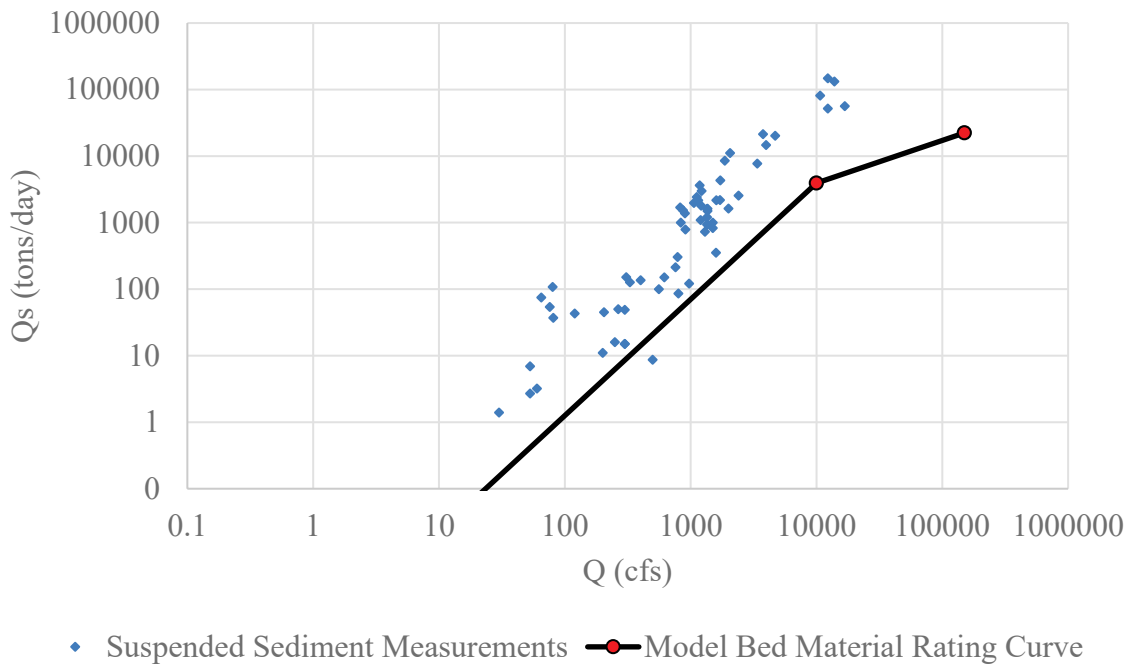

Figure 25. Chariton River Sediment Loads

The sediment load and gradation for the Osage River was based on USGS gage data for the Osage River below St. Thomas, MO. USGS data yielded overall concentrations and % fines. The gradational breakout of the suspended sands was assumed to be predominantly fine and medium sand. Bed load data was assumed to be 5% of suspended with predominantly fine and medium sand. Table 10 and Figure 26 provide the rating curve for the Osage River.

Table 10. Osage River Bed Material Load Rating Curve and Gradation

Q (cfs)	100	1000	5000	40000	100000
Qs (tons/day)	6	66	350	2993	4581
VFS	0.5	6	31	257	388
FS	1.7	19	101	856	1304
MS	2.9	33	175	1497	2291
CS	0.6	7	39	342	528
VCS	0.1	1	4	42	70

Figure 26. Osage River Sediment Loads

The sediment load and gradation for the Gasconade River was based on USGS gage data for the Gasconade River at Jerome, MO. USGS data yielded overall concentrations. The % fines was taken from the Osage River and the same assumptions were made for the gradational breakout of sands and bed load as the Osage River.

Table 11. Gasconade River Bed Material Load Rating Curve

Q (cfs)	100	1000	5000	25000	100000
Qs (tons/day)	1	59	1085	19839	95736
VFS	0.1	5	95	1714	8109
FS	0.3	17	312	5681	27256
MS	0.4	29	542	9919	47868
CS	0.1	6	122	2254	11038
VCS	0.0	1	13	270	1465

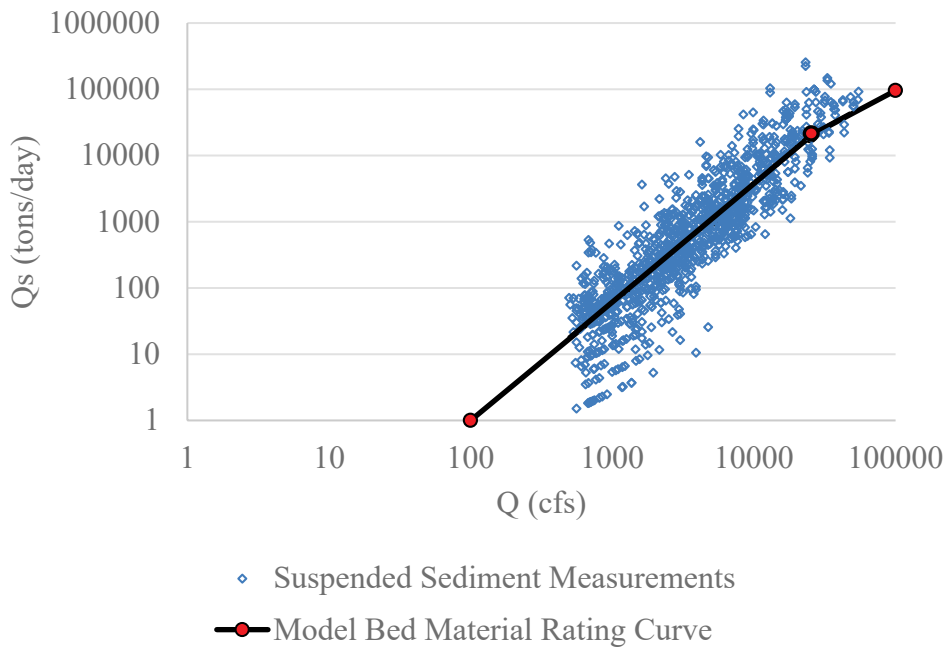

Figure 27. Gasconade River Sediment Loads

2011 Flood Boundary Conditions

As shown in Figure 3, the sediment concentrations were dramatically lower during the 2011 flood than typical. For March – November, 2011, the suspended sediment load was computed by the formula Qs = 0.7641 Q + 6910.7, where Qs = suspended sediment in tons/day and Q = daily flow in cfs. Bedload, computed with the rating curve depicted in Figure 20, was added to this value to yield the total bed material load for the day at St. Joseph. This load was transferred upstream by subtracting the load for the Nodaway. This flow/load/gradation curve is unique to the 2011 event.

Dredging

Commercial dredging on the Missouri River was a significant driver of bed degradation during the calibration period (USACE 2011). The resolution of dredging data varies over time. From 1994 – 1996, the annual tons dredged were reported to USACE's regulatory branch on a reach basis. Since 1997, daily tons dredged and river miles were reported.

Dredging was included in the degradation model as monthly totals at each cross-section with the start date the first day of the month and the end date the last day of the month. For 1997 and later, the reported monthly tonnages of dredging were assigned to the appropriate cross-sections and to the appropriate month. Annual, reach-scale tonnages for 1994 – 1996, were apportioned according to the temporal and spatial distribution of dredging from 1997 – 2009. Figure 28 provides the spatial distribution for dredging for each year.

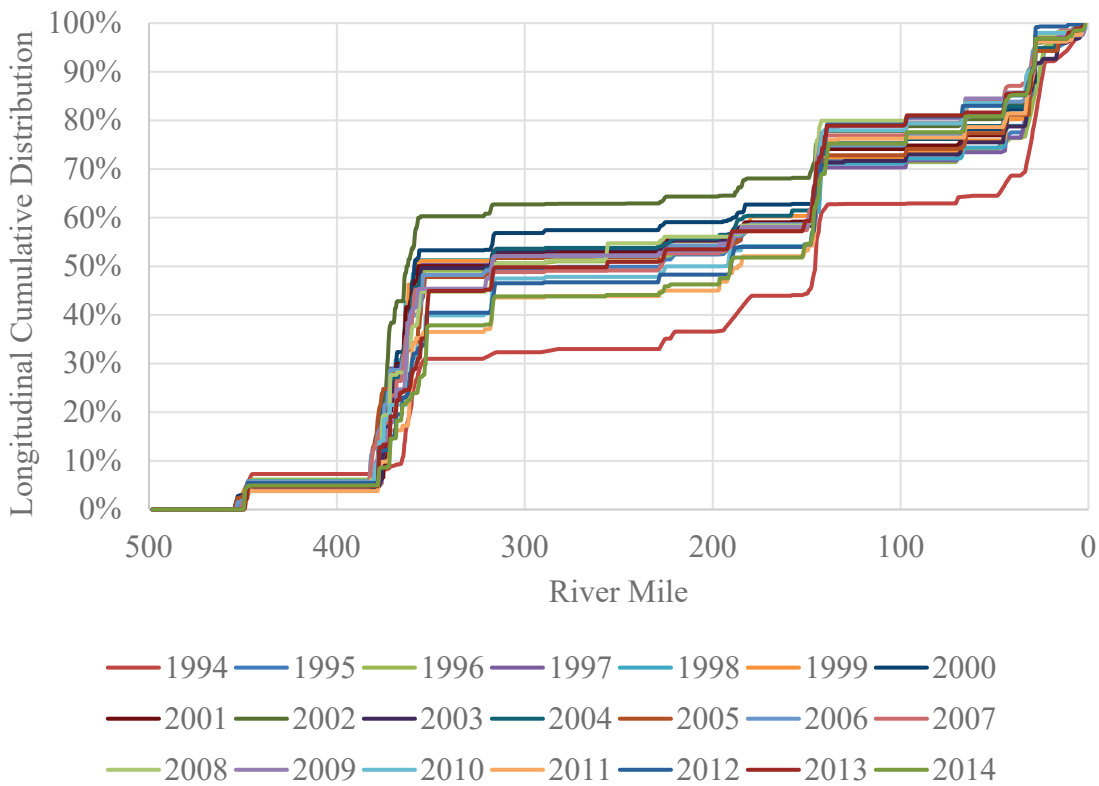

Figure 28. Longitudinal Cumulative Dredging Distribution by River Mile

The impact of dredging was restricted to the actual dredging tonnage, i.e. one ton of extracted material lowers the bed by a volume equivalent to one ton. Potential dredging effects due to material sorting, re-discharge, and bed disturbance were not included. Dredging volumes or locations were not adjusted during calibration.

Unmeasured Sediment Inflows

Sediment budgeting was used to estimate unmeasured sediment inflows for inclusion in the model. A sediment budget quantifies the terms in the continuity equation: Sediment_In – Sediment_Out= Δ Storage. The following equation provides the sediment budget from the St. Joseph to the Kansas City gages, from 1994 to 2005:

$$SJ + PR + KR + UnM - D - FP - KC = \Delta Bed \qquad \text{(Equation 1)}$$

Where SJ = the sand load passing the Saint Joseph gage (tons)

PR = the sand input from the Platte River (tons)

KR = the sand input from the Kansas River (tons)

UnM = the unmeasured sediment inflows (tons)

D = the dredging volume (tons)

KC = the sand load passing the Kansas City gage (tons)

ΔBed = the total mass of bed change (tons)

PR, KR, and KC were taken from USGS (Heimann et al. 2010), using model rating curves to fill in the gaps as needed. As a full 2005 bathymetric survey is not available, the 1994 – 2007 bed change was divided by 13 years then multiplied by 11 years to approximate the 1994 – 2005 bed change. Floodplain deposition (FP) was assumed negligible for 1994 to 2009. The unmeasured sediment (UnM) was solved for arithmetically. Table 12 presents the numerical values for each variable. (Note: Significant digits are retained to the ton in Tables 12 – 14 to make the math reproducible, not to imply that any of these quantities are known to the ton.)

Table 12. Sediment Budget 1994 – 2005 for St. Joseph to Kansas City

Budget Term	Mass (tons)
SJ	116,179,350
PR	3,345,417
KR	10,091,852
UnM	10,778,755
D	20,981,695
FP	0
KC	147,369,350
ΔBed	-27,955,671

A similar analysis was performed for the reach from Kansas City, MO to Herman, MO. Table 13 presents the numerical values for each variable.

$$KC + GR + CH + OS + GS + UnM - D - FP - HR = \Delta Bed \qquad \text{(Equation 2)}$$

Where KC = the sand load passing the Kansas City gage (tons)

GR = the sand input from the Grand River (tons)

CH = the sand input from the Chariton River (tons)

OS = the sand input from the Osage River (tons)

GS = the sand input from the Gasconade River (tons)

UnM = the unmeasured sediment inflows (tons)

D = the dredging volume (tons)

HR = the sand load passing the Hermann gage (tons)

ΔBed = the total mass of bed change (tons)

Table 13. Sediment Budget 1994 – 2005 for Kansas City to Hermann

Budget Term	Mass (tons)
KC	147,369,350
GR	13,796,832
CH	492,949
OS	2,792,519
GS	3,136,888
UnM	60,718,243
D	36,042,315
FP	0
HR	199,524,347
ΔBed	-7,259,881

The unmeasured sediment load incorporates all non-specific sediment sources needed for the sediment budget to balance, including bank erosion, gullies, tributaries, and shallow water habitat construction activities. In addition, the unmeasured term incorporates error in the upstream, downstream, and tributary rating curves. The procedure used to input this sediment to the model causes the needed additional sediment to be more or less uniformly distributed between the gages.

The UnM values listed in Tables 12 and 13 were entered into the model using rating curves tied to the flow boundary conditions representing ungaged inflows. Rating curves of the type Qs = aQ, were created, with *a* set so that the sum of Qs from 1994 to 2005 equals the UnM values presented in Tables 12 and 13.

The flows that drive the unmeasured sediment rating curves are scaled-down versions of the ungaged water inflows. These inflows were computed as the difference between flows at gages that are not accounted for by tributary inflows. On any given day, differences in flows at gages may be negative due to unsteady hydrograph effects. To avoid problems with the rating curves during negative uniform lateral flows, separate flow boundary conditions that are always positive were created for use with the unmeasured sediment rating curves. These separate flow boundary conditions were scaled down by 10,000 so that only negligible additional flow is added.

Floodplain Deposition

As depicted in Figure 2, levees which line most of the Missouri River confine flows to a narrow corridor. These levees reduce floodplain deposition of sediments during moderately high flows, but very high flows which overtop levees can deposit tremendous volumes of sediment on the

floodplain. While the precise volumes of floodplain deposition cannot be quantified with existing data, available data do allow approximations based on sediment budgeting (1993 flood) and aerial photographic analysis (2011 flood).

1993 Flood

A sediment budget analysis similar to that presented in the previous section was performed from 1987 to 1994. This time period includes the historic flood of 1993 which deposited tremendous quantities of sediment on the floodplain. The Soil Conservation Service (SCS 1993) reports that the 1993 flood deposited 546 million cubic yards of sediment on the floodplain, though this value includes sediments sourced from significant scour holes in the floodplain as well as the from the channel. Sediment budget analyses Equations 1 and 2 were used to determine the floodplain deposition amount (FP) to be sourced from the channel during the 1993 flood. The ungaged sediment contribution was computed using the *a* and *b* values computed from the analysis described in the previous section. Tables 14 and 15 provide the computed values.

Table 14. Sediment Budget 1987 – 1994 for St. Joseph to Kansas City. Used to solve for the 1993 floodplain deposition.

Budget Term	Mass (tons)
SJ	72,440,000
PR	1,647,389
KR	13,151,706
UnG	8,978,963
D	1,600,786
FP	**51,071,910**
KC	84,240,000
ΔBed	-40,694,638

Table 15. Sediment Budget 1987 – 1994 for Kansas City to Hermann. Used to solve for the 1993 floodplain deposition.

Budget Term	Mass (tons)
KC	84,240,000
GR	7,039,551
CH	234,738
OS	1,475,300
GS	1,678,128
UnG	14,977,292
D	20,980,378
FP	**98,220,908**

HR	84,240,000
ΔBed	-152,526,276

This analysis computes 149 million tons of channel sediments deposited on the floodplain during the 1993 flood from St. Joseph, MO to Hermann, MO. Extending the analysis to the entire model space with the same overall tons/mile rate of deposition = 212,422,000 total tons of floodplain deposition during the 1993 flood.

2011 Flood

The floodplain deposition amount for the 2011 flood was computing following the same analysis used in USACE (2017), which is the aerial extend of sand deposition from Alexander et. al, (2013) times the suggested minimum depth of 2 ft. See Figure 29.

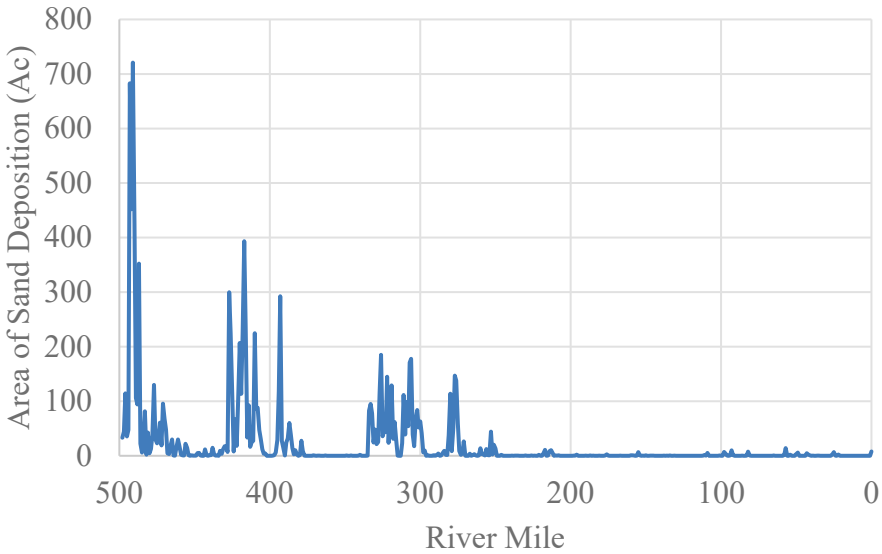

Figure 29. Acreage of Floodplain Sand Deposition from the 2011 flood. Data from Alexander et. al (2013).

The 1993 and 2011 flood events offer two data points from which to interpolate and extrapolate floodplain deposition to other floodplain deposition events. This was accomplished by creating rating curves of the type $FP = aQ^b$, where Q = the daily flow in the mainstem Missouri River and *a* and *b* were chosen such that the total floodplain deposition over the flood event was correct for both the 1993 and the 2011 floods. For flows below a threshold, FP was assumed zero. Table 16 provides the parameters.

Table 16. Parameters Used for Floodplain Deposition

Floodplain Equation	Gage(s)	Flow Threshold (cfs)	a	b
#1	Rulo	160,000	5.84E-08	2.43
#2	St. Joseph	200,000	3.65E-06	2.43
#3	St. Joseph + Platte River	200,000	3.65E-06	2.43
#4	Waverly	200,000	1.22	1.21
#5	Boonville	260,000	1.22	1.21
#6	Boonville	260,000	2.53	1.21

The sediment loads so calculated were entered into the model as lateral loads at discrete locations which correspond to the locations of the 2011 floodplain deposition. Several of the computed loads were split to two cross section locations to better distribute the effect of floodplain deposition. Table 17 indicates the lateral loads entered into the HEC-RAS model. In future projects, the same locations for floodplain deposition seen in the 2011 flood are used for any flood that exceeds the flow thresholds.

Table 17. Source of Lateral Loads for Floodplain Deposition

RAS RS	Entered into RAS
492.5	Eq#1 * 75%
478.4	Eq#1 * 25%
427.13	Eq#2
410.01	Eq#3
325.2	Eq#4 * 50%
301.97	Eq#4 * 25%
279.13	Eq#4 * 25%
187.55	Eq#5 * 50%
133.66	Eq#5 * 50%
88.92	Eq#6 * 50%
20.66	Eq#6 * 50%

Table 18 indicates that the model inputs closely match the best computed values for the 1993 and 2011 flood. Figure 30 presents the computed floodplain deposition and the location/magnitude entered into the model for the 2011 flood event. Values are negative because they draw sediment from the channel.

Table 18. Computed Floodplain Deposition vs. Included Model Floodplain Deposition

Reach	1993		2011	
	Computed (tons)	Model (tons)	Computed (tons)	Model (tons)
SJ to KC	-56,847,829	-56,751,019	-14,864,605	-14,832,221
KC to HR	-102,116,528	-101,748,539	-13,454,765	-13,406,075
Full Model	-225,539,173	-225,621,716	-45,695,231	-45,915,488

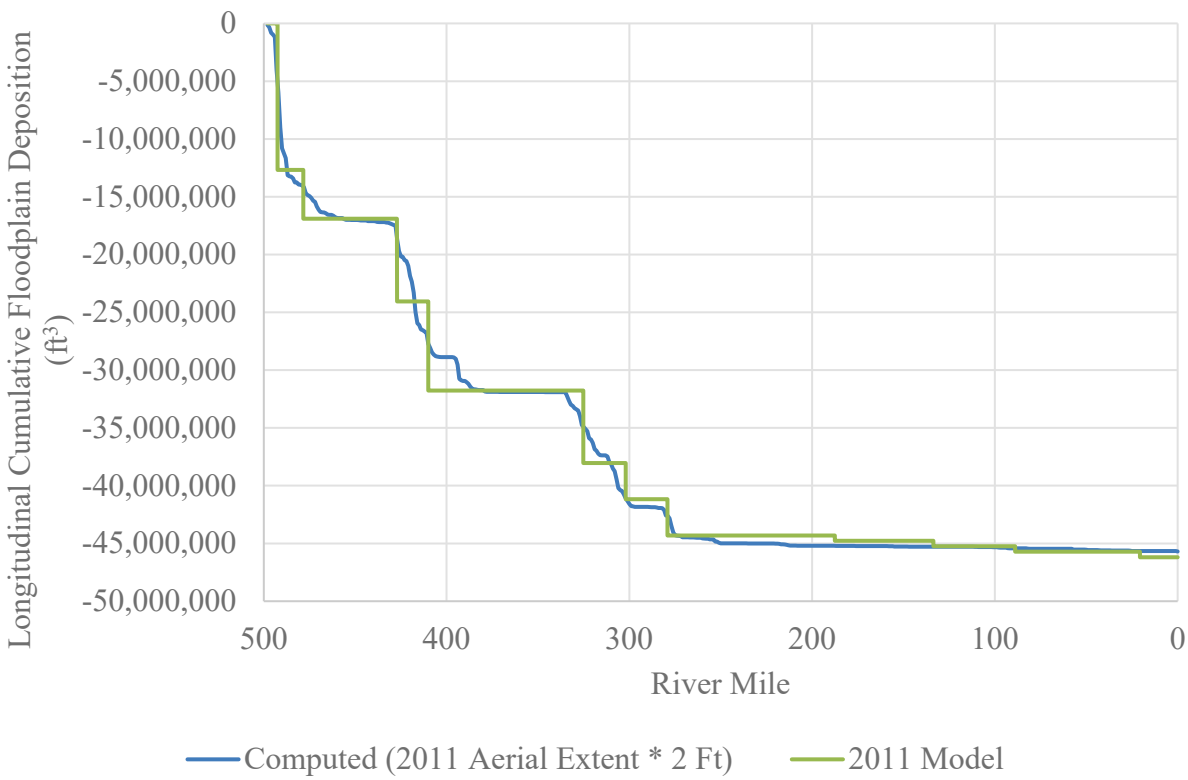

Figure 30. Floodplain Deposition in the Model During the 2011 Flood

3.5 Model Parameters

Model parameters include sediment transport formula, bed mixing algorithm, and computational time steps. These model parameters are described in the following paragraphs.

Sediment Transport Formula

Multiple sediment transport formula were tested, including Laursen-Copeland, Meyer-Peter and Muller, Toffaleti, and Yang. The Toffaleti (1968) sediment transport formula was selected to

compute the sediment transport capacity due to its applicability and history of use on large, sand-bed rivers including the Missouri River (USACE 2017) and because it yielded reasonable initial results. During calibration, it was found that Toffaleti produced insufficient transport during the flood of 2011. To increase the transport capacity at high flows, the combined Toffaleti/MPM function was used with a coefficient of 1 and a power of 1.5. This provides slightly more transport capacity, particularly at high flows. The Toffaleti fall velocity method was also used. HEC (2010) details the Toffaleti computational procedure.

Bed Mixing Algorithm

Two bed mixing/armoring algorithms were tested: Exner 5 and Exner 7. Exner 7 produced excessive degradation compared to the prototype and was not selected. Exner 5 yielded reasonable results for total bed degradation and was selected for use in the model.

Computational Increment

The computational increment was set based on the flow rate. It ranges from 24 hr when flow is less than 60,000 cfs to 30 min when flow exceeds 200,000 cfs. Bed exchange iterations per time step was set to 10, the HEC-RAS default.

4.0 Calibration/Verification

The principle calibration period runs from Aug 1, 1994 to Oct 1, 2009. This time period includes a range of high and low flows and is most representative for future prediction. Water surface elevations at multiple gages, sediment loads, and repeat cross sections in 2007 and 2009 offer robust calibration data over this period. A second time period from Oct 1, 2009 to July 29, 2014 was also used in calibration. However, because this time period includes the historic Missouri River Flood of 2011 which exhibited unique boundary conditions, this time period serves more as a verification of reasonableness than a second calibration point. The principal parameters which were varied to achieve calibration were the Manning ‘n’ values for the active channel, inter-sill region, and inter-dike region, the flow-based ‘n’ adjustment factors, bed gradation data, the sediment loading from Kansas River and Grand River, and the moveable bed extents. As described in the previous paragraphs, these calibrated initial conditions and boundary conditions have physical basis in measured data.

Early Hydraulic Calibrations

The model bathymetry is from 1994. The calibration period starts in Aug 1, 1994. On Aug 16 and 17, 1994, the water surface was measured at multiple points along the river. These measured water surface elevations are subject to greater error than USGS gage measurements but are still useful to verify the hydraulic model. Figures 31, 32, and 33 illustrate the model agreement to the low water surface elevations collected on August 16 and 17, 1994. The average absolute difference between modeled and measured water surfaces for August 16 and 17 is 0.8 ft. This analysis is similar to a “fixed-discharge, fixed-bed” analysis for a low discharge because it occurs so soon after the model start.

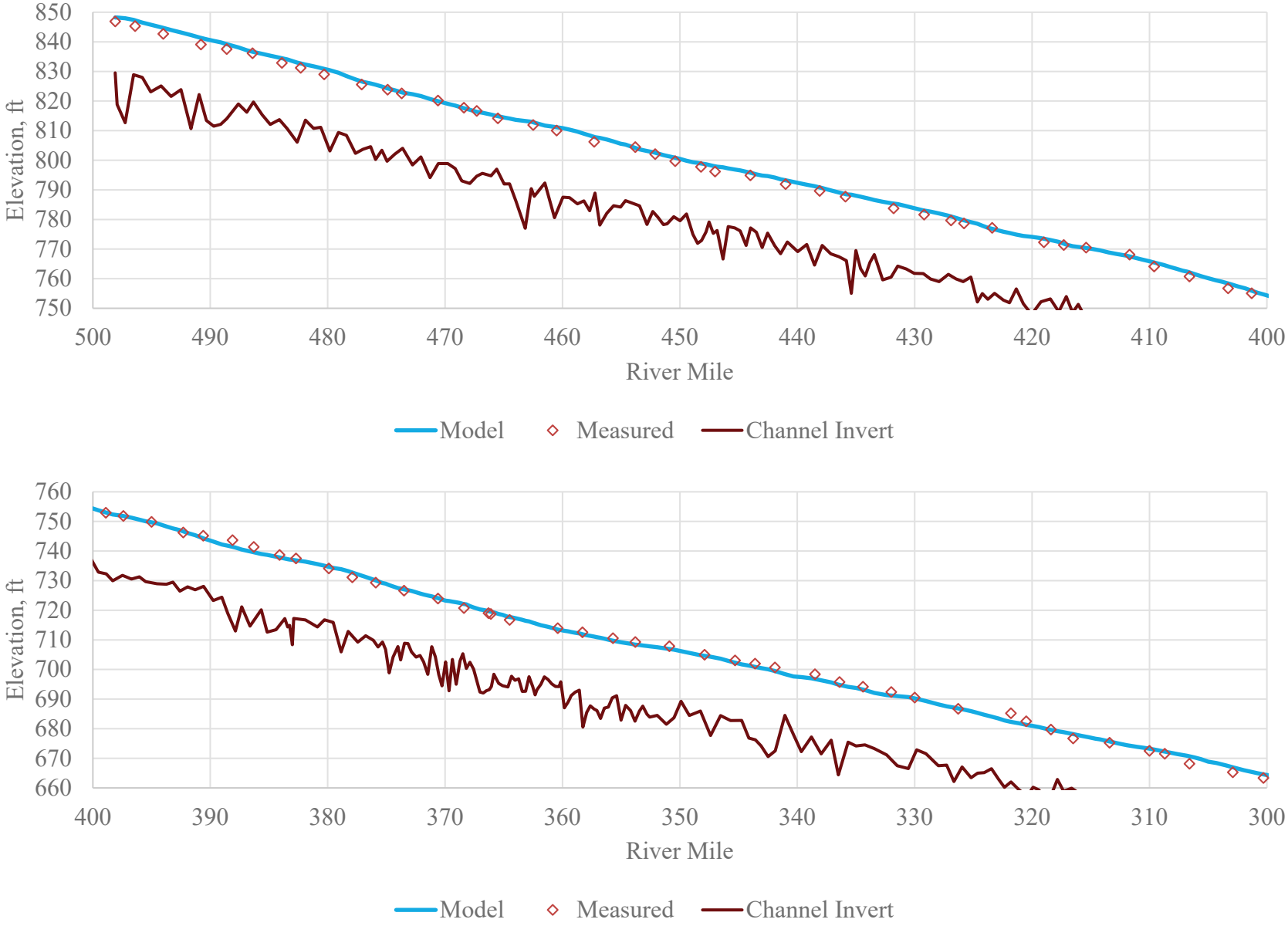

Figure 31. Model hydraulic comparison at low flow: River Miles 500 - 300

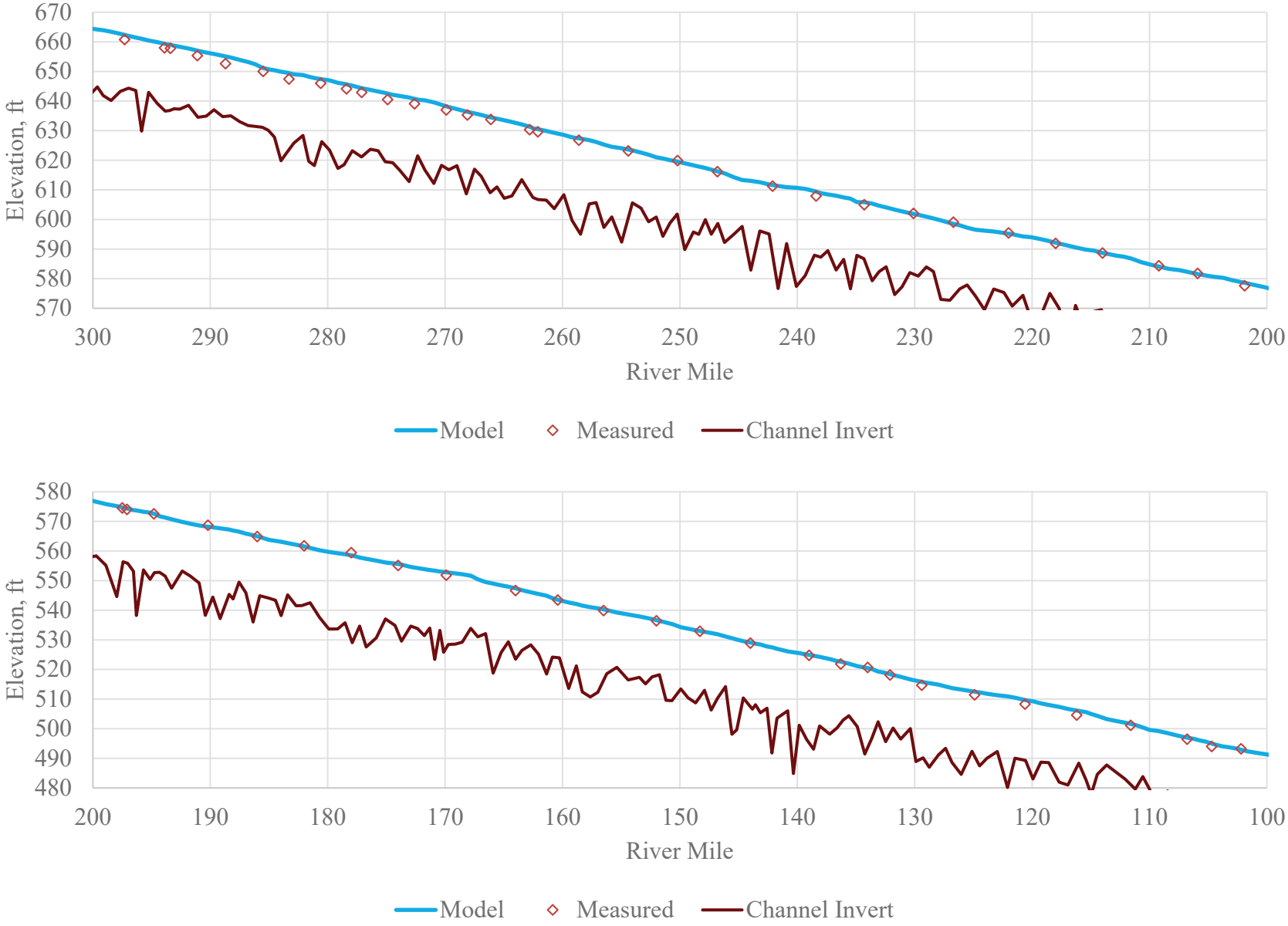

Figure 32. Model hydraulic comparison at low flow: River Miles 300 - 100

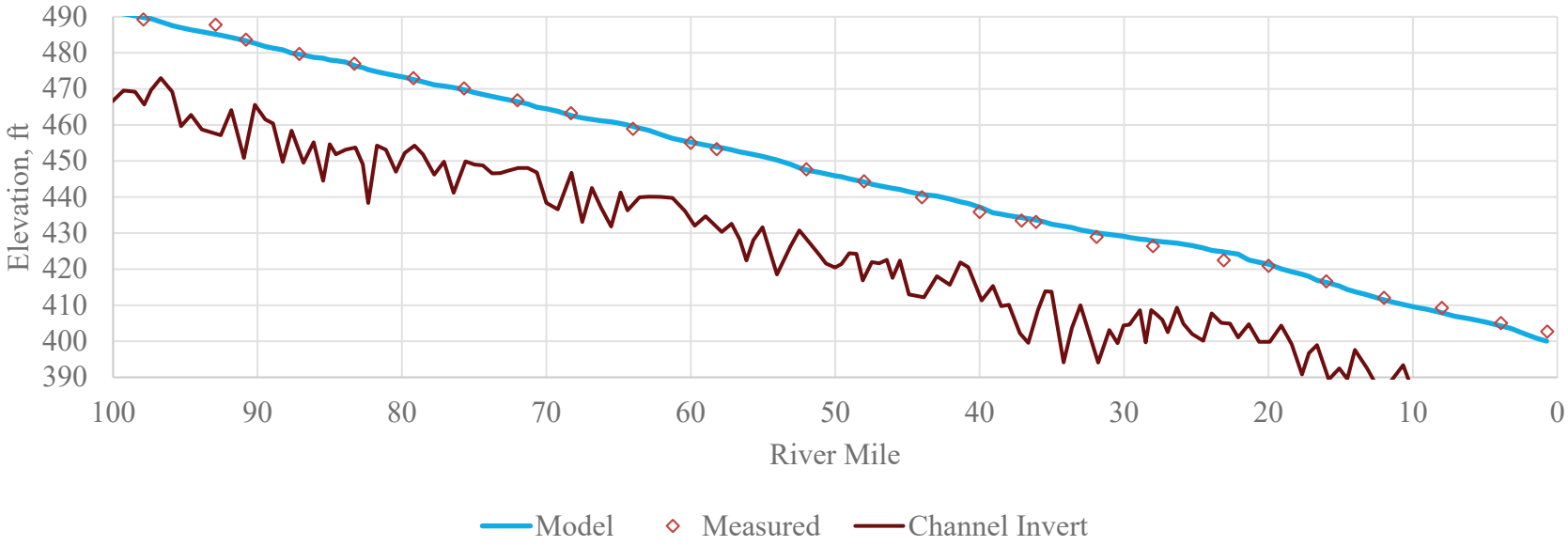

Figure 33. Model hydraulic comparison at low flow: River Miles 100 - 0

A moderately high flow event occurred within a year of the model start. Figures 34 – 39 compare model results to the water surface elevation at the USGS Missouri River gages at St. Joseph, Kansas City, Waverly, Boonville, Herman, and St. Charles, respectively.

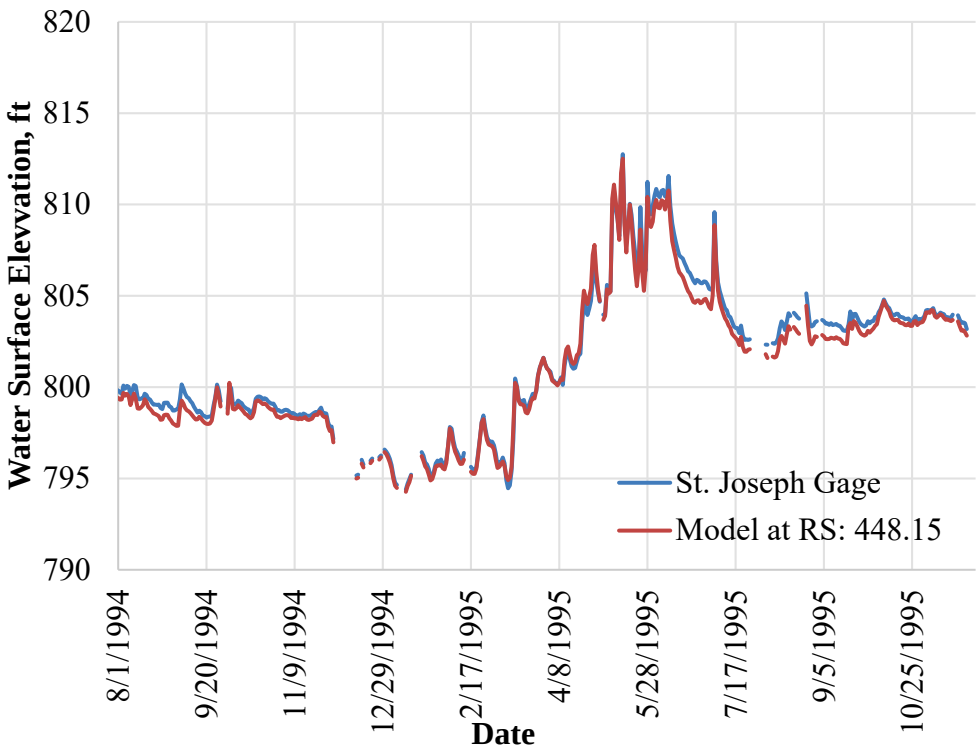

Figure 34. Water surface at the St. Joseph gage during first year of calibration period

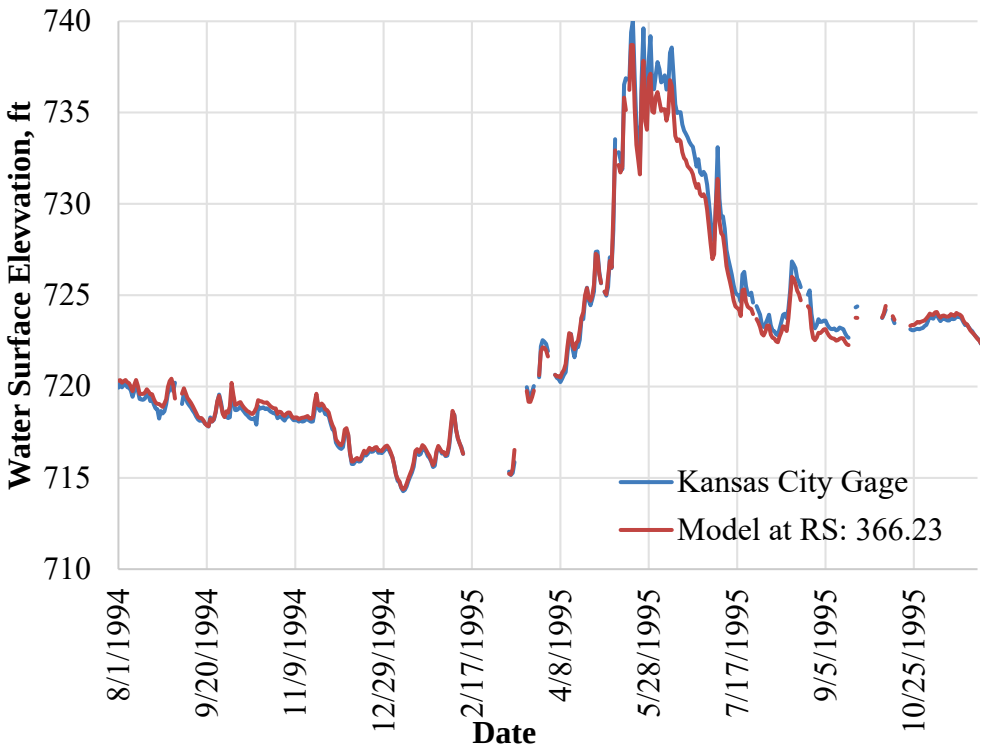

Figure 35. Water surface at the Kansas City gage during first year of calibration period

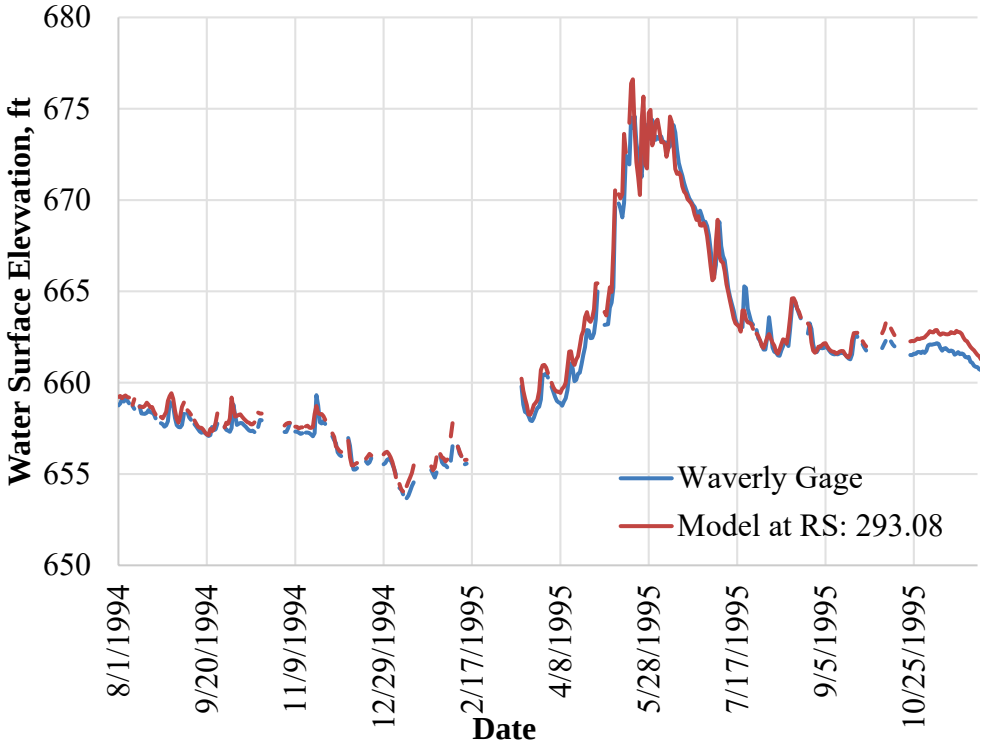

Figure 36. Water surface at the Waverly gage during first year of calibration period

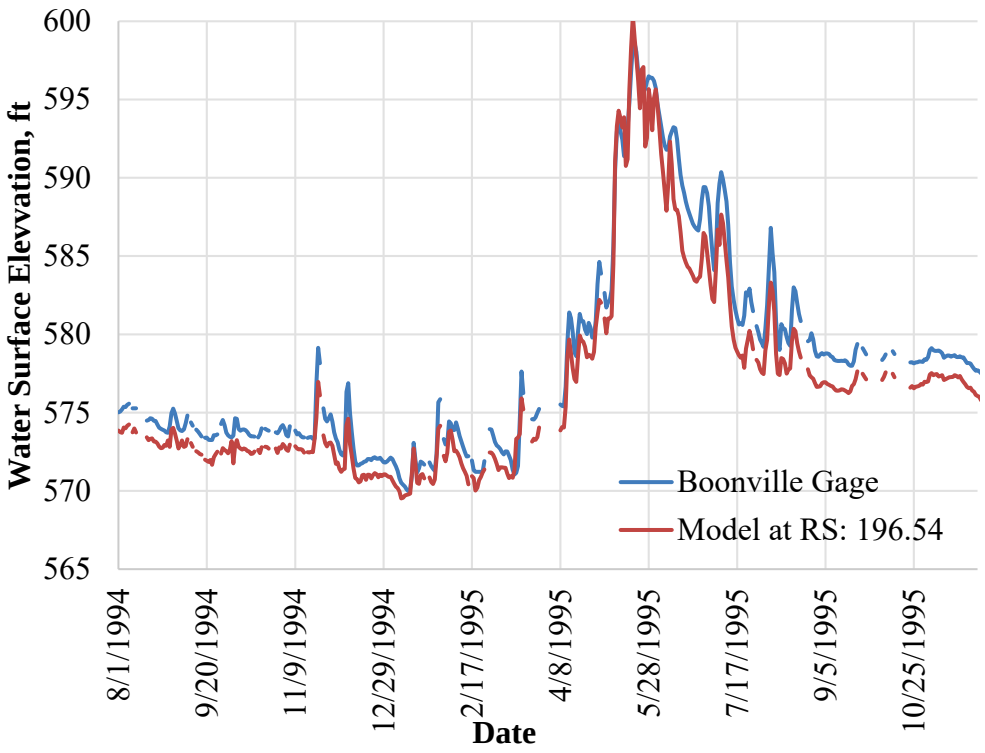

Figure 37. Water surface at the Boonville gage during first year of calibration period

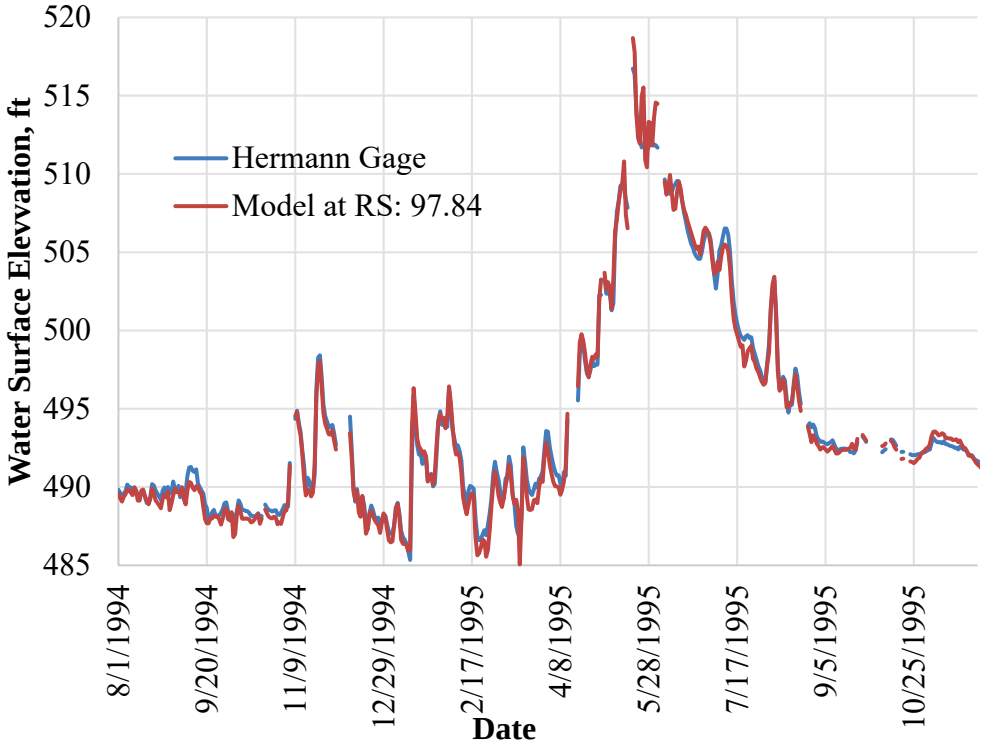

Figure 38. Water surface at the Hermann gage during first year of calibration period

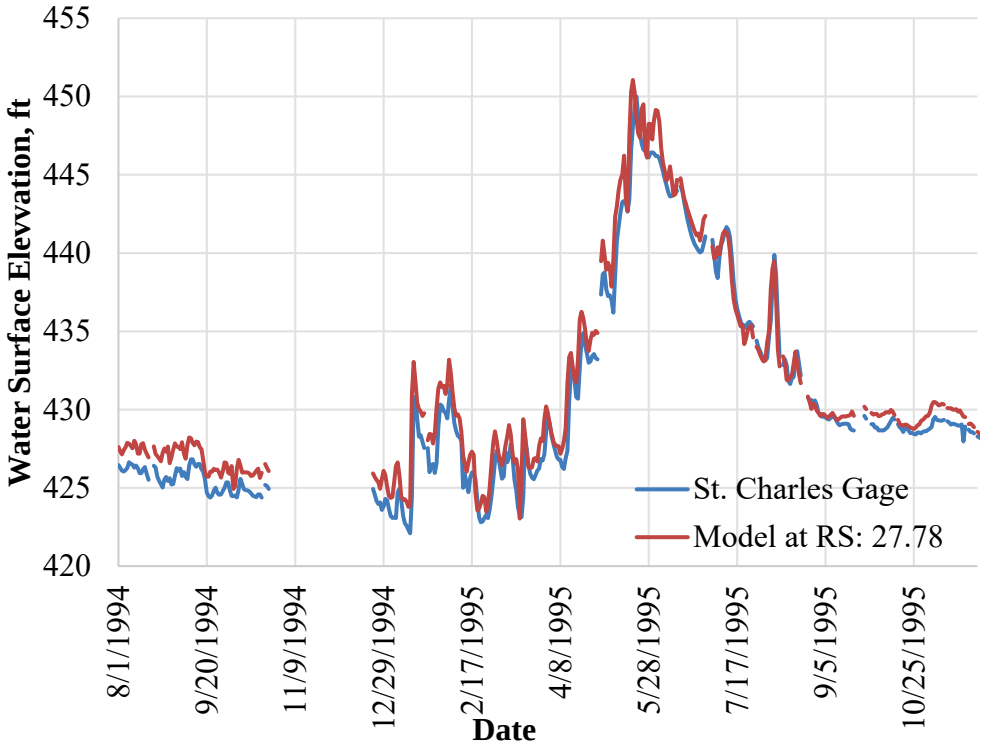

Figure 39. Water surface at the St. Charles gage during first year of calibration period

Output shown in Figures 34 to and 39 is from the mobile-bed model and therefore includes slight bed changes over the course of the first year. Table 19 provides the average absolute difference between the model and measured water surfaces. This is reasonable agreement, given the 498 mile length of this quasi-unsteady model. Attempts to reduce the discrepancy at Boonville were found to cause unreasonable departures in other calibration metrics.

Table 19. Average Absolute Departure from Daily Gage Measurements in the First Year of Simulation (ft)

SJ	KC	WV	BV	HR	SC
0.30	0.46	0.51	1.58	0.53	1.19

Hydraulic Calibration- Long Term

The agreement of the model water surface elevation over the full calibration period (1994 to 2014) is a verification of the temporal fidelity of the sediment modeling. Table 20 indicates small departures over the course of the 20-year simulation.

Table 20. Average Absolute Departure from Daily Gage Measurements over Full Calibration Period -- Aug 1994 to July 2014 (ft)

SJ	KC	WV	BV	HR	SC
-0.03	-0.70	0.15	-0.81	-0.18	0.12

Velocity Calibration

Channel velocities were measured during, soon after, and one year after the 2011 flood via ADCP. As seen in Figure 40, model velocities are in reasonable agreement with measured velocities. The measurements in July of 2012 purposefully measured locations with the greatest dike constriction, which explains some of the higher velocities.

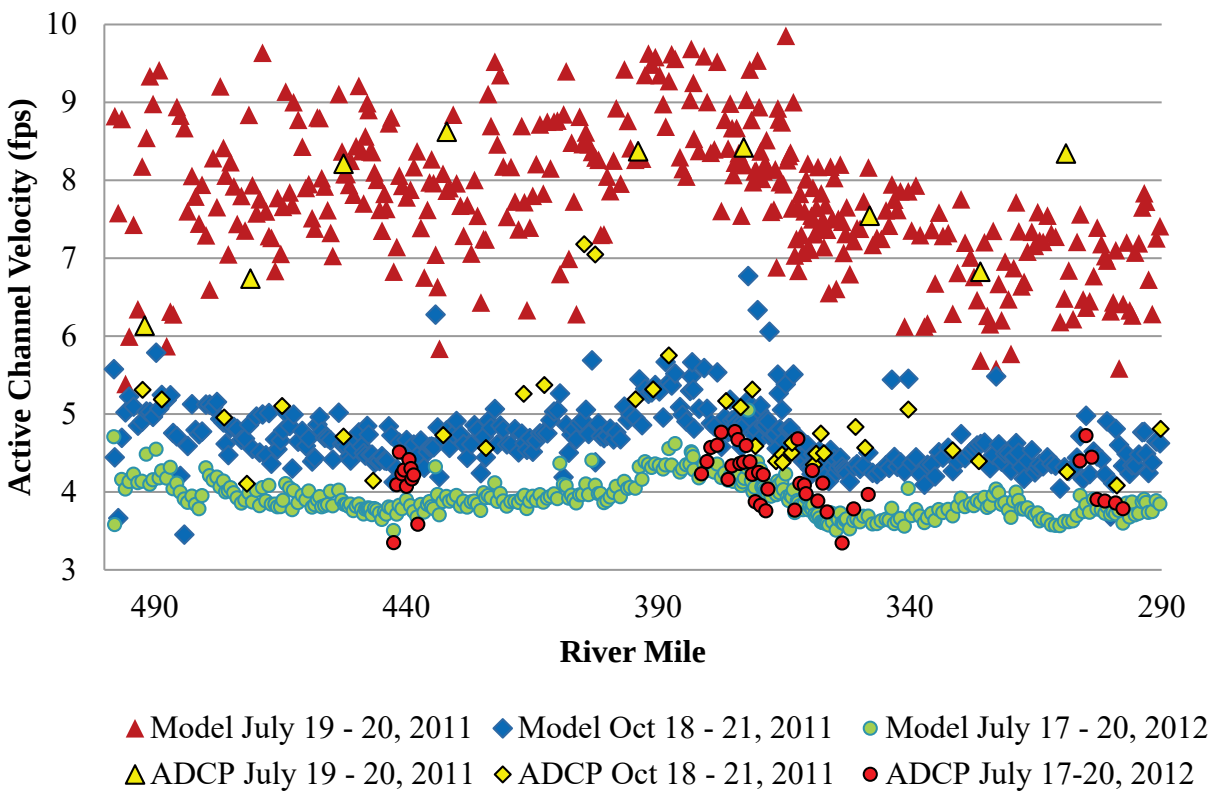

Figure 40. Velocity Comparison

Sediment Load

USGS (Heimann et al., 2010) provides an estimate for annual suspended sediment sand loads through water year 2005 at multiple gages on the Missouri River. Table 21 compares these suspended sediment values plus bedload values from rating curves developed from Abraham et al. (2017) against model values for sediment transport at the gages. The model output agrees quite well with the measured values and is well within the uncertainty estimates presented in (Heimann et al., 2010).

Table 21. Sediment Load Comparison from 01 Oct 1994 to 30 Sep 2005 at Mainstem Gages

Gage	Model	USGS+Bedload	Model/Measured
SJ	113,817,726	116,179,350	0.98
KC	140,280,159	141,362,547	0.99
HR	175,773,026	189,286,266	0.93

Bed Elevation and Mass Calibration

Figure 41 presents bed elevation change at each model cross-section and each measured location. As seen, the model accurately reproduces degradation trends, though both measured data and model output exhibit significant variability and scatter. The nature of the active bedforms on the Missouri River causes individual cross sectional measurements to vary by several feet even without persistent geomorphic change. USACE (2015) finds that 75% of cross sections varied 0.25 ft to 3 ft from 2008 to 2009, but some temporarily rose or fell by as much as 11 ft in a single year.

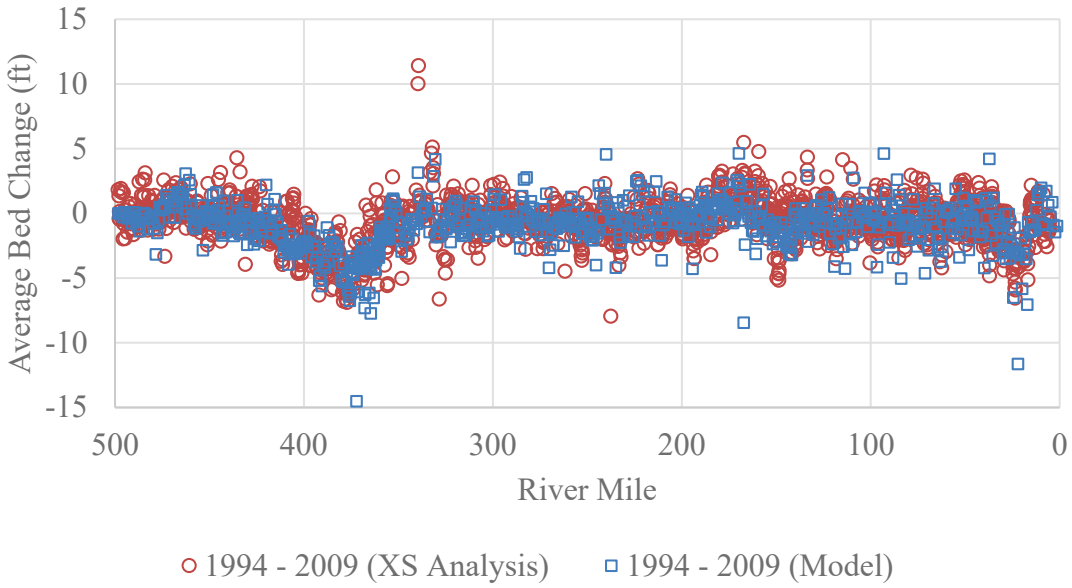

Figure 41. Model vs. Measured Bed Elevation Change 1994 to 2009

With a sufficient number of cross sections, these random fluctuations average out, which makes volume or mass change over reaches especially useful for comparing model to measured output rather than bed change at an individual cross section. Figure 42 plots the longitudinal cumulative mass change for both model and measured cross sections from 1994 to 2009. As seen in Figure 42, the calibrated model closely approximates the magnitude and location of mass change from 1994 to 2009. This time period includes both high flows and low flows and a range of channel mining rates and indicates the strength of the calibration for long-term modeling.

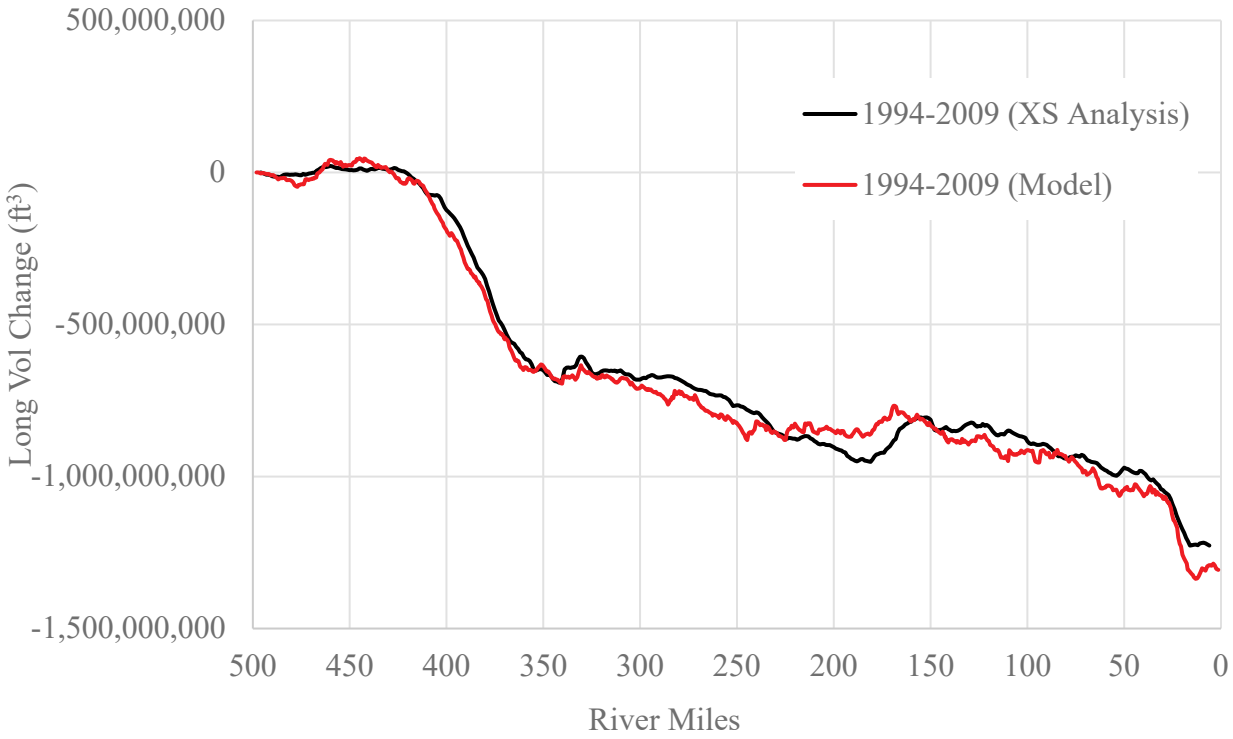

Figure 42. Longitudinal Cumulative Mass Calibration: 1994 to 2009

Figure 43 presents an initial longitudinal cumulative mass change from 2009 to 2014. The 2011 flood and post-flood rebound dominates the bed change over this time period. As seen, the model reasonably reproduced upstream headcut migration visible from RM 500 to aprx. RM 388, as well as the general degradation trend from RM 181 to RM 0. The model did not reproduce the rebound observed from RM 350 to 181. The cross section analysis (depicted in Figure 12) indicates that the sediment eroding from RM 500 to 388 did not simply redeposit downstream; from year 2009 to 2012 the headcut progressed upstream while the downstream channel was also erosional. The rebound occurred after the flood--from 2012 to 2013 and from 2013 to 2014. The mainstem and tributary rating curves developed from USGS data as used in this model do not bring in sufficient sediment to account for the post-flood rebound. Anecdotal evidence suggests that the source of the sediment may be eroding banks or headcutting up tributaries—but these sources have not been quantified.

Including an additional 23 million tons in sediment load from unknown sources following the 2011 event yields Figures 44 and 45. As seen, this provides a better estimate for the post-flood rebound following the 2011 event. To avoid negative bias in future projections, the 23M will be added in after a repeat of the 2011 event in the period of record. As Figure 12 does not indicate a similar rebound following the 1993 flood, the extra tonnage is not added following the 1993 flood or other floods in the projection period.

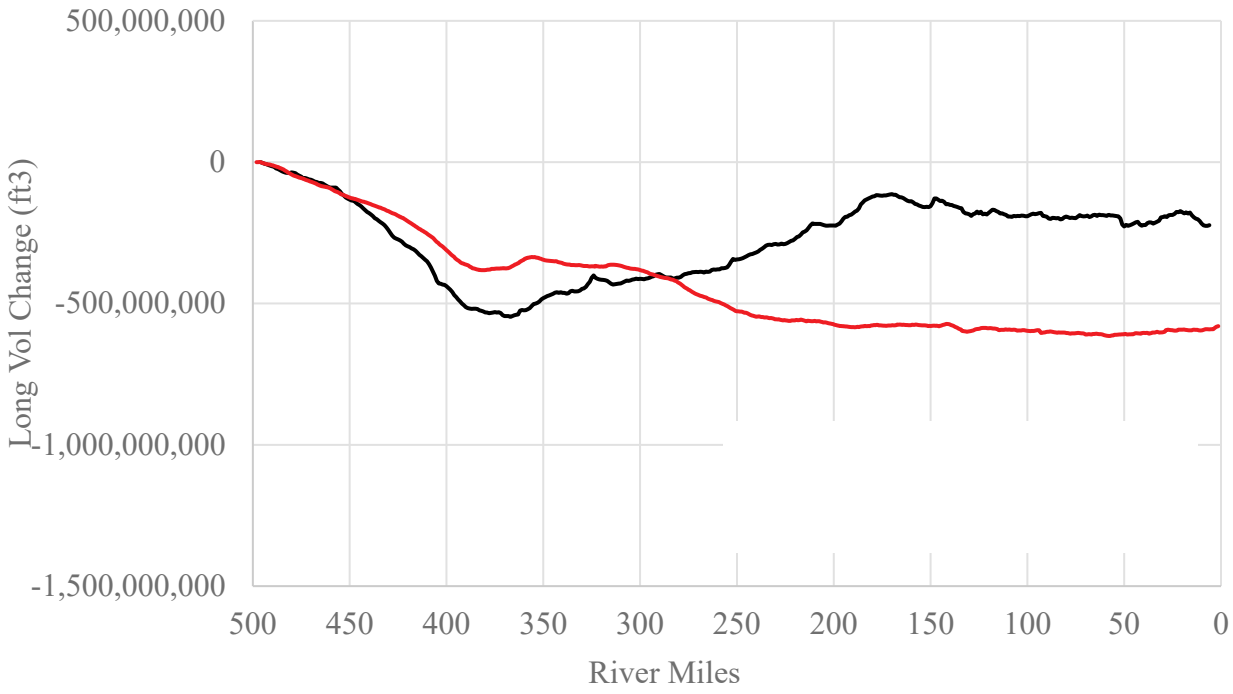

Figure 43. Longitudinal cumulative mass calibration: 2009 to 2014 with no additional post-2011 sediment

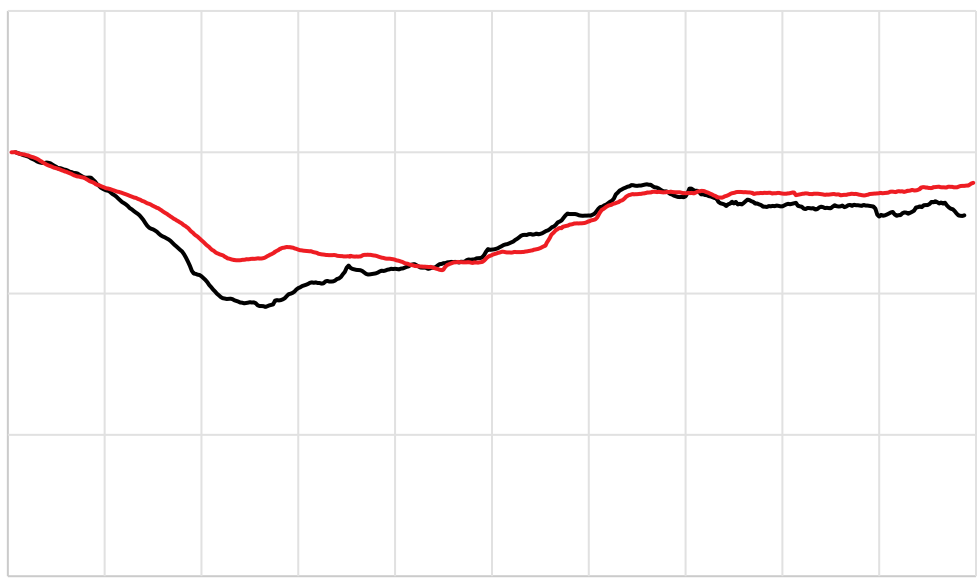

Figure 44. Longitudinal Cumulative Mass Calibration: 2009 to 2014 with additional 23M tons of post-2011 flood sediment

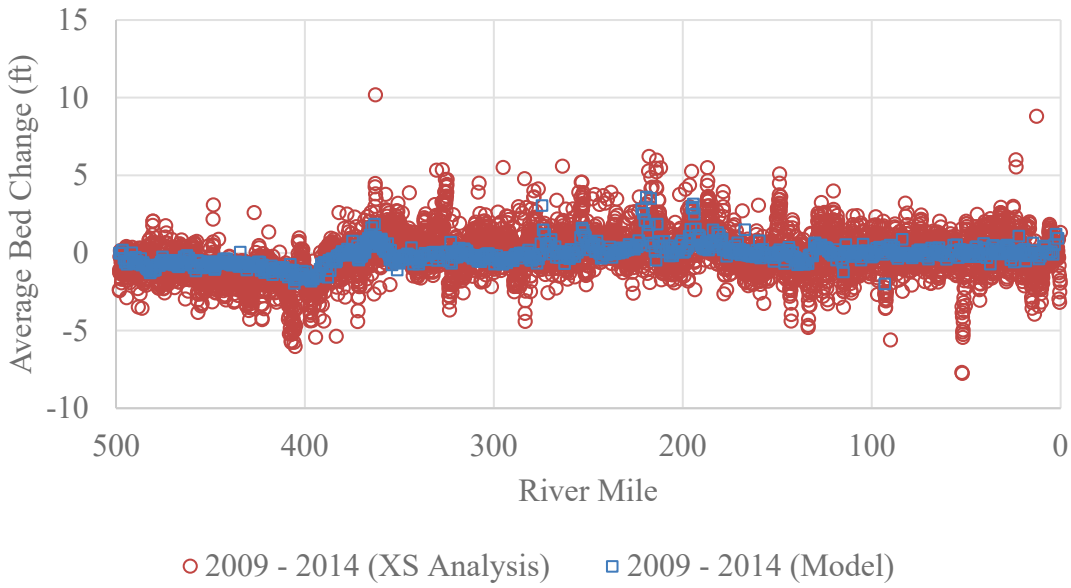

Figure 45. Model vs. Measured Bed Elevation Change 2009 to 2014. Model output includes 23M tons of post-2011 flood sediment.

Conclusion

This report described the mobile-bed model developed for modeling bed change on the lower 500 miles off the Missouri River. It served as an orientation to the inputs, assumptions, and modeling choices that have occurred. The model outputs for water surface, velocity, sediment transport, bed elevation change, and bed volume change over the calibration period reasonably match the prototype using realistic initial conditions and boundary conditions and appropriate model parameters. The model has been calibrated to the Missouri River and is deemed suitable use in MRRP planning.

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April 23, 2020

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

Commercial sand dredgers provide most of sand material for the construction industry. The sand goes into concrete and asphalt that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades.

Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Jon Ohmes

CEO Champion Precast Inc.

April 23, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

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Sincerely,

Christy Martin

Christy Martin
Executive Director

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Hot Mix
Materials, Inc.

2701 E. 85th St.
Kansas City, MO 64132

Phone: 816 333-1200
Fax: 816 333-1203

April 23, 2020

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

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Very truly yours,

M. Allen Conway, GM

M. Allen Conway

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

April 23, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

Commercial sand dredgers provide most of sand material for the construction industry. The sand goes into concrete that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades. Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits. The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River. The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Daniel B. Bruns
President

cc:

Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

755 S. New Ballas Road, Suite 150, St. Louis, MO 63141
www.kienstrareadymix.com
Phone: 314-994-1616
Fax: 314-994-1618

The Monarch Cement Company
P O Box 1000, Humboldt, KS 66748
Office: 1-800-362-0570
Order Desk: 1-800-221-4374

Jay Taff
District Sales Manager
P O Box 4664
Springfield, MO 65808
Cell: 417-839-7429

April 23, 2020

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Jay Taff

---

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

PETERSON GRAVEL & READY MIX, INC.
WEST BUSINESS 60 EXIT -- 8727 OUTER ROAD
P.O. BOX 409
MOUNTAIN GROVE, MISSOURI 65711

PHONE: (417) 926-4375
TOLL-FREE: 1-800-771-RMIX (7649)
FAX: (417) 926-5205

April 23, 2020

Matt Shively, Regulatory Project Manager
Matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

RE: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Lease Company; and J.T.R., Inc.; hereinafter "Dredgers".

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Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

We support the Corps re-issuing permits for commercial sand dredging on the Missouri River. Thank you in advance for your consideration of this important request.

Sincerely,

Matt Peterson

Cc: Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102-0176

DREDGING INC.
dba **Scott's Concrete**
#1 Gobbler Road • Camdenton, Missouri 65020
573-346-2450 FAX **573-346-5026** Toll Free **888-346-2450**

April 23, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Joe E. Martin, President

DREDGING INC.
dba **Scott's Concrete**
210 Gobbler Road • Camdenton, Missouri 65020
573-346-2450 FAX **573-346-5026** Toll Free **888-346-2450**

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Capital Sand Company, Inc.
P.O. Box 104990
Jefferson City, Missouri 65110-4990
(573) 634-3020
Fax # (573) 636-5734

"Aggregates for the Construction Industry"

April 24, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice issued March 18, 2020, and is in support of the permit applications of Capital Sand Company, Inc.

Capital Sand supports commercial sand dredging on the Missouri River. Commercial sand dredging from the Missouri River provides over 80% of the sand necessary for the production of concrete, asphalt and other aggregate materials within the boundaries of the State of Missouri. This sand is also utilized in industries other than concrete and asphalt construction, which allows for a much wider distribution area outside of the State of Missouri.

It helps drive the economy of the State and provides jobs, both directly and indirectly, to its citizens.

Missouri River sand is of the highest quality and supports excellent construction.

Capital Sand, in extracting sand from the River and transporting sand on the River, has made appropriate accommodations as part of its permits for protection of the endangered pallid sturgeon. Capital Sand has complied with all permit conditions relating to the rights granted it by the State and the United States.

The bed of the River is owned by the citizens of Missouri. The citizens have the right to benefit from their asset. Restrictions on tonnage deny the citizens of Missouri access to their assets and to the use and utilization of their owned resources.

Previous permits have taken steps to contain the issue of bed degradation. Restrictions on the acquisition of sand in the areas permitted to Capital Sand should be relaxed in favor of greater tonnage.

Capital Sand has requested an increase in tonnage for its operations in the Waverly segment. Adequate sand resources exist in this area to support an increase in allocation for operations at our Lexington and Missouri City plants. River bed surveys establish that this area adequately recovers from the amount of material extracted in this area. Capital Sand requests an increase of 82,500 tons each year from the current 2020 authorized amount. This is a consistent yearly increase provided in the current permits formula.

Capital Sand has also requested an increase in tonnage for its operations in the Jefferson City segment. Capital Sand requests an increase of 100,000 tons to meet volume demand expectations at the Jefferson City plant.

Consistent with previous discussions, Capital Sand requests that the amount of tonnage provided in its other areas remain as to the last permit cycle. We believe that the data supports this decision.

Capital Sand notes it is the only company forced to make accommodation for other companies' presence in their segments. Tonnages should be fairly allocated based on histories in the area and all tonnage previously requested by Capital Sand should be available.

We support the Corps' use of the previous EIS in making evaluations during this permit cycle. We appreciate the Corps' efforts to continue commercial sand dredging and navigation on the Missouri River.

Very truly yours,

CAPITAL SAND COMPANY, INC.

Jason Branstetter
Operations Manager

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

MISSOURI FARM BUREAU FEDERATION
P.O. Box 658, 701 South Country Club Drive, Jefferson City, MO 65102 / (573) 893-1400

April 24, 2020

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Dear Mr. Shively:

Our farmers and ranchers depend on a sound infrastructure system to continue to deliver our products to the marketplace each and every day. Access to high-quality materials is key to a first-class infrastructure system. Commercial sand dredgers provide most of the sand material for the construction industry. The sand goes into concrete that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and is an important component in infrastructure projects in our region.

Commercial dredgers are seeking re-issuance of permits to continue their work. Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits, including environmental provisions to protect the endangered pallid sturgeon.

In addition to compliance with previous permits, the Dredgers are a good neighbor in their respective communities, by providing employment, paying local taxes, and playing an active role in community betterment.

We support the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Blake Hurst
President, Missouri Farm Bureau

President:
Mike Kappel - *Byrne & Jones Construction*

Vice-President:
Mike Harman - *Plattin Creek Excavating*

Secretary/Treasurer:
Jennifer Bouquet - *J & J Boring*

Executive Director:
Terry Briggs

SiTE IMPROVEMENT ASSOCIATION

Representing:
Concrete Contractors
Earthmoving Contractors
Highway/Bridge Contractors
Landscaping Contractors
Asphalt Paving Contractors
Sewer/Utility Contractors
Specialty Contractors

April 24, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Dear Mr. Shively:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment. And, in light of the current coronavirus pandemic, dredgers have kept their operations open, providing for all the above-mentioned benefits to federal, state and local governments.

2071 Exchange Drive | St. Charles, MO 63303 | Phone: (314) 966-2950 | Fax: (314) 966-2999

www.sitestl.org

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

Re: Missouri River Commercial Sand Dredging Permits

SITE Improvement Association, representing some 225 contractors and businesses associated with the construction industry in eastern Missouri, supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Terry W. Briggs

Terry W. Briggs, Executive Director

SITE Improvement Association.

---

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

AGRI Services
OF BRUNSWICK LLC
PO Box 38 - Brunswick, Missouri - 65236
www.agriservices.com

April 27, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

Brunswick West - 660-549-3351 - 800-279-4229 - FAX 660-549-3442
Brunswick East - 660-548-3177 - 888-548-3177 - FAX 660-548-3541
Mendon - 660-272-3213 - 800-272-7501 - FAX 660-272-4116
Agland - 660-258-7493 - FAX 660-258-2594

AGRI Services
OF BRUNSWICK LLC
PO Box 38 - Brunswick, Missouri - 65236
www.agriservices.com

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Kevin Holcer
General Manager

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Brunswick West - 660-549-3351 - 800-279-4229 - FAX 660-549-3442
Brunswick East - 660-548-3177 - 888-548-3177 - FAX 660-548-3541
Mendon - 660-272-3213 - 800-272-7501 - FAX 660-272-4116
Agland - 660-258-7493 - FAX 660-258-2594

ALLEN READY MIX CONCRETE, INC.
BRAD OR KENNA FLOREA
28693 268TH STREET
MARYVILLE, MO 64468
PHONE: (660)582-3580
FAX: (660)582-5100
EMAIL: AllenConcrete@hotmail.com

April 27, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Kenna Florea, President

Kenna Florea, President

R.L. Hannah & Sons Trucking, Inc.
P.O. Box 508
28110 S.W. Outer Rd.
Harrisonville, MO. 64701-0508
816-380-4510
Fax: 816-884-3176

Sharon@rlhannahtrucking.com
April 27, 2020
VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits
Gentlemen:
This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc. Hereinafter "Dredgers." Commercial sand dredgers provide most of sand material for the construction industry. The Sand goes into concrete that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades.

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The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.
The Dredgers provide a source of employment and pay taxes in their respective communities.
They participate in their local communities, providing donations and other contributions to civic Betterment. The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.
Very truly yours,

Sharon Green
VP

Cc: Missouri Department of Natural Resources
P O Box 176
Jefferson City, Mo. 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson St., Suite 430
Topeka, Ks. 66612-1367

P.O. Box 104855
Jefferson City, MO 65110-4855
Phone: (573) 635-6071 **FAX: (573) 635-6134**

April 27, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the Missouri River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The Missouri Asphalt Pavement Association (MAPA) supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Dale A. Williams

Dale A. Williams, PE
Executive Director

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

April 27, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River. The Dredgers provide a source of employment and provide much needed tax revenue to their local communities. They participate in their local social and civic events, providing donations and other contributions to the benefit of the entire community.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

President/CEO
Missouri Soybean Association
Missouri Soybean Merchandising Council

cc: Missouri Department of Natural Resources

PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

April 28, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Todd M. LaTorella, P.E.
Executive Director
MO/KS Chapter, American Concrete Pavement Association

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

EMERY SAPP & SONS

April 28, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: **Missouri River Commercial Sand Dredging Permits**

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

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The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Shawn N. Sapp, Executive Vice-President
Emery Sapp & Sons, Inc.

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

MissouriCorn GrowersAssociation
PLANTING OPPORTUNITY

MISSOURI CORN GROWERS ASSOCIATION
3118 Emerald Lane • Jefferson City, MO 65109

April 28, 2020

Matt Shively, Regulatory Project Manager matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Dear Mr. Shively,

On behalf of the Missouri Corn Growers Association (MCGA), I am writing in response to the Public Notice dated March 18, 2020, regarding permits requested by various dredging business along the Missouri River. Commercial sand dredgers serve a critical purpose on our river system and provide most of the sand material for the construction industry. As it pertains to corn producers in the state of Missouri, this is important for several reasons.

First, the sand material provided for highway construction directly impacts our state's rural roads and surface transportation infrastructure. As I work to get my harvest to market, I depend on the road system and realize the value in maintaining it. Secondly, dredging helps with flood mitigation. While this is not the underlying reason for commercial sand dredging, it is safe to say without dredging the flooding we have experienced would be considerably more damaging in years like 2011 and 2019. Lastly, commercial sand dredging helps to enable commerce on our inland waterways. This is also important to me as a corn farmer when I consider the various modes of transportation my harvest takes getting to market.

Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits. The permits provide for an accommodation of the endangered pallid sturgeon. The dredgers present no other impacts to any other endangered or threatened species on the River.

The Missouri Corn Growers Association supports the Corps' re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Mike Moreland
President
Missouri Corn Growers Association

Phone: (573) 893-4181 • Fax: (573) 893-4612 • Web: www.mocorn.org

Local 513 Hoisting and Portable
International Union of Operating Engineers, AFL-CIO

3449 Hollenberg Drive
Bridgeton, Missouri 63044
(314) 739-3983
FAX: (314) 739-0457
www.iuoe513.org

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Timothy Sappington
President -
Business Manager

Bill Suddarth
Vice-President

Steve Farrar
Recording Secretary

Steve Straatmann
Financial Secretary

Byron Saunders Sr
Treasurer

Andy Schalk
Executive Board

Mike Femmer
Executive Board

April 29, 2020

U.S. Army Corps of Engineers
Mr. Matt Shively – Regulatory Project Manager
matthew.s.shively@usace.army.mil
Kansas City Regulatory Office
Kansas City, MO 64106

RE: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc., Hermann Sand & Gravel, Inc., Holliday Sand & Gravel Company, Con-Agg of Missouri, LLC, Limited Leasing Company, and J.T.R. Inc., hereinafter "Dredgers:.

Commercial sand dredgers provide most of sand material for the construction industry. The sand goes into concrete that provides our roads, bridges, sidewalks, homes, driveways, etc., in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades.

Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Sincerely,

Timothy J. Sappington

Tim Sappington
President/Business Manager
I.U.O.E. Local 513

Local 513 Hoisting and Portable
International Union of Operating Engineers, AFL-CIO

3449 Hollenberg Drive
Bridgeton, Missouri 63044
(314) 739-3983
FAX: (314) 739-0457
www.iuoe513.org

®72

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President -
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cc: Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102-0176

Kansas City Department of Health & Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

HERMANN Sand&Gravel, Inc.

MRT MISSOURI RIVER TOWING

April 30, 2020

Via Email and U.S. Mail

Matthew Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106
By email: Matthew.S.Shively@usace.army.mil

Re: Missouri River Commercial Sand Dredging Permit, Hermann Sand & Gravel, Inc.

Dear Mr. Shively,

This letter is in response to your Public Notice issued March 18, 2020, and is in support of the permit applications of Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.R.T, Inc.; hereinafter "Group."

Hermann Sand & Gravel, Inc., through the Group, supports commercial sand dredging on the Missouri River. Commercial sand dredging from the Missouri River provides over 80% of the sand necessary to produce concrete within the boundaries of the State of Missouri. Material is also provided to parts of Kansas. It helps derive the economy of the States and provides jobs, both directly and indirectly, to its citizens. It is the major element required for the transportation networks of Missouri and Kansas.

Missouri River sand is of the highest quality and supports excellent construction.

Commercial sand dredging does not cause harm to navigation structures on the River. The Group companies combined are the largest navigators by tonnage on the River. Over the last ten years, commercial sand production and transport represents 91% of all commerce on the River.

Hermann Sand & Gravel, Inc., has made appropriate accommodations as part of its permits and methods for protection of the endangered pallid sturgeon. Hermann Sand & Gravel, Inc., has

Telephone: 573-486-2913 • P.O. Box 261 • Hermann, Missouri 65041 • Fax: 573-486-1407
Hermannsand.com • info@hermannsand.com

complied with all permit conditions relating to the rights granted to it by the State and the United States to protect fish.

Riverbed conditions prior to 2019 demonstrate that the adaptive management process incorporated into the current permit is successful and should continue. In fact, the process demonstrates that reasonable tonnage increases have been justified and should be permitted in the new permit cycle.

Hermann Sand & Gravel, Inc, through the Group is repeatedly on record regarding MRRP IRCs, and that USACE efforts to improve survey data should not impact the permits for commercial sand dredging in any way.

The previous permits have demonstrated successful performance and an accurate EIS expectation.

Hermann Sand & Gravel, Inc., in its current application has requested to continue mining in the St. Charles and Jefferson City segments. The requested permit renewal includes the amounts of 144,000 tons in each segment for a total of 288,000 tons. We believe that previous survey data demonstrate that the River can sustain these requested amounts.

Hermann Sand & Gravel, Inc., as part of the Group, requests that the Corps issue new 404 permits and States accompany that decision by issuance of 401 certifications consistent with the applications submitted by the members of the Group.

Very Truly Yours,
Hermann Sand Gravel, Inc.

Steven W Engemann

Steven Engemann, President

Cc: Missouri Department of Natural Resources
P.O. Box 176
Jefferson City, MO 65102-0176

KAPA
Kansas Aggregate Producers' Association
800 SW Jackson Street, Suite #1408
Topeka, Kansas 66612
Phone: 785-235-1188 Website: www.kapa-krmca.org

April 30, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
matthew.s.shively@usace.army.mil
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

Thank you for the opportunity for the Kansas Aggregate Producers Association (KAPA) to provide comments in support of reissuance of commercial dredging permits on the Lower Missouri River.

Commercial sand dredging on the Missouri River provides an extremely cost-effective way of supplying the sand material necessary for the infrastructure and building construction that creates the best quality of life for citizens of Kansas and Missouri. Producing that sand at the lowest price possible results in lower costs of construction which positively impacts the bottom line of state and local government infrastructure budgets as well as the price paid by homeowners and businesses for residential, commercial and industrial construction. All those advantages are gained from dredging Missouri River Sand.

Dredging has taken place on the Missouri River under a permit structure for many years. By all indications, the dredging of sand under those associated permit requirements has provided a controlled means of realizing the positive economic impacts to society while still protecting the elements of a river environment important to the public at large. For example, the existing permits provide for an accommodation of the endangered pallid sturgeon.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

KAPA believes a strong case is made for continuing to allow permitted sand dredging on the Lower Missouri River and ask the Corps to consider as such.

Thank you.

Jerry Younger, P. E.
Managing Director

---

c: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

Lathrop GPM

Lathrop GPM LLP
lathropgpm.com

314 East High Street
Jefferson City, MO 65101
Main: 573.893.4336

David A. Shorr
Partner
david.shorr@lathropgpm.com
573.761.5005

April 30, 2020

VIA EMAIL AND U.S. MAIL
matthew.s.shively@usace.army.mil

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Dear Mr. Shively:

This letter is in response to your Public Notice issued March 18, 2020, and is in support of the permit applications of Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Group."

The Group supports commercial sand dredging on the Missouri River. Commercial sand dredging from the Missouri River provides over 80% of the sand necessary to produce concrete within the boundaries of the State of Missouri. Material is also provided to parts of Kansas. It helps drive the economy of the States and provides jobs, both directly and indirectly, to its citizens. It is the major element required for the transportation networks of Missouri and Kansas.

Missouri River sand is of the highest quality and supports excellent construction.

Commercial sand dredging does not cause harm to navigation structures on the River. The group companies combined are the largest navigators by tonnage on the River. Over the last ten years, commercial sand production and transport represents 91% of all commerce on the River.

The dredgers who move sand from the River and on the River have made appropriate accommodations as part of their permits and methods for protection of the endangered pallid sturgeon. In general, all members of the Group have complied with all permit conditions relating to the rights granted them by the State and the United States to protect the fish.

The bed of the River is owned by the citizens of Missouri and Kansas. The citizens have the right to benefit from their asset. Restrictions on tonnage deny the citizens of Missouri and Kansas access to their asset and to the use and utilization of their owned resource.

Previous permits have taken steps to contain the issue of bed degradation. Restrictions on the acquisition of sand throughout the River should be relaxed in favor of greater tonnage. It remains the position of the Group that the major causes of bed degradation are the containment of sediment behind the dams in the reservoirs and the failure to properly and adequately maintain training structures in the Bank Stabilization and Navigation Project (BSNP). It is well documented that the River is "sediment starved" as a result of the presence of the mainstem reservoirs and the BSNP. Those who claim the restricted tonnage allowed to be removed by commercial sand dredging has a significant impact in any segment are misinformed or relying on "old news".

Surveys in 2014 and 2018 demonstrate that targeted tonnage reductions, targeted "hot spot" restrictions and adaptive management stabilized bed degradation and that many areas had accretion. The present cooperative adaptive management strategy remains positive.

Bed conditions prior to 2019 demonstrate that the adaptive management process incorporated into the current permits is successful and should continue. In fact, the process demonstrates that reasonable tonnage increases are justified and should be permitted in the new permit cycle.

To the extent the bed has been modified by the Flood of 2019, we believe the bed will self-correct as it is designed to meet the requirements of USACE, and any failure to self-correct is a failure of that design. Dredging on the River predates that of the BSNP, which design should have recognized pre-existing human considerations. The channel bed and structures proved remarkably intact following this historic event, with the infrastructure maintaining channel integrity.

We continue to believe and argue that the mobile bed model is not accurate when used in micro conditions such as five-year permitting and that the model should be revised and not used as a surrogate for actual survey data. The USACE efforts to improve actual survey data and increased survey efforts by the agency are the most accountable method for dredge permit performance evaluations.

The Group is repeatedly on record regarding MRRP Interception Rearing Complexes ("IRC"), and that such improvements should *not* impact the permits for commercial sand dredging in any way. We have repeatedly demanded that the regulatory platform for these improvements be revealed in advance of this permitting effort. We have continued to cooperate with the USACE in that regard to advance the experiment. We commend USACE staff on their effort to interact with the commercial sand dredging industry on design and siting efforts. Should the USACE decide to impact commercial sand dredging due to IRC development, it would not be unreasonable to expect a challenge for permit conditions so issued.

The previous permits have demonstrated successful performance and an accurate EIS representation.

We appreciate the efforts of USACE-KCD at dialog and coordination on commercial sand issues.

The Group requests that the Corps issue new 404 permits and the States accompany that decision by issuance of 401 certifications consistent with the applications submitted by members of the Group.

Very truly yours,

Lathrop GPM LLP

David A. Shorr
Partner

DAS/jf

cc: Missouri Department of Natural Resources
PO Box 176
Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367

The American Waterways Operators

1113 Mississippi Avenue, Suite 108
St. Louis, MO 63104

PHONE: 314.308.0378
EMAIL: lmuench@americanwaterways.com

Lynn M. Muench
Senior Vice President – Regional Advocacy

May 1, 2020

Mr. Matt Shively
Regulatory Project Manager
U.S. Army Corps of Engineers
601 East 12th Street
Kansas City, MO 64106

Re: Missouri River Commercial Sand Dredging Permits

Dear Mr. Shively:

On behalf of The American Waterways Operators, the national trade association for the tugboat, towboat, and barge industry, I write today in support of the reissuing permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.

Since 2001, AWO has been a member of the Coalition to Protect the Missouri River (CPMR), a group of stakeholders that advocate for the responsible management of Missouri River resources to ensure maintenance of the river's Congressionally authorized purposes. CPMR also supports responsibly managed and properly balanced efforts to recover threatened and endangered species. In addition, AWO has been a member of the Missouri River Recovery Implementation Committee (MRRIC) since its inception in 2008. As a result of AWO and CPMR advocacy efforts, reliable flows have returned and commercial traffic on the Missouri River has been increasing steadily for more than five years.

Any new restrictions to commercial activity on the Missouri River, including dredging, could have a negative economic impact on the region. Commercial dredging has helped rejuvenate commerce on the Missouri River. Absent the dredgers' tonnage, the justification for and support of the Corps' continued efforts to maintain the Bank Stabilization and Navigation Project (BSNP) project that is critical for the maintenance of the navigation channel and levee stabilization could dissipate. It would also put the flows that maintain navigation on the Missouri and Mississippi rivers in jeopardy. Diminished support for navigation would harm one of the two primary Congressionally authorized purposes of the river.

Dredging has a direct impact on the economy of the region. Dredgers provide a source of employment and pay taxes in their respective communities. The products are utilized

throughout Missouri and the region for construction. The dredgers also accommodate the endangered pallid sturgeon's life cycle and, the dredgers present no impacts to other endangered or threatened species on the river.

As a Missouri citizen, I understand the critical importance of the Missouri River's environmental, cultural, and economic value. The federal government should look for opportunities to grow the economic viability of the river instead of restricting it, particularly in these tough times. I strongly urge the Corps to reissue permits for commercial sand dredging on the Missouri River.

Sincerely,

Lynn M. Muench
Senior Vice President – Regional Advocacy

Holliday Sand and Gravel Company, Inc.
P.O. Box 23910
Overland Park, Kansas 66083

May 1, 2020
VIA EMAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
matthew.s.shively@usace.army.mil

Re: NWK-2011-00363

Dear Matt:

Please accept the following comments from Holliday Sand & Gravel Company (Holliday) supporting our request for renewal of our Missouri River commercial dredging permit. We believe our comments will serve to inform interested parties that river dredging is both sustainable and critical to the infrastructure of greater Kansas City(KC), and at the existing reduced permit levels is not injurious to the public and as such, its continuation is in the public interest.

A Critical Economic Value for Kansas City

Commercial River Dredging on the Missouri River continues to be a tremendous economic asset for the community. The average annual savings to the cost of area construction from Missouri River sand dredging are in excess of ten million dollars every year as compared to other sources of aggregate such as pit mining. According to an independent economic study completed for Holliday as part of the Missouri River Degradation Feasibility Study (Study), Missouri River dredging, versus pit mining, will save the public $640 Million over the next 50 years.[1]

Sand is an essential commodity for the construction and maintenance of infrastructure that literally supports our way of life. It is necessary for building new infrastructure and maintaining existing roads. Holliday does not create this demand for sand in KC, that demand is created by a growing economy and region. Holliday, through the very hard work of its skilled and dedicated team members, operates and maintains dredges, towboats and barges on the Missouri River in all conditions, rain or shine, to meet this demand for sand that benefits every person in greater KC and St. Joseph. Equally importantly, the sand from the Missouri River is a renewable resource and is replenished constantly by the flow of the Missouri River.[2]

Reduced Missouri River Dredging in Kansas City

[1] *Impact on Commercial River Dredging Operations for the USACE's Missouri River Degradation Feasibility Study,* Alvarez & Marsal, November 9, 2016
[2] Holliday pays the State of Kansas sand royalties per ton.

Holliday Sand and Gravel Company, Inc.
P.O. Box 23910
Overland Park, Kansas 66083

Due to concerns about bed degradation, in 2010 the Missouri River Dredgers were required by the U.S. Army Corps of Engineers (USACE) to submit an Environmental Impact Statement[3] (EIS). Based on the EIS it was determined that dredging in the Kansas City Segment at a level equal to only 10% of the average riverbed sand load would not result in any significant impacts to structures. Holliday has complied with the following restrictions that resulted from the EIS and were instituted by the USACE[4]:

1. Holliday reduced the volume of sand that it dredges in the Kansas City Segment of the Missouri River by 79%, from 2.68 million tons per year to 540,000 tons.
2. 5-mile reaches were established in the degrading areas and limited to 300,000 tons in each reach per year, which has spread dredging over a 20-mile reach, mostly downstream of downtown KC.[5]
3. Dredge monitoring equipment was installed to record exactly when and where our dredges are dredging every 5 minutes or less. This location data is logged along with scaled tonnage and provided to and checked every 30 days by the USACE Program Manager.
4. Dredgers must provide a survey of the riverbed every 500 feet for the entire 500 miles of the lower Missouri River, and if the riverbed drops an average of 2 feet over a moving 5-mile reach, dredging must stop until the bed recovers.

These controls are almost identical to what USACE instituted on the Kansas River in 1992. Those restrictions, which reduced dredging to 1 million tons per year on the Kansas River near KC, successfully halted degradation, but also pushed sand dredging to the Missouri River during the 2000s housing boom to unprecedented levels. However, that changed dramatically after 2010 and the Commercial Dredging EIS.

Recognizing the lack of any suitable alternatives, these restrictions were included in the Environmentally Preferred Alternative (EPALT) under the EIS. The EPALT as stated in the Dredging EIS Section 2.7.3, page 2-86 is:

> ***"It was determined that the Environmentally Preferred Alternative should be the highest annual dredging amount that would result in no more than slight degradation, or less than approximately 2 feet in the short term and long term in each segment."***

Progress on Degradation

After 2010, with the significant (79%) tonnage reduction in permitted dredging limits and 5-mile reach dredge limits, which effectively pushed dredge locations an average of 5 to 15 miles further downstream from KC, the riverbed no longer showed degradation near dredging. Comparison of river cross section surveys completed in 2009, 2012, and 2013 by the USACE indicated that the channel bed of the Missouri River was recovering after 2011 flooding and aggraded (the riverbed raised) from River Mile 325 to RM 370. This information was presented by the USACE at the *2015 Annual Missouri River Dredgers Update Meeting*, on February 9, 2015. This reach of the Missouri River includes where Holliday had been dredging sand over the same time period per its

[3] *Missouri River Commercial Dredging FEIS,* USACE 2011
[4] *Commercial Sand and Gravel Dredging on the Lower Missouri River Record of Decision*, USACE, March 2011
[5] Sand from the suspended bed load that moves down river along with large gravel screened from the sand on the dredge refill the dredge hole in a matter of days. 300,000 tons over a 5-mile reach is equal to 3.4" if there was no refilling at all. However, it does fill in and Holliday has been dredging what has refilled in the same spots for decades.

Holliday Sand and Gravel Company, Inc.
P.O. Box 23910
Overland Park, Kansas 66083

allocation. The average bed aggradation through this reach over the 2009 through 2013 time period was approximately 0.5 feet and included the time period of the record sustained high flow release in 2011. The average slope line of the construction reference plane water surface profile had also elevated approximately 0.5 feet through this reach over this same time period. That bed aggradation represented approximately 2.5 to 3.0 million tons of bed material deposition in this reach over this 3 to 4 year time period. The Dredger's sponsored survey in 2014 and USACE's bed change report presented on July 7, 2015, confirmed that much of this bed recovery occurred after the high flow event in 2011. In summary, both channel bed and associated water surface elevations increased in this reach with a combination of ongoing dredging by Holliday within the regulatory limits and an historic high flow event in 2011.

This was exciting evidence for the KC reaches, that the current dredge levels were sustainable, the BSNP structures were intact, and the survey resulted in increased tonnage being granted by the USACE in the Waverly Segment. Unfortunately, another record flood duration and discharge event in 2019 has set back the progress in refilling the riverbed after 2011's event. The 2019 River bed survey will be discussed more below and we are confident that once again the riverbed will recover through KC at the same reduced dredge levels.

Isn't Dredging the Problem?

It's not that simple - there's 10 times more sand moving past KC just during average flows than Holliday is allowed to dredge. Dredging, as mentioned above, was reduced 79% in KC to levels that the 2010 EIS determined would not have more than slight impacts to degradation. Reducing dredging beyond the current levels is not likely to improve degradation and will result in significant increased costs for construction.

The US Geological Survey (USGS) measures suspended bed material sediment discharge on the Missouri River at Kansas City and summarized annual bed material sediment loads in their report *Characteristics of Sediment Data and Annual Suspended Sediment Loads and Yields for Selected Lower Missouri River Mainstem and Tributary Stations*, 1976-2008. For the time period from 1995 through 2006 (years that included an extreme system wide drought) the **USGS reports that approximately 11.7 million tons per year of bed material sediment (very fine sand or coarser material) is transported by the Missouri River through Kansas City.** This quantity of sediment load is at least 10 times greater than the bed material sediment dredged by Holliday on an annual basis since 2009, indicating that the ambient background sediment inflow to this reach adequately replenishes the bed material sediments extracted through ongoing dredging operations.[6]

Is River Dredging Really Necessary?

Yes. To date no KC area Missouri sand pits have been able to produce sufficient quantities of quality concrete sand. Missouri flood plain pits are extremely difficult to site and operate and have higher costs due to the low deposit yield. One of the existing pit operators has decided to move production to the Missouri River after determining their pit is not a viable concrete sand producer.

Existing Kansas sand pits are needed for the west side of the city and are operating at peak. Efforts to site new pits have been extremely unpopular as they require trucking on country-neighborhood roads or directly through

[6] Holliday's quota was transitioned down to the current 540,000 tons over a 5-year period by the USACE after the EIS.

Holliday Sand and Gravel Company, Inc.
P.O. Box 23910
Overland Park, Kansas 66083

the local town. Bottomland with good access is rarely for sale and the Missouri River floodplain sand deposits are often intermixed with cobbles and clay.

In 2011, USACE did not heed Holliday's remarks that existing pit sites would fail to be an alternative to river dredging.

USACE Response to Holliday's comments stated:

Commercial Sand and Gravel Dredging on the Lower Missouri River
Record of Decision, March 2011, Section 4, Alternative Analysis, page 3-37,38

> ***"The USACE has received letters from the Master's Dredging Company and Missouri Sand Company LLC (see letters in Appendix A) rebutting this assertion and providing credible information about existing and planned sand mining operation with ample reserves of sand that meets the requirements and can fulfill the market needs now and in the future."***

Holliday can now say that since 2011 the two operational and one planned sand pit have not developed into viable sources of concrete sand. As Holliday predicted, Missouri River pits continue to be very difficult to site, permit and operate, and are **NOT** going to be able to replace river dredging. This is why Missouri River dredging is necessary at existing permitted levels that in 2014 had shown not to impact degradation as compared to the other EIS identified causes of degradation (floods, cutoffs, droughts, perched dikes, floodway encroachment).

Should Missouri River Dredging Be Increased?

Holliday Sand has not requested an increase in tonnage from any of the three segments it operates in. Due to present conditions related to the pandemic, we see a slightly reduced demand for sand in the near term with a delayed continuation of the housing uptick along with a likelihood of some federal infrastructure programs to stimulate the economy. We only dredge what is needed for the construction market. Though the permitted amounts seem excessive now, that could change with a recovery from COVID-19, so we request no reductions to the current levels. Maintaining the existing small amount of tonnage in the KC segment is critical for our operation during high river flows as we cannot move our dredge into or out of the Waverly segment under the bridges above a 25-foot KC stage. Should tonnages need to be cut somewhere we ask for an equivalent increase in another segment to make up for any reductions.

Section 408 Review

For the first time, commercial dredging must receive a 408 Review to assess the impacts of dredging on federal projects. A 408 Review has traditionally been reserved for reviewing a construction project on the riverbank that requires excavation of or near USACE structures.

In 2015 it was decided that due to the results of the *Missouri River Bed Degradation Feasibility Study Technical Report*, USACE, May 2017 (Study), commercial dredging must now receive a 408 review. What was discovered in the Study that resulted in this added review? Did the Study look at dredging survey data over the previous

Holliday Sand and Gravel Company, Inc.
P.O. Box 23910
Overland Park, Kansas 66083

decades to confirm causation? Did it discover the undermining of revetment, dikes, levees and bridge piers[7] by dredgers? No. In fact it was found that these structures are stable and intact even after the record channel flows of 2011 and are not about to fall into the Missouri River as was feared in 2007.

The author was present at the Degradation Study meeting when John Grothaus, NWK Chief of Planning, told us that they (USACE) were pleased with the manageability of impacts to the BSNP in KC following the epic 2011 flow event. They were able to survey during the flood and were able to place some rock in the toe trench near the KS River that is a chronic issue. Placement of toe trench rock prevents the sloughing of rock banks. Toe trench repair, we understand, is not unusual and is needed from time to time. Prior to the 2011 event it was feared that the floodwalls in downtown KC would slough into the River if we ever had an event like 2011. But USACE surveys conducted during and after the 2011 event demonstrated this was unfounded. The BSNP structures are more than piles of loose rock, they were built to last, on piling and mats, to be resilient. But, these structures, like everything, must be maintained.

A major portion of the Study's time and resources was devoted to developing a HEC-RAS Mobile Bed Model (MBM) to predict long term degradation in order to test various alternatives: less or no dredging, dike shortening/lowering, and grade control structures. The MBM , which is a one-dimensional model: sediment in less than sediment out = degradation. The complex system of the BSNP navigation channel scouring dikes was approximated by narrowing the channel and adding a roughness coefficient, like a corrugated pipe flow calculation. The MBM "calculated" that over the next 50 years the least costly alternative to deter degradation was reducing commercial dredging. It evidently determined that removing dikes has no power to refill degraded areas. This result is questionable as experience shows that just notching some dikes can quickly fill the channel with sand and has received complaints from navigators that they are getting grounded.[8]

Nevertheless, the MBM (and incomplete study) could be wrongly interpreted by some to establish a correlation between dredging and degradation.[9] The truth is no such causation has been established, other than a very general notion that removing less tons from the river leaves more tons in the river, which seems so intuitively obvious, but nevertheless steered the Study to immediate conclusions that the primary response to degradation is less and less, especially when the USACE decided there was no "project" to be done and no federal interest that justified continuing the Study further. **The USACE Study authors essentially relied upon the**

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[7] The Degradation Study's poster child was the washed-out footings for the Argosy casino bridge over Line Creek. Holliday's Riverside plant is next door and we observed the placement of the concrete footings. They were placed atop the fill that was deposited by the 1993 flood. In other words the footings were placed too high to begin with. The Jersey Creek outlet piling wall is another structure where itss failure was blamed on degradation or dredging. Our conversations with the contractor, L.G. Barcus, confirmed that the walls were leaned out toward the Missouri River indicating a tieback failure. If it had failed from erosion/undercutting, the piling would have slid out at the bottom and would have been leaning inward toward the levee.

[8] For example, Sandy Hook Bend, at RM 168 is problematic due to a notched dike.

[9] The following is from the Study Executive Summary: *"The* [Degradation] *reconnaissance study indicated that flood events, operation of the Missouri River Bank Stabilization and Navigation Project (BSNP), and commercial sand and gravel mining could be contributing to the bed degradation problem. The level of contributions by these factors to the problem were not fully evaluated at that time and additional study was recommended."*

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P.O. Box 23910
Overland Park, Kansas 66083

patently false assumption that discontinuing Missouri River dredging would have no impact or cost. That assumption, which was known to be false by the authors of the study, completely negated all the USACE Study engineering done to design structures that would stop degradation. Sadly, without allowing the model to factor in the additional costs for relocating to sand pits, USACE could not justify continuing. This was a huge disappointment to Holliday as well as the other Study stakeholders.

In short, the bureaucratic maneuver by the USACE was to intentionally ignore the Alvarez & Marsal study submitted by Holliday because Holliday had submitted the study to the USACE initially in a redacted format to preserve business confidential cost and price data. This claim of Confidential Business Information was justified by Holliday at the time because of the competition in the sand business, and the submission followed all USACE regulations. Nevertheless, Holliday's study completed by Alvarez & Marsal was not allowed by USACE to be included in the Degradation Study economic model.[10] Without considering the data in the economic study showing an impact of more than half of a billion dollars, the Study's authors were able to state that there was no economic impact. Again, the Study's authors knew of the study, of the economic impact, but did not consider it, invalidating the entire premise of the degradation study. Holliday was a stakeholder/contributor to the Degradation Study, and had even significantly funded this worthless exercise, making the bureaucratic slight of hand even more offensive. In any event, the redacted report is again presented, attached to this document.

Degradation Financial Impacts

Below are the Degradation Study results of the future potential economic impacts:

50-Year Impacts from Degradation[11]:	
USACE costs to maintain the BSNP and wildlife habitat -	$82.9MM
Water and Electric Utilities -	$34.6MM
Maintenance to tributary structures -	$21.4MM
Total Cost not related to dredging -	**$139MM**

Holliday's cost to replace its Missouri River dredging with sand pits in the flood plain - $640MM[12]

Therefore, the potential economic impact of degradation (even if the Degradation Study had shown causation between dredging and degradation—which it did not) are far exceeded by the impacts to the KC economy if Holliday's river dredging is terminated and replaced with Missouri flood plain pits, by a factor of 4.6:1!

[10] Holliday even later offered to provide the unredacted report if the claims of CBI could not be honored. But the USACE also rejected this information with no explanation.
[11] "8.2 Future Without-Project Economic Analysis", *Missouri River Bed Degradation Feasibility Study Technical Report*, USACE, May 2017
[12] *Impact on Commercial River Dredging Operations for the USACE's Missouri River Degradation Feasibility Study,* Alvarez & Marsal, November 9, 2016
.

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P.O. Box 23910
Overland Park, Kansas 66083

If this economic report had been factored into the economic model, the focus would have appropriately shifted from eliminating dredging to realizing that commercial dredging can only cause slight degradation and continuing it allows another $640,000,000. to be added to the economic impacts of degradation, justifying a federal project such as building structures or modifying dikes or sediment augmentation in selected degraded locations. Because dredging relocation costs were not allowed to be factored in, the USACE essentially threw up its hands and quit.

Our 408 Study Concerns

The 408 Review engineering study, we fear, has not done what was recommended from the USACE Degradation Feasibility Study: further study the level of degradation contribution from dredging and known causes:

> *"The* [Degradation] *reconnaissance study indicated that flood events, operation of the Missouri River Bank Stabilization and Navigation Project (BSNP), and commercial sand and gravel mining could be contributing to the bed degradation problem. The level of contributions by these factors to the problem were not fully evaluated at that time and additional study was recommended."*[13]

We are concerned that **the 408 Review, based on the public notice and the annual dredger's meeting presentation appears to have concluded that based on the results of the MBM computer modeling in the Degradation Study, dredging is responsible for impacts from degradation in general even after the USACE Study determined that there have not been significant impacts that would justify a federal project, interest or further study.**

Bed Model Not Useable

Holliday hired Northwest Hydraulics Consultants, Inc. (NHC), experienced professional HEC-RAS modelers to review the HEC-RAS mobile bed sediment model (MBM), developed for the Degradation Study as a tool to maximize the potential for degradation and its impacts and hopefully justify a fully federally funded project that would fix degradation, which it tried, but failed to do. **NHC has found that the MBM is seriously flawed and should not be used for permitting purposes.**

The following is from NHC's most recent review of the expanded MBM[14] (500 miles): *Review Of USACE Lower Missouri River Movable-Bed Sediment Model* [15]:

> *"These unresolved issues indicate the existing Model 500 has several technical flaws and should not be used in its present setup and configuration to support any ongoing or future permitting, planning, or design efforts on the Missouri River."*

[13] Executive Summary, *Missouri River Degradation Feasibility Technical Report*, USACE, May 2017
[14] The MBM was expanded to 500 miles so it could be used to evaluate Missouri River dredge impacts statewide.
[15] *Review Of USACE Lower Missouri River Movable-Bed Sediment Model*, by Northwest Hydraulics Consultant, Inc., Brad Hall and Andrey Shvidchenko, PhD, April 6, 2020

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P.O. Box 23910
Overland Park, Kansas 66083

The problem is the MBM has switches and methods to tweak the model to make it arrive at any result, and any flaw becomes magnified when projected out 50 years into the future. These manipulations are often needed to get the model to calibrate, or agree with real data, such as the depth of the riverbed and the sediments actually measured by the USGS over the years. The HEC-RAS 5.0.3 software MBM developed for the Study was replaced with 5.0.7 because the developers found "serious software bugs" in it. When the MBM was redone using the valid 5.0.7 version, it could not be calibrated without manipulations that are not normal or acceptable, such as the addition of 23 million tons of sediment into the model downstream of KC, the "additional amount is greater than the average annual sand load in the Missouri River", according to NHC (see Section 6.1, page 18). This and three other "key technical issues" render the MBM in its present form unusable for determining how much degradation could occur from dredging. However, this is exactly what was the Study appears to have done with the flawed MBM. To the layperson that doesn't understand what the model actually can and can't do, the model provided confirmation bias against sand dredging at any level.

With regard to the current 408 Review analysis, Holliday is concerned that the flawed Degradation Study analysis based on a flawed model and a "report" done by USACE personnel that was not distributed for public review and comment is being used as a platform to support and further the assumption that dredging is "synonymous with degradation" and will lead to a flawed 408 analyses of looking at degradation impacts and imputing those to dredging. With this knowledge we have of the flawed model from NHC, the model being the basis for the flawed Degradation Study "conclusions", Holliday objects to a 408 Review approach where dredging = degradation = impacts to the BNSP. This is not a valid premise. Direct and local impacts from the dredging process must be the action to be studied, not global impacts from degradation that are assumed to be the result from dredging.

For example, USACE has publicly shown river bed survey cross sections with slight slope changes described as sliding revetment rock which they deem to be the impact of degradation on the BSNP. This sloughing can only occur if there has been toe trench erosion. Toe trench erosion can also occur from localized scour processes independent of river profile degradation, such as excessive velocity and shear forces during high river flow events such as occurred in 2011 and 2019. In other words, the size of the riprap toe stone is too small for the force of the current and was displaced allowing the slope above it to slough or slide. Now if it was determined, based on dredge location gps data logging that a dredge operated too closely to the reveted bank at that location, that impact would be due to dredging and increased setbacks would be appropriate, along with responsibility for the dredger to compensate USACE for repairs. However, the 408 Study must not assume without foundation that degradation has aused all bank rock slides, and deduce that since dredging may contribute to degradation, dredging must stop especially in light of just experiencing in 2019 the record for discharge flow resulting in 55 days of near to above flood stage flows in KC in March, May and June of 2019.[16]

[16] Source: USGS National Water Information System
https://nwis.waterdata.usgs.gov/nwis/dv?cb_00065=on&format=html&site_no=06893000&referred_module=sw&period=&begin_date=2019-01-01&end_date=2019-12-31

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P.O. Box 23910
Overland Park, Kansas 66083

Holliday is very concerned that the 408 Review analysis has become an analysis of whether degradation impacts federal projects with an assumption that dredging is the cause of degradation. As noted above, bank revetment failure can occur due to localized scour processes, regardless of whether or not river profile degradation occurs.

Additional Basis for Holliday's Concerns on the 408 Analysis:

The following is from the February 25, 2020 Annual Dredgers Meeting, page 18:

> ***"DEGRADATION AND DREDGING***
>
> 1. ***Impacts to BSNP and MRRP are triggered by degradation –regardless of the cause***
> 2. ***Specific causes of degradation do not need to be identified when assessing impacts***
> 3. ***If critical degradation levels are triggered by a flood, activities that could contribute/worsen the damage need to be considered"***

The above appear to be the corollaries used by the USACE to build a connection between dredging and impacts to the BSNP and MRRP for the 408 Review.[17] Each are addressed below.

1. ***"Impacts to BSNP and MRRP are triggered by degradation –regardless of the cause"***

This first statement appears to make sense, but can't those impacts be "triggered by" other forces than degradation, such as deflected scour from BSNP dikes, or shear forces from high velocities (localized scour) during flooding? Those forces have evidence of impacting the BSNP, and they have nothing to do with degradation.

The Missouri River dredgers have been meeting with the Kansas City District (NWK) every year or more over the last 9 years or so and never has there been any mention of impacts to BSNP structures. Quite the contrary, when we met in 2014 it was announced that the bed was showing recovery since the 2011 record reservoir discharge event. And, as a result, permit tonnages were increased in 2015 in the Waverly segment.

The problem with this type of analysis based on correlation is it isn't scientific and has not been quantified. In contrast, Holliday and the other dredgers have on many occasions reminded USACE that real data was collected by the USACE over the years on dredge holes during and after dredging occurred. The holes almost completely refill within days without any evidence of headcutting. This data has never been released but represents real engineering that USACE is capable of.

So what level of dredging is allowable?

[17] Bullet numbers were added to aid clarity.

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P.O. Box 23910
Overland Park, Kansas 66083

Again, the question of how much dredging causes too much degradation was studied and answered in the multi-million-dollar Dredging EIS:

The EPALT as stated in the Dredging EIS Section 2.7.3, page 2-86 is:

> ***"It was determined that the Environmentally Preferred Alternative should be the highest annual dredging amount that would result in no more than slight degradation, or less than approximately 2 feet in the short term and long term in each segment."***

The Dredging Study did not say that if degradation is greater than 2 feet there can't be any dredging. That additional conservatism was justifiably implemented after the EIS in 2010 when the USACE was wondering if the next event would cause catastrophic riverbanks failures in Kansas City. Thankfully the record 2011 event proved that the BSNP is resilient and can withstand the worst velocities over the longest period ever. **But to not allow even 540,000 tons per year at the rate of 300,000 tons per 5 miles if there is ANY degradation in KC after the 2019 flood is unneeded and excessive conservatism. A better solution than no dredging would be to reduce the reach limit to 200,000 tons per five miles.**

2. ***"Specific causes of degradation do not need to be identified when assessing impacts"***

This second "corollary" of the USACE 408 Review from the February 25, 2020 Annual Dredgers Meeting, page 18, is patently unfair. It proclaims that it doesn't matter whether dredging is causing the impact if there is a degradation impact. This was not the purpose intended for a 408 review. There needs to be a direct connection between the activity being reviewed and an impact. Since there is no direct evidence, causation doesn't matter? This seems like a Catch 22 rather than an analysis.

3. ***If critical degradation levels are triggered by a flood, activities that could contribute/worsen the damage need to be considered"***

The test for dredging impacts to federal structures should not be whether it seems possible that flood impacts are exacerbated or not. **If this is the test for harm, then bridges and levees would not be allowed in the KC reach because they have the likelihood to exacerbate flood impacts to the BSNP!**

The following is from the February 25, 2020 Annual Dredgers Meeting, page 19:

"BSNP

- Adequacy of current dredge standoff distances from BSNP structures
- Impact on structure height as bed drops
- Loss of revetment resiliency/stability (increasing slope)

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P.O. Box 23910
Overland Park, Kansas 66083

- Impacts to flood profile near degraded areas"[18]

With the exception of the first item, dredge standoff distances, all the other investigations are related to degradation and even other causes such as excessive dike scour, localized scour from flood velocities or even inadequate design. **Unless USACE can show that a dredge has impacted a federal structure then discussion of the potential impacts from degradation in general are moot and should not be attributed to commercial dredging without direct evidence.** It seems obvious that the "corollaries" on the previous page 18 are an attempt to sidestep this critical issue of proof of causation that is essential for this permitting process and a requirement of due process. On all fronts we hope there are none, but we remain prepared to modify per the adaptive management feature of the existing permits should the need arise.

Instead we would expect a 408 Review to investigate whether current dredging practices have undermined the bank revetment or the dikes by dredging too deep and too close to those structures. Since instituting the HyPack system on the dredges, the operator has real time graphics showing them the exact location of the dredge cutter in relation to all structures in and around the river along with clear boundary lines that must be avoided to comply with our permit dredge setbacks.

2019 River Survey

The Dredger's 500-mile river survey performed for 2014 demonstrated that the Missouri River had recovered approximately two-thirds of the bed loss from the historic 2011 reservoir discharge event and was expected to recover more. This data was presented to the Dredgers by the USACE on July 7, 2015, as part of the permit process. Also reported was that since 2009 there had been no correlation between degradation and dredging; and the Waverly segment, where increased tonnages have been requested, aggraded an average of 0.30 feet over 107 miles of river (equivalent to approximately 4MM tons of bed material).This was indeed good news from the USACE about bed recovery at the new reduced permit tonnages, especially after the record discharge event in 2011.

However, the most recent river survey this last summer/fall of 2019 coincided with another record flow event with flood stages off and on most of the spring/summer. Because of the flood plain encroachments in KC, flows and floods of this magnitude are a scour event of the magnitude that can dwarf the minor amount of sand dredged by a factor of 7:1 for every foot of scour. Floods often scour 5 feet or greater and then eventually recover 3 feet at normal flows. Dredge holes almost completely refill within days.
The points to be made are:

1. Current levels of dredging are insignificant to recent flood scours[19]
2. It is not appropriate to base dredging levels from survey data taken immediately after a summer long

[18] Holliday added the bullets for clarity.
[19] Dredging 540,000 tons equates to 1" of sand over the 33 mile KC Segment, or 3" over the mandated 10-mile minimum reach for removal.

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P.O. Box 23910
Overland Park, Kansas 66083

flood

3. It would be miraculous if there wasn't some kind of velocity and/or degradation impact to the BSNP structures from these levels of flood flows, and
4. Dredging by comparison is an insignificant loss of sediment for an essential purpose that does not have a good alternative.
5. Continued dredging at the levels that have been allowed under the EIS would not prevent a recovery, as evidenced by the recovery that occurred from 2011 to 2015.

The Future

If Missouri River dredging is terminated, bed degradation will continue as long as there are scouring dikes and flooding, and sand will have to be hauled farther and farther from outside the city (right now the Missouri River does that for us at no cost and with no impacts) where pits can be sited, bringing its own array of impacts on county roads, permanent loss of farmland and ongoing new impacts to land from the clearing, stripping and excavating of 40 or more acres of prime bottom land each and every year from now on.

This is why we need to continue permitting river dredging with short, 5-year permits and continue to use adaptive management to monitor and control local impacts. The most recent Missouri River survey provided by the dredgers has evidently shown some areas where rock is sliding which will require further surveying and determination if it is directly due to dredging in the area.
This system for dredge permits has worked on the Kansas River and prior to 2019, it was working in the KC and Waverly segments. With time, the bed will recover from the 2019 floods at the existing reduced levels of dredging in KC since 2009.

You can tell we are passionate about dredging and have attempted to set the record straight as well as voice our concerns with the direction the 408 Study seems to be taking based on what has been provided. There are a lot of great folks at the USACE and we sincerely thank them for their tireless efforts to protect federal resources and still balance the needs of the states and local communities.

Sincerely yours,
Holliday Sand & Gravel Company

Mike Odell
Vice President

Attachments:
Impact on Commercial River Dredging Operations for the USACE's Missouri River Degradation Feasibility Study, Alvarez & Marsal, November 9, 2016

Holliday Sand and Gravel Company, Inc.
P.O. Box 23910
Overland Park, Kansas 66083

*Review Of USACE Lower Missouri River Movable-Bed Sediment Model***,** by Northwest Hydraulics Consultant, Inc., Brad Hall and Andrey Shvidchenko, PhD, April 6, 2020

CC:
Stacia Bax
wpsc401cert@dnr.mo.gov
Missouri Department of Natural Resources

Scott Satterthwaite
ssatterthwaite@kdheks.gov
Kansas Department of Health and Environment
Bureau of Water - - Watershed Management Section

Alvarez & Marsal
Disputes and Investigations, LLC
1100 Walnut Street, Suite 2970
Kansas City, MO 64106
Phone: +1 816 412 6500
Fax: +1 816 412 6501

November 9, 2016

VIA ELECTRONIC TRANSMISSION &
FEDERAL EXPRESS

Christina Ostrander, PMP
Project Manager
U.S. Army Corps of Engineers, Kansas City District
c/o CENWK-PM-PR (Degradation Study)
601 E. 12th Street, Kansas City, MO 64106
Christina.Ostrander@usace.army.mil

Re: *Impact on Commercial River Dredging Operations for the USACE's Missouri River Degradation Feasibility Study*

Dear Ms. Ostrander:

This letter sets forth our findings regarding our independent analysis on the economic consequences of moving Holliday Sand and Gravel's ("Holliday") Missouri River commercial dredging operation to pit mining in the Missouri floodplains. This analysis was prompted by the USACE's Missouri River Degradation Feasibility Study. It is our understanding that the reduction of Missouri river dredging is an alternative being considered by the USACE as a potential solution to ongoing riverbed degradation on the Missouri River.

Our analysis considers the economic impacts associated with producing two million tons of marketable sand in the Missouri floodplains instead of dredging two million tons of marketable sand from the Missouri River. We note that our findings consider only the marginal impacts of producing two million tons of marketable sand based on current river dredging costs.

Holliday operates three river dredging plants along the Missouri River. The Riverside and Randolph plants are fully operational, and their average 2013 costs were utilized as the basis for the river dredging costs. Increases or decreases to these costs were made to account for differences in equipment, headcount, maintenance, fuel and real estate costs between river dredging and pit mining. Beginning in 2013, Holliday

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opened a pit mine in Kansas. Financial data, where available[1], was utilized to account for costs specific to pit mining, i.e., stripping and reclamation and excess waste rehandling costs. Adjustments to the Kansas pit costs were necessary to consider the difference in deposits between the Kansas pit and Missouri floodplains, which affects production costs. The Missouri floodplains contain surplus fine material and soils, yielding a lower quality of product than the Missouri River yields, which also increases pit mining production costs. All adjustments are outlined below and/or described further in the accompanying attachments.

Findings

The economic impact of pit mining in the Missouri floodplains results in a [redacted] increase in costs compared to Missouri River dredging. This increase is driven primarily by the transportation costs of the finished product due to additional distances trucks must travel to and from the pit mines. Construction-grade sand is a high-volume, low value commodity that cannot be transported long distances economically. The cost increase is also largely impacted by the stripping required by a pit mine, and, in particular, to the nature of the clayey soil of the Missouri floodplains. A 1998 study of the Kansas River Corridor noted that a Missouri floodplain dredge would cost 50-60% more than sand from a river dredge.[2] In fact, before accounting for costs associated with additional inputs needed to obtain the same quality of sand or the additional trucking miles to the pit mine, our analysis found that the production costs of sand mining are 53% higher in an open pit compared to river dredging.

The same 1998 study notes the following costs of a floodplain pit mine:

- "Initial Costs: Land costs, test drilling, legal fees, and permits.
- Overburden: Thickness, type, water content, depth to water table.
- Stripping: How much to open the pit, cost per cubic yard for overburden removal, placement of stripped overburden and hauling to placement area, cost to replace overburden after dredging back into the pit.

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[1] The pit did not operate for the full year, and many of the pit mining costs were not fully captured in the accounting system. Adjustments were made where necessary and as discussed throughout this analysis.

[2] The Kansas River Corridor – Its Geological Setting, Land Use, Economic Geology, and Hydrology, by Lawrence L. Brady (compiler), David A. Grisafe, et al., January 1998, Economic Resources, p. 6.

- Deposit: Thickness, amount that can be used, percent sand and percent gravel, recoverable percentages, costs associated with unusable material disposal, reserves in place and recoverable reserves.
- Production: In addition to stripping and reclamation costs per ton of sand and gravel associated with overburden removal and return, there may be expenses associated with site preparation (e.g., berms), road and bridge construction, additional land costs associated with setbacks, and overburden storage.
- Roadblocks: Opposition to the operation and acceptance by various organizations and government agencies. Time and money is required to overcome objections or to satisfy agencies.

With all these variables, it is difficult to compare pit- versus river-dredging costs. Such comparison must be made on a case by case basis, at a specific site."[3]

While a more precise analysis of costs is site-specific, consideration has been given to each of these items where possible. We note that there is a high degree of uncertainty related to selection of actual pit sites which cannot be overcome until actual sites are selected, permitted, etc. A more detailed comparison of the costs between Missouri River dredging and pit mining are explained further below and in the attached exhibits. A summary of total and incremental pit costs can be found on the Summary Exhibit.

Stripping and Reclamation Costs

Four operations are necessary in open-pit mining: (1) preparation of the site, including wetland mitigation and thereafter, stripping overburden, (2) mining and conveying, (3) processing, including screening, washing, blending and stockpiling of the mined materials, and (4) reclamation of the mined area. The first and last operations are not required in river dredging. Stripping and reclamation costs, therefore, increase the cost of a pit's operations as compared to river dredging. River dredging on the Missouri River requires the transporting and unloading of barges as opposed to the Kansas River. These added transporting costs on the Missouri River have been accounted for in the analysis. As noted above, Holliday's Kansas pit costs were adjusted, as further explained here, and utilized to estimate the Missouri pit stripping costs.

[3] Ibid., p. 7.

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Stripping costs at the Kansas pit totaled $[redacted] per cubic yard. Consideration must be given to the type of soil at the Kansas pit versus that expected from the Missouri floodplain. The expansion of the soil from bank cubic yards to loose cubic yards is measured by the swell. The Kansas pit has silty soil with a swell of [redacted]%. The Kansas pit soil does not hold moisture and is easier to dig. Soil from the Missouri floodplains is clay with a swell of [redacted]% and retains moisture making it hard to dig, drive over, place and compact. This [redacted]% swell differential translates into $[redacted] of stripping costs per bank cubic yard, or $[redacted] per ton of sand sold. (See Exhibit A)

The stripping costs referred to above do not include reclamation costs. Reclamation includes sloping, seeding and mulching the pit banks as well as site grading and equipment removal. For a [redacted] acre site, reclamation costs total $[redacted] per ton. (See Exhibit A)

Surplus Waste Rehandling Costs

Dredging sand generates the following waste material: the stripped overburden, excess fines and excess gravel. As coarse sand products account for approximately [redacted]% of sales, waste fine sand and oversize gravel are generated in quantities much greater than their market demand and must be rehandled until sold (which can take decades depending on the project haul distance). River dredging allows for the product to be sourced with less waste (averaging [redacted]% compared to [redacted]% in pit mining), and the river dredging waste is dropped back into the dredged hole at no additional cost of handling. Excess waste fines in pit mining, however, must be rehandled away from the plant and dredging area. There is some value to this excess waste but it is limited to fill sand, and sales of this fill sand will be directly dependent on active construction projects within close proximity to the pit site. Because sales are directly dependent on active construction projects nearby, sales of fill sand will vary greatly from year to year. Holliday believes a reasonable estimate of fill sand sales is [redacted] tons annually. The remaining waste is processed in the plant, dewatered and stockpiled and then must be relocated. Finding storage space for surplus fines is problematic. Processing and rehandling the waste in pit mining requires an additional $[redacted] per ton. This process and cost is in addition to the stripping overburden costs calculated in the above section as well as the material placement and dozing calculated in the above reclamation costs. (See Exhibit B)

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Dredging Costs

A river dredge is directly connected to a floating plant, whereas pit mining utilizes a pipeline up to a mile in length to pump the sand to the processing plant. Because of the surplus waste sand, the pit dredge must pump twice the sand volume as the river dredge to achieve the same net tonnage of marketable sand. This results in additional energy and pipeline costs. For that reason, the pit dredge uses [redacted] gallons of diesel per hour compared to [redacted] gallons per hour for the river dredge. At $[redacted] per gallon, the diesel cost per ton is $[redacted] compared to $[redacted] for the river dredge. This additional $[redacted] increases the cost of pit mining compared to river dredging. (See Exhibit C)

On-Site Transportation Costs

In river dredging, processing of the sand takes place on the attached floating processing plant. The processed sand is then loaded onto barges and towed to the unloading dock. In pit mining, the sand is pumped from the pit through long pipelines to the processing plant then stockpiled by specification. Transporting sand from the river to the unloading dock requires the use of a towboat and four to five additional operators not necessary in pit mining; as well as equipment to unload the sand at the unloading dock. The operating cost of the towboat, additional labor, and the operating cost of the equipment to unload the sand from the towboat are eliminated in pit mining. These eliminated costs total $[redacted] per ton. (See Exhibit D) The equipment costs are evaluated below in the "Equipment" section. Pit mining requires the use of long pipelines and booster pump(s) not needed in river dredging. The parts, fuel, repairs and depreciation costs for the pipelines and booster pumps total $[redacted] per ton. (See Exhibit E)

Adjusting for Pit Deposit Yield

As noted above, pit mining produces [redacted] more waste fine sand than in river dredging, thereby increasing the costs of pit mining. To account for the increased costs related to the lower yield, a [redacted] cost increase was added related to dredging, processing and stockpiling. For example, dredging costs were increased by $[redacted] to account for the additional fuel necessary to pump the additional waste sand based on the same end product volume when compared to river dredging. These costs were not already increased for the additional volume incurred due to the [redacted] excess waste. (See Summary Exhibit)

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Adjustments Included for Comparable Product Quality

The sand mined from a pit in the Missouri floodplain is not the same quality as that dredged from the Missouri River. Material specifications are a science in itself, but the performance of the finished products that use sand, primarily ready-mix concrete, needs to be factored into this analysis. Pit sand contains more lignite, a soft coal that can stain and damage concrete, than river sand. This is based on Holliday's years of experience removing lignite from both pit and river sand deposits. At least 99% of the lignite must be removed in Missouri sand that is used for concrete, especially flatwork. The process of removal of lignite also requires removing fine sand and the efficiency of the process has limitations. It is difficult to sufficiently remove lignite without generating additional waste fine sand. This additional waste sand from the lignite removal process has already been included in the [redacted] reduced pit yield above, but has been presented here to further explain the low sand yield in Missouri pits versus river sand.

The surplus pit fines naturally result in a finished product that is finer than river sand. A term called the Fineness Modulus (FM) is used to measure this, and a lower FM (finer sand) requires more oil if used for asphalt or more cement if used for concrete to attain the same performance. The increased oil or cement increases the production cost of asphalt or concrete essentially increasing the cost of using pit sand versus river sand. Studies show that the cost of concrete mixes can vary 6.5% depending on the FM, along with other performance criteria. Changes in mix designs to accommodate low FM sand can increase the cost of concrete 6.5%, resulting in an increase cost of up to $1.50 per ton of the lower FM sand. [Refer to: http://www.nbmcw.com/articles/concrete/582-effect-of-fineness-of-sand-on-the-cost-and-properties-of-concrete.html]. This assumes a concrete mix cost of [redacted], and 1,300 pounds of sand per cubic yard. The alternative to producing lower FM sand from a pit is to waste more fines. Currently active pits in the Kansas City area must compete with river sand and produce a comparable FM sand for the above reasons. The amount of wasted fine sand to achieve a comparable FM to river sand has been included in the [redacted] reduced pit yield above. Therefore, no added concrete costs have been included in this analysis. However, should river sand no longer be available, the FM of pit sand could be reduced to attempt to reduce the amount of wasted sand. This will then result in the higher oil and cement costs of up to [redacted] per ton along with other reductions in concrete performance as stated in the above referenced article.

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Off-Site Trucking and Other Costs

As noted previously, construction sand and gravel cannot be transported long distances economically. Typically, buyers are located within a [redacted] radius. Holliday's Riverside plant customers are located approximately [redacted] weighted average ton-miles from the plant, and the Randolph plant's customers are located approximately [redacted] weighted average ton-miles from the plant. As explained further below, Holliday conducted an in-depth evaluation of the nearest feasible pit sites to replace their two Kansas City based river dredging operations. Assuming the potential pit sites identified could be purchased, permitted, etc., customers of the current Riverside plant would have to travel an additional [redacted] weighted average ton-miles, and customers of the current Randolph plant would have to travel an additional [redacted] weighted average ton-miles. Additionally, the nearest potential pit sites are located outside of the commercial zone, which limits truckloads from an average net payload of [redacted] tons to an average net payload of [redacted] tons. Thus, less sand per truckload is hauled over a longer distance, which increases trucking costs by $[redacted] per ton. (See Exhibit F)

Our analysis does not consider any additional costs after the first pit sites are depleted. Logically, however, the next replacement pit sites will be farther out and will further increase the off-site trucking costs. We note that it is estimated the initial pit sites totaling [redacted] acres[4] will be depleted in five years based on the current calculated yield of [redacted] tons per acre and including the acreage necessary for indirect production uses.

Additionally, there are other added costs, social and environmental, primarily related to greater fuel usage and trucking farther from remote pit sites. These costs are not as significant as the direct production costs; regardless, they serve to encourage the maximum usage of the existing river dredging terminal locations in conjunction with a sustainable level of river sand dredging.

Real Estate Costs

Holliday undertook a lengthy and in-depth analysis of potential pit sites in an effort to locate the closest, most feasible locations for pit dredging operations. [redacted] of parcels spanning [redacted] were initially assessed. None of

[4] It is assumed the nearest potential pit sites to replace each of the current Riverside and Randolph plants total [redacted] as it is not economically feasible to operate a pit site of less than [redacted].

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these parcels were deemed feasible as potential pit sites due to [redacted]. Holliday expanded the search and identified two higher potential areas. An attempt was made to contact the current owner of record of each parcel in the potential area to see if (a) they were willing to sell their land, and (b) at what price per acre they would be willing to sell. We received either a "not interested [in selling]" response or were unable to reach the current owner. We conducted a search of online sites to compile the asking price of local parcels greater than [redacted] and also utilized the price per acre paid for Holliday's Kansas pit site acquired in 2006. Finally, a local broker was contacted in our search for a representative price per acre. Our discussion with the broker was limited in order to protect Holliday's identity and interests, and without a specific site to discuss the broker admitted that land prices can vary greatly depending on the site and soil quality. There are seven comparables used in our analysis, but it should be noted that all but one of these is based on the asking price of a willing seller for land that is not necessarily suitable for a pit mine. It is reasonable to give more weight to an actual transaction price paid for a pit mine, so we have done just that in our analysis, which results in an average price per acre of $[redacted]. (See Exhibit G)

From the evaluation of geotechnical drill logs from the Missouri floodplains, Holliday estimates a typical pit depth of [redacted] will yield [redacted] of specification sand, which equates to just over [redacted] tons per acre and requires mining a total of [redacted] annually to replace the current permit for river dredging volume of two million tons of finished product. In addition to the [redacted] a pit site requires additional land for setbacks, equipment and stockpiles, roads and the truck scale. Holliday estimates approximately [redacted] of the gross pit site acreage is required for these indirect production uses. Thus, approximately [redacted] total pit site acres are needed annually. Assuming the purchase of [redacted] in total for a pit mine or pit mines to service the current Riverside and Randolph customers, the pit(s) would be depleted in approximately five years. At this same production rate over a 50-year period, [redacted] sites of [redacted]s would be needed or a total of [redacted] over 50 years. Assuming the inflation and discount rates were equal and offsetting, the present value of the real estate costs to Holliday amount to over $[redacted] or $[redacted]5 per ton. (See Exhibit G)

The above $[redacted] in land costs do not take into account the cost of exploration and testing, permitting, wetland mitigation and site setup expenditures that are incurred each time a site is depleted and replaced. Holliday estimates these costs run around [redacted] of the land purchase cost per acre, or an additional $[redacted] per

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ton. (See Exhibit G) This assumes that 5% of the site is wetlands that must be permitted and mitigated at about $[redacted] to $[redacted] per acre. The total land and site cost of $[redacted] per ton does not include any loss of future land use.

Equipment

Much of the same or similar equipment is used to dredge, process and stockpile on the river as in the pit mine. While river dredging requires the use of barges and a towboat, a pit mine requires a fleet of earth moving equipment to strip and rehandle waste sand, in addition to a booster pump (the dredge alone can only pump sand to a plant up to a distance of [redacted] t) and pipeline. [redacted] Earthmoving equipment, pipelines and the plant foundations and electrical have either a shorter life, or must be abandoned upon pit depletion, resulting in higher depreciation expense. [redacted]

Conclusion

An in-depth analysis comparing the delivered cost of sand produced at current river dredging operations versus replacement pit mining operation(s) revealed an increase of nearly [redacted]. The costs due to the overburden fine sand waste, stripping and reclamation, booster pump and pipeline, and ongoing land and setup costs associated with pit mining outweighed the cost of barging and unloading sand at the Missouri River plants. Further, the next[5] nearest potential pit sites are located farther from customers, increasing both trucking and other costs. While an additional cost was not calculated, it should be noted that replacing river dredging with pit mining for the next 50 years and beyond requires ongoing land acquisition, permitting and plant setup at sites that are ever farther from the end user, ever increasing the impacts of trucking sand back

[5] The word next is used here as there are two existing sand pits currently operating five miles east of the Randolph Plant. It has been assumed that these sites will continue to operate as they have been with the current market demand for the next [redacted] years, or if able to ramp up production to supply an additional [redacted] tons to replace river dredging, in which case they would be depleted in [redacted] or less. (This assumes a combined remaining deposit of [redacted] acres at [redacted] tons per acre.)

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to Kansas City. The marginal economic impact of moving commercial river dredging operations to open pit mines results in approximately $644 million over a 50 year period, as reflected in the below table.

River Dredging v. Pit Mining Cost Analysis
(Based on a Production of 2 Million Tons)

	River Dredging	Pit Mining
Total Costs	$ [redacted]	$ [redacted]
Increase (Decrease) of Pit Mining		$ 12,882,000
Total Increase (Decrease) Over 50-Year Period		$ 644,100,000

Very truly yours,

Charles E. Finch, CVA
Managing Director

Enclosures

cc: Aaron Courtney, Stoel Rives LLP
Kevan Fouts, President Holliday Sand & Gravel Company, LLC
Mike Odell, Vice President Holliday Sand & Gravel Company, LLC

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Exhibit A

Holliday Sand and Gravel

Stripping & Reclamation Costs Specific to Pit Mining

	Pit Size (acres)	Pit Depth (ft)	Typ. Depth of Stripping in MO Pit (ft)	MO Pit Stripping (BCY/acre)	Swell Factor in MO Pit	Swell Factor in KS Pit	KS Pit Cost $/BCY	MO Pit Cost $/BCY	Sand Yield Factor	Depth of Saleable Sand (ft)	Spec Sand Yield (tons/acre)	Pit Stripping Cost $/ton
Stripping	200	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$ [redacted]	$ [redacted]	[redacted]	[redacted]	[redacted]	**$** [redacted]

2. Reclamation Costs

The above stripping costs do not include reclamation costs. [redacted]

Sloping Banks	Pit Size (acres)	Perimeter (feet)	Pit Depth (feet)	Finish Slope:1V	CY/LF	Total CY	$/CY	$/Pit Acre	Sand Yield Factor	Depth of Saleable Sand (ft)	Yield (tons/acre)	$/ton
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$[redacted]	$[redacted]	[redacted]	[redacted]	[redacted]	**$** [redacted]

Seeding and Mulching Banks	Pit Size (acres)	Perimeter (feet)	Slope & Bench Length (ft)	Slope Area (acres)	Seeding Cost ($/acre)*	Total Seeding Cost ($)		$/Pit Acre	Sand Yield Factor	Depth of Saleable Sand (ft)	Yield (tons/acre)	$/ton
	[redacted]	[redacted]	[redacted]	[redacted]	$[redacted]	$[redacted]		$[redacted]	[redacted]	[redacted]	[redacted]	**$** [redacted]

Site Grading/Equip Removal/Misc. Reclamation **$** [redacted]

*Seeding Cost includes some redressing of slopes and reseeding.

Total Est. Reclamation Cost/Ton **$** [redacted]

Exhibit A

Holliday Sand and Gravel

Stripping & Reclamation Costs Specific to Pit Mining

Stripping and reclamation costs are not incurred in river dredging and are additive to the cost of pit mining. Holliday has a sand pit operation in Kansas that started in 2013. The costs associated with this pit formed the basis for the Stripping $/ton at a proposed MO Pit. Adjustments to the KS pit costs are necessary to account for (1) the lack of sufficient cost accounting in the KS Pit costs, (2) difference in soil type, and (3) lack of reclamation costs in the KS Pit costs.

KS Pit Stripping Costs ($/cy)

The KS pit began in 2013. The costs related to stripping and bank cubic yards stripped were available for the period May through October to determine the $/cy as reflected for each line item below.

Current KS Pit Stripping Costs (a)	$ [redacted]
Labor: Additional Fringe Benefit Costs (b)	$ [redacted]
Maintenance: Additional Maintenance Costs (b)	$ [redacted]
	$ [redacted]

The following are additional cost adjustments to the KS Pit stripping costs because of insufficient cost accounting:

Stormwater practices	$ [redacted]
Engineering, Supervision	$ [redacted]
Permits, misc	$ [redacted]
Total KS Pit Stripping Cost ($/cy)	**$** [redacted] ↓

(a) - The stripping cost account includes expenses related only to fuel, rent of equipment and labor.

(b) - Fringe benefits, repairs and maintenance of stripping equipment costs are not recorded in the stripping cost account, so must be added.

Determination of $/Ton for Theoretical MO Pit

1. Stripping Costs

The above $/cy is based on Kansas soil in bank cy. It is used as a basis to determine the stripping $/ton for the MO Pit with different soil depth, type and sand yield. Stripping costs are greater in the MO River floodplain because of the soil conditions that affect swell and loadability.

Loadability: The ease at which the soil is excavated. KS Pit has silty soil that is very easy to dig and does not hold moisture. MO Pit soil is saturated clay that is very hard to dig and retains moisture that makes it difficult to drive over, to place and compact.

Swell: Expansion of the soil from bank cubic yards (BCY) to loose cubic yards (LCY) based on soil type. KS has silty soil (swell =10%); MO has clayey soil (swell = 50%). The swell factor is used to adjust the stripping costs to account for both the swell and loadability of the soil.

Exhibit A

Holliday Sand and Gravel

Stripping & Reclamation Costs Specific to Pit Mining

	Pit Size (acres)	Pit Depth (ft)	Typ. Depth of Stripping in MO Pit (ft)	MO Pit Stripping (BCY/acre)	Swell Factor in MO Pit	Swell Factor in KS Pit	KS Pit Cost $/BCY	MO Pit Cost $/BCY	Sand Yield Factor	Depth of Saleable Sand (ft)	Spec Sand Yield (tons/acre)	Pit Stripping Cost $/ton
Stripping	200	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$ [redacted]	$ [redacted]	[redacted]	[redacted]	[redacted]	**$** [redacted]

2. Reclamation Costs

The above stripping costs do not include reclamation costs. Sloping a 95 foot deep wall to a 4:1 average slope requires approx. 400 cy of fill per linear foot of pit bank.

For a 200 acre pit, the perimeter is approx. 11,000 feet. Total CY handled = 4.4MM CY. Estimated $/CY is $0.50 (Dozer = 200 cy/hr @ $100/hr).

Seeding and mulching or hydroseeding costs run approximately $3K/acre. Slope acres for 200 acre pit = 11000' x 80' slope/43560 = 20 acres.

Sloping Banks	Pit Size (acres)	Perimeter (feet)	Pit Depth (feet)	Finish Slope:1V	CY/LF	Total CY	$/CY	$/Pit Acre	Sand Yield Factor	Depth of Saleable Sand (ft)	Yield (tons/acre)	$/ton
	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$[redacted]	$[redacted]	[redacted]	[redacted]	[redacted]	**$** [redacted]

Seeding and Mulching Banks	Pit Size (acres)	Perimeter (feet)	Slope & Bench Length (ft)	Slope Area (acres)	Seeding Cost ($/acre)*	Total Seeding Cost ($)		$/Pit Acre	Sand Yield Factor	Depth of Saleable Sand (ft)	Yield (tons/acre)	$/ton
	[redacted]	[redacted]	[redacted]	[redacted]	$[redacted]	$[redacted]		$[redacted]	[redacted]	[redacted]	[redacted]	**$** [redacted]

Site Grading/Equip Removal/Misc. Reclamation	**$** [redacted]
Total Est. Reclamation Cost/Ton	**$** [redacted]

*Seeding Cost includes some redressing of slopes and reseeding.

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Exhibit B

Holliday Sand and Gravel

Surplus Waste Rehandling Costs Specific to Pit Mining

Pit dredging averages about [redacted] total waste material and river dredging averages about [redacted] waste material. The excess fines and gravel from river dredging are dropped back into the dredge hole at no added cost of handling, but the waste from pit dredging must be rehandled away from the plant.

The cost to rehandle just the soil stripping is already included in the stripping cost analysis (see Exhibit A).

Holliday estimates [redacted] tons of fill sand will be sold each year. This can vary greatly and will be dependent upon large projects in the near vicinity.

1. Determine quantity of fine sand waste to rehandle

From the Dredging EIS evaluation of geotechnical Drill Logs:

Sand Yield Factor	[redacted]

MO Pit	Total Depth	Over-burden	+4M & -200M waste	Total Sand Depth	Spec Sand (less waste) (ft)	Waste sand/ gravel	Fill sand sales (tons/yr)	Annual Sales	Total Waste (tons/yr)	Waste to Rehandle (tons/yr)
Depths (ft)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
CY/acre						[redacted]	[redacted]			
tons/acre					[redacted]					
Waste/Spec Sand (CY/ton)						[redacted]	a			

2. Calculate the cost to rehandle the excess waste

Waste sand is processed in the plant, dewatered and stockpiled. Once the stockpile is full, the sand must be relayed using front-end loader and at some distance trucks.

Material placement and dozing is excluded here as it has been included in the reclamation costs. The costs below include equipment operating costs plus labor.

Waste Sand Hauling Equip.	$/hr operated	CY/hr	$/CY	$/ton sold
Front end loader	$ [redacted]			
2 Haul Trucks	$ [redacted]			
Dozer	$ -			
Total	**$** [redacted]	[redacted]	**$** [redacted]	b
Processed Fines rehandling cost per ton sold				**$** [redacted] **= a x b**

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CONTAINING CONFIDENTIAL PROPRIETARY BUSINESS INFORMATION

Exhibit C

Holliday Sand and Gravel

Additional Dredge Costs Specific to Pit Mining

There is an additional energy cost associated with a long ([redacted] foot average) pipeline used in pit dredging. This [redacted] foot pipeline is not needed in river dredging because the river dredge is attached to the floating plant barge. The pit dredge must also pump twice the sand volume as the river dredge to achieve the desired net tonnage of marketable sand, which results in the additional energy charge.

1. Compare operating cost for dredge engines, pit vs river due to pumping distances

	Marketable Yield (%)	Net Tons/Hr Req'd.	Gross Tons/Hr Req'd.	GPM	Discharge Head (ft)	Pump eff.	HP	Diesel (gal/hr)	Diesel ($/ hr) @$2.66/gal	Diesel Cost ($/ton)
Pit Dredge	[redacted]%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$ [redacted]	$ [redacted]
River Dredge	[redacted]%	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	$ [redacted]	$ [redacted]
									Added fuel cost of pit dredge engine	**$ [redacted]**

Pit dredge must pump twice as much sand to yield the same net tonnage of marketable sand.

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Exhibit D

Holliday Sand and Gravel

Transportation Costs Specific to River Dredging

Barge towing is a transportation cost specific to river dredging, and reduces the transportation costs of pit dredging. Barge towing requires five additional operators per shift and increased costs associated with the operation of the towboat and equipment used in unloading sand from the barge.

Assume Annual Tons Sold [redacted]

Description of Added River Cost	Annual Savings $	Explanation	Production Rate (tons/hr)	Hours/ Year	$/Hr
[redacted] operators instead of [redacted] per shift	[redacted]	Labor: [redacted] Less Operators @ $[redacted]/hr (a)	[redacted]	[redacted]	$ [redacted]
Towboat Op Cost of Towing Sand	[redacted]	Average tow = [redacted] miles (one way): fuel ($2.66/gal), boat ($[redacted]/hr), barge ($[redacted]/hr)	[redacted]	[redacted]	$ [redacted]
Equip Op Cost of Unloading Sand	[redacted]	Dock barge ($[redacted]/hr), Loader ($[redacted]/hr)	[redacted]	[redacted]	$ [redacted]
Total Added Annual Cost	[redacted]				
Added ($/ton)	[redacted]				

(a) Five operators used in river operation that are not needed in pit operation:

- Towboat Operator
- Towboat Deckhand
- Dredge Engineer
- Dock Barge Operator
- Stilt Shed Operator

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Exhibit E

Holliday Sand and Gravel

Transportation Costs Specific to Pit Dredging

Pit mines require long pipelines and booster pumps that are not needed for river dredging.

1. Estimate the annual cost per ton to operate a booster and pipeline in a pit

Tons Produced	[redacted]
Tons/Hour	[redacted]
Hours/Year	[redacted]

	Approx $/hour	Annual Costs ($)	
Booster Pump Parts	$ [redacted]	[redacted]	
2000' 16" Pipeline Costs	$ [redacted]	[redacted]	
Fuel Cost (a)	$ [redacted]	[redacted]	
Repair Labor	$ [redacted]	[redacted]	
10 year Depreciation	$ [redacted]	[redacted]	
Total		[redacted]	
		$ [redacted]	**$/ton**

(a) Fuel costs based on the following:

Diesel gal/hr		[redacted]
$/gal	$	2.66

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Exhibit F
Holliday Sand and Gravel
Trucking Costs For River Dredging and Pit Mining

Two potential pit mine sites were identified, one to replace Holliday's current Riverside Missouri River dredging plant, and the other to replace the Randolph Missouri River dredging plant. It is assumed Holliday would be able to purchase these properties, although the property owners were unable to be reached. The distances from the current customers to each current plant and the replacement pit mine sites were calculated and compared to determine additional travel miles (based on the weighted average ton-mile) and associated costs.

1. Off-Site Trucking Costs

	Current		
Trucking cost per ton-mile:	$ [redacted]	(a)	
Annual Production	[redacted]		
Number of Loads with 33-Ton Limit	[redacted]		
Number of Loads with 23-Ton Limit	[redacted]		
Increase in Loads	[redacted]%	(b)	
	Revised Cost		
Trucking cost per ton-mile of increased loads:	$ [redacted]		

	Riverside	Randolph
Distance between current customer base to Potential Pit Site: (c)	[redacted]	[redacted]
Distance between current customer base to Current Plant:	[redacted]	[redacted]
Trucking Costs to Potential Pit Site:	$ [redacted]	$ [redacted]
Trucking Costs to Current Plant:	$ [redacted]	$ [redacted]
Net	$ [redacted]	$ [redacted]
Average Additional Trucking Costs:	**$ [redacted]**	

(a) The current average cost of $[redacted] per ton-mile was obtained from Holliday's discussions with their customers. We note this is also the average cost per ton-mile provided in the 1998 Kansas River Corridor Study.

(b) The estimated average trucking payload inside the Commercial Zone in MO is [redacted] tons per load. The estimated average trucking payload outside the Commercial Zone in MO and all to or from KS is [redacted] tons per load. Given the locations of the nearest potential pit sites, it is most likely that any additional distances will be outside the commercial zone. Therefore, trucks will have to travel farther and with less product, increasing trucking costs. That is, approximately 43% more loads will be necessary due to the lower ton limit in rural areas. All potential pit

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Exhibit F
Holliday Sand and Gravel
Trucking Costs For River Dredging and Pit Mining

sites extend into the rural areas.

(c) A potential pit site was identified and assumed to be available for purchase to replace the [redacted] plant for this analysis. A second potential pit was identified and assumed to be available for purchase to replace the [redacted] plant for this analysis.

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Exhibit G

Holliday Sand and Gravel

Real Estate Costs Specific to Pit Mining

Pit mining requires obtaining enough acreage suitable for a dredging operation. The site cannot be located near water wells and must avoid levees, dense populations and extensive wetlands. Holliday performed an in-depth search of potential sites, evaluating truck access, bridges in route, and known permitting levee, railroad and wetland issues.

1. Total Acres per Pit Site

MO Pit	Total Depth	Sand Yield Factor	Spec Sand (less waste) (ft)
	[redacted]	[redacted]	[redacted]

Tons/Acre	[redacted]
Total acres to produce [redacted] tons annually	[redacted]
Total production acres needed for a 5-year site	[redacted]
Total pit site acres	[redacted]

2. Total Acres Over 50-Year Period

Number of sites in a 50-year period	[redacted]
Number of acres over 50-year period	[redacted]0

(a) It is estimated that setbacks require [redacted]% of the site's acreage. Additionally, approximately [redacted]% of the site's acreage are needed for plant equipment, stockpiles, roads and the truck scale. The net acreage remaining for production is [redacted]%.

3. Land Price

	Acres	Price	$/Acre	Weight
Land Comp 1 (a)(d)	[redacted]	$ [redacted]	$ [redacted]	1
Land Comp 2 (b)(e)	[redacted]	$ [redacted]	$ [redacted]	1
Land Comp 3 (b)	[redacted]	$ [redacted]	$ [redacted]	1
Land Comp 4 (b)(e)	[redacted]	$ [redacted]	$ [redacted]	1
Land Comp 5 (c)			$ [redacted]	1

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Exhibit G

Holliday Sand and Gravel

Real Estate Costs Specific to Pit Mining

Land Comp 6 (e)	[redacted]	$ [redacted]	$ [redacted]		1
Land Comp 7 (f)			$ [redacted]		2
Average price per acre			$ [redacted]	$ [redacted]	
Total Land Cost Over 50-Year Period:				$ [redacted]	(g)
Land Cost per Ton:				$ [redacted]	
Site Setup Costs per Acre: ([redacted]%)				$ [redacted]	
Total Costs				**$ [redacted]**	

(a) There was one property listed for sale of [redacted] acres or more in [redacted] County, Missouri, per [redacted]. This land may or may not be suitable for a pit mine, but was used as a price per acre comp.

(b) There were three properties listed for sale of [redacted] acres or more in [redacted] County, Missouri, per [redacted]. These properties may or may not be suitable for a pit mine, but were used as a price per acre comp.

(c) Per a local broker when asked for a general price per acre for [redacted] or more acres in the surrounding Kansas City rural areas, the general range was $[redacted] to $[redacted], but the broker noted that could vary drastically depending on the site and soil.

(d) There was one non-commercial property listed for sale of [redacted]acres or more in [redacted] County, Missouri, per [redacted]. This land may or may not be suitable for a pit mine, but was used as a price per acre comp.

(e) There were three non-commercial properties listed for sale of [redacted]acres or more in [redacted] County, [redacted] per [redacted]. These properties may or may not be suitable for a pit mine, but were used as a price per acre comp.

(f) Price per acre paid for Holliday's Kansas pit mine.

(g) It is assumed the inflation and discount rates would offset each other, so the present value of the real estate costs would be $[redacted] million over the 50-year period.

LafargeHolcim

May 6th, 2020

VIA EMAIL AND U.S. MAIL

Matt Shively, Regulatory Project Manager
U.S. Army Corps of Engineers
Kansas City Regulatory Office
601 East 12th Street
Kansas City, MO 64106

matthew.s.shively@usace.army.mil

Re: Missouri River Commercial Sand Dredging Permits

Gentlemen:

This letter is in response to your Public Notice dated March 18, 2020, regarding permits requested by Capital Sand Company, Inc.; Hermann Sand & Gravel, Inc.; Holliday Sand & Gravel Company; Con-Agg of Missouri, LLC; Limited Leasing Company; and J.T.R., Inc.; hereinafter "Dredgers."

Commercial sand dredgers provide most of sand material for the construction industry. The sand goes into concrete that provides our roads, bridges, sidewalks, homes, driveways, etc. in the State of Missouri and parts of Kansas. Missouri River sand is of high quality and important to the construction trades.

Dredging has taken place on the Missouri River long before the Corps developed the Bank Stabilization and Navigation Project. The dredging interests have complied with permit requirements previously issued by the Corps of Engineers in previous permits.

The permits provide for an accommodation of the endangered pallid sturgeon. The Dredgers present no other impacts to any other endangered or threatened species on the River.

The Dredgers provide a source of employment and pay taxes in their respective communities. They participate in their local communities, providing donations and other contributions to civic betterment.

The undersigned supports the Corps re-issuing permits for commercial sand dredging on the Missouri River.

Very truly yours,

Joe Berlucchi
Commercial Manager, River Region

cc: Missouri Department of Natural Resources
PO Box 176

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Jefferson City, MO 65102-0176

Kansas Department of Health and Environment
Bureau of Environmental Field Services
Watershed Management Section
1000 SW Jackson Street, Suite 430
Topeka, KS 66612-1367