US Army Corps
of Engineers ®
Kansas City District

Missouri River Bed Degradation Feasibility Study

Technical Report

May 2017

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Executive Summary

The U.S. Army Corps of Engineers, Kansas City District (USACE), in cooperation with the Mid-America Regional Council, has conducted a study to evaluate the bed degradation problem to determine if there is a federal interest in any alternatives to eliminate or minimize bed degradation in portions of the lower Missouri River and its tributaries between river mile (RM) 457 near St. Joseph, Missouri and RM 329 near Waverly, Missouri. The Mid-America Regional Council serving as the non-federal sponsor, facilitated the engagement of a supporting stakeholder group made up of entities representing a wide variety of interests including water supply, utility, transportation, levee districts, counties, municipalities, and commercial sand and gravel mining (also referred to as commercial dredging). The study was conducted under Section 216 of the Flood Control Act of 1970 (Public Law 91-611). The study did not result in the development of a recommended plan for implementation. This technical report has been prepared to document and present information regarding the evaluation conducted and the technical findings of the project.

Bed degradation is the erosion or down cutting of the river channel. Bed degradation in this portion of the river is a significant problem that has caused considerable and costly damages to federal, state, and local infrastructure. Depending on the extent, continued bed degradation has the potential to negatively impact navigation structures, levees and floodwalls, bridges, water supply-intakes, and a host of other features. Results from this study indicate cumulative expenses (investments and repairs) in the amount of $269 million (fiscal year 2017 dollars) would be incurred to adjust for degradation and associated low-water-surface elevations over the 50-year period of analysis if the problem is not addressed. The average annual cost would be $5.3 million assuming the fiscal year 2017 discount rate of 2.875%. The study was initiated after conducting a reconnaissance study to determine if there was a federal interest in addressing the bed degradation problem. The 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.

This study considered both structural measures that could be recommended for implementation under the Section 216 study authority as well as non-structural measures (i.e. channel-mining restrictions) that could be considered for analysis as part of the Section 10 of the River and Harbors Act of 1899 and Section 404 of the Clean Water Act permitting process and/or Section 14 of the Rivers and Harbors Act of 1899, 33 USC 408 (Section 408) permitting process. However, optimization of non-structural

measures (i.e channel-mining restrictions) that could be implemented under these permit authorities are beyond the scope of the analysis. This study quantified the effectiveness of structural and non-structural measures individually and in combination, which allowed for the evaluation of a full range of alternatives as required in Engineering Regulation 1105-2-100, Planning Guidance Notebook and the Council of Environmental Quality's National Environmental Policy Act implementing regulations (40 CFR Part 1502.14(c)).

The report also documents the development of two models that were used to evaluate alternative plans: (1) A Hydrologic Engineering Center River Analysis System (HEC-RAS) sediment model to project future water surface and bed elevations and (2) an economic model that assesses the economic damages of projected bed degradation. These are new tools that were developed specifically for this study that were not available to previous studies that evaluated bed degradation within the study area. The HEC-RAS sediment model is also referred to as the Mobile-bed model. The economic model was approved for one-time use in this analysis. It is noted that while the economic model and HEC-RAS sediment model may potentially have application toward other studies, a review of suitability to meet the study specific objectives would be needed. The report documents the findings from the evaluations conducted using these models.

The HEC-RAS sediment model was used to project future bed and water-surface elevations for a variety of alternative plans including the future condition if no actions were to be taken to address bed degradation. Plan formulation involved the identification of measures that met the project objectives and avoided project constraints. Measures that were removed from consideration based on these criteria included sand and gravel augmentation to the river, sediment bypass around Gavins Point Dam, and abandonment of the maintenance of the BSNP structures. Details concerning the screening out of these and other measures are included in the body of this report.

Measures that were retained for evaluation included modifying the BSNP dike and sill structures, widening the channel banks, installing new rock grade-control structures, and modifying the amount of commercial sand and gravel mining in the river (Table 9.1). These measures were carried forward as independent alternatives, or combined together to develop a total of 15 alternative plans for the study. Plans that were less physically robust (less comprehensive BSNP adjustments) were not evaluated in detail based on the low performance outcome of the more robust plans. This resulted in nine of the plans being evaluated in detail between RM 457 near St. Joseph, Missouri and RM 329 near Waverly, Missouri:

- Alternative 1A – No-Action/Future Without-Project Condition which Maintains Existing Commercial Sand and Gravel mining.
- Alternative 1B – Reduced Commercial Sand and Gravel Mining,
- Alternative 1C – Eliminate Commercial Sand and Gravel Mining,
- Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining,
- Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining,
- Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining,
- Alternative 5A – Install New Rock Grade-Control Structures & Maintain Existing Commercial Sand and Gravel Mining,
- Alternative 5B – Install New Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining, and
- Alternative 5C – Install New Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining.

For Alternative 1A – No-Action/Future Without-Project Condition, which assumes that commercial sand and gravel mining in the channel continues at the currently permitted amounts into the future, model projections indicate that the reach of the river between St. Joseph and the Platte River confluence would continue to degrade. The projected degradation at St. Joseph, Missouri reaches 4.6 feet by the end of 50 years. The Kansas City area is expected to continue a recovery trend for the near term. Projections indicate that at the currently permitted commercial sand and gravel mining quantities, degradation in the reach downstream of the Kansas City area will migrate upstream over time and induce a new degradation trend starting in about year 2043. Reaches between the downstream boundary of the Kansas City metropolitan area and Waverly, Missouri are projected to degrade up to an additional 4.2 feet.

The technical evaluation found that lowering BSNP dikes and sills (Alternatives 4A, 4B, and 4C) would be largely ineffective in addressing the bed degradation problem. It also determined that rock grade-control structures (Alternatives 5A, 5B, and 5C) could address bed degradation in the vicinity of St. Joseph, Missouri but this would decrease bed recovery in the Kansas City area. While bed stabilization within the upper study reach can be achieved with fewer grade-control structures, ensuring river navigability requires additional, closer-spaced grade-control structures which greatly increases cost. Rock grade-control structures are not economically viable alternatives.

Currently, channel mining is authorized at approximately six million tons/year (4.4 million cubic yards/year) over the lower 500 miles of the Missouri River. Of that, approximately 2.6 million tons/year (1.9 million cubic yards) is authorized for extraction within the study reach (from the Missouri River between St. Joseph and Waverly, Missouri). Reductions and eliminations in commercial sand and gravel mining (Alternatives 1B and 1C) substantially reduce bed degradation in St. Joseph and result in increased bed recovery in Kansas City compared to the current degraded condition. By the end of the 50-year period of analysis, none of the alternatives evaluated would result in bed elevations in Kansas City returning to elevations observed in 1987.

The economic evaluation of alternatives was conducted using the Missouri River Economic Model to determine National Economic Development (NED) benefits as required to determine federal interest in a structural solution to the problem. The alternative that would provide the greatest net-economic benefits is a non-structural alternative: Alternative 1C – Eliminate Commercial Sand and Gravel Mining. Alternative 1B – Reduced Commercial Sand and Gravel Mining, also a non-structural alternative would provide a very similar amount of net benefits to Alternative 1C. Note that the economic model does not attempt to optimize sand and gravel mining in terms of net NED benefits. The model evaluated net NED benefits for all alternatives, including the No-Action Alternative at three levels of dredging (currently permitted dredging, reduced dredging, and elimination of dredging), which were held constant over the 50-year period of analysis.

BSNP modifications when combined with modification of sand dredging: Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining and Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining provide nominal positive-net-economic benefits in the base-case analysis, and greater positive-net-economic benefits in the more-degradation scenario as well as the three-year advance sensitivity analysis. These alternatives do not provide positive-net economic benefits at the less-degradation scenario. For detailed descriptions regarding the less-degradation, more-degradation and three-year-advance scenarios see Appendix C – Future Without-Project Model Projections with Risk and Uncertainty, and Appendix O – Economic Analysis.

The BSNP modification Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining does not provide positive-net-benefits in the base-case analysis or other scenarios (less-degradation, more-degradation, or three-year advance sensitivity analysis).

It is important to note that in the base-case, more-degradation and three-year-advance sensitivity analyses alternatives 4B and 4C have lower NED benefits than Alternatives 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining, respectively, indicating that additional benefits from BSNP adjustments do not justify the additional cost compared to channel mining reduction or elimination alone.

Alternatives that include measures for grade-control structures (Alternatives 5A, 5B, and 5C) would not result in positive-net-economic benefits under base-case assumptions nor under any of the sensitivity analyses conducted.

Based on the economic analysis, the base-case alternatives 4B and 4C have lower NED benefits than Alternatives 1B and 1C, respectively, which indicates that there is no federal interest in a structural solution to the problem. The alternatives that would result in the greatest positive NED benefits are the reduction or elimination of commercial sand and gravel mining in the study reaches of the Missouri River (Alternatives 1B and 1C). It is noted that the terms dredging and mining have been used interchangeably in reference to in-river sand and gravel mining in this study and other studies historically. Modifications to the permitted quantity of commercial sand and gravel mining are outside the Section 216 decision authority. Rather, these activities are regulated under the purview of the USACE regulatory and USACE Section 408 processes.

Decisions in the permit renewal/reissuance process are made using criteria established in the adaptive management framework that was adopted in the *Record of Decision for Authorization of Commercial Sand and Gravel Dredging on the Lower Missouri River*, dated March 2011. Information regarding the adaptive management framework can be found in section 4.2.3.1.3 of the record of decision. Permits are evaluated every five years. The most recent permit renewal decision was made in Renewal/Reissuance recorded in January 2016. A link to the regulatory documents is located on the regulatory website at: http://www.nwk.usace.army.mil/Missions/Regulatory-Branch/Missouri-River-Commercial-Dredging/. Information pertaining to the Section 408 permitting process can be found in Engineering Circular 1165-2-216 Policy and Procedural Guidance for Processing Requests to Alter U. S. Army Corps of Engineers Civil Works Project Pursuant to 33 USC 408. A copy of this document can be found at: http://www.usace.army.mil/Missions/Civil-Works/Section408/. As there is no federal interest in a structural solution at the currently permitted level of commercial sand and gravel mining, the economic evaluation does not support justification of a project recommendation that would require congressional authorization.

Policy requires evaluation of acceptability in addition to the evaluation of completeness, effectiveness, and efficiency of the alternative plans. Acceptability is the extent to which alternative plans are acceptable in terms of applicable laws, regulations, and public policies. Because the study did not recommend a structural plan for implementation pursuant to Section 216 authority, these items were not evaluated to the level of detail that is typical for a feasibility study decision document or a National Environmental Policy Act decision document such as an environmental assessment or Environmental Impact Statement. Limited analysis of potential environmental consequences and cursory-Regional Economic Development (RED) analysis was conducted to help understand acceptability.

Regional income and regional employment are the metrics that are typically evaluated for an RED analysis. Only existing publically available information was used to conduct the RED analysis because more direct information from the sand and gravel mining industry was not made available in time for consideration. Existing publically available information including detailed industry operation information as well as information regarding distances from pit mine and dredged material stockpiles. Additional information was gathered from regional price quotes.

The RED analysis focuses on the local impact of reducing or eliminating commercial sand and gravel mining from the bed of the Missouri River within the focused study area. Note that the primary economic evaluation criterion for this study is changes to NED based on a national perspective without differentiation of which sector of the economy or which region of the country benefits or is adversely affected. Therefore, RED impacts were not fully examined as part of this study. Overall, the RED effects of reducing or eliminating commercial dredging from RM 457 near St. Joseph, Missouri to RM 329 near Waverly, Missouri are estimated to be marginal and any employment and income losses would be largely offset by employment and income gains in land-based operations that provide commercial sand and gravel.

Direct impacts to the single entity that commercially mines sand and gravel from the Missouri River in the St. Joseph and Kansas City reaches and direct impacts to the two entities that commercially mine sand and gravel from the Missouri River in the Waverly reach were not evaluated. Direct impacts to either a single entity or both entities may require further consideration under any future decision-making processes concerning commercial sand and gravel mining in the study reach of the Missouri River.

Because environmental impacts of alternatives were not evaluated in detail, it is uncertain if any of the alternatives described would result in significant direct, indirect, or cumulative impacts to the environment. Compared to the existing condition, the geomorphology of the river would change for all of the alternatives, including the No-Action/Future Without-Project Condition. A detailed assessment of flood heights or flood damages was not undertaken as part of this study. Some of the alternatives would have the potential to result in impacts to flood heights, as well as water quality, fish and wildlife, threatened and endangered species, land use, and cultural resources.

In the 2011 *Missouri River Commercial Dredging Final EIS* (USACE, 2011a) it was determined that commercial sand and gravel mining cumulatively affected geomorphology (river geomorphology and sediment), water quality, aquatic resources including fish and wildlife habitat and diversity of habitat, threatened and endangered species, economics, cultural resources, and infrastructure. River geomorphology was the primary cumulatively affected resource. These resource categories could also be cumulatively impacted by alternatives described in this report. Other resource categories not identified here also have the potential to be impacted directly, indirectly, or cumulatively.

While the study conducted and documented in this Missouri River Bed Degradation Feasibility Technical Report did not find a federal interest in a structural solution to the problem or a project implementable pursuant to Section 216 authority, the evaluation and findings provide new and useful information that was not available during previous investigations concerning bed degradation within the study area. The study also addressed uncertainty described in the *Missouri River Bed Degradation Reconnaissance Study, Section 905(b) Analysis* (USACE, 2009) and the *Missouri River Commercial Dredging Final EIS* (USACE 2011a) related to the effectiveness of potential modifications to the BSNP to reduce ongoing bed degradation. A summary of key findings is presented in Section 13 of the report.

The HEC-RAS sediment model and the economic model, while limited to the geographic scope of this study, are recommended to the agency to inform future agency decisions. The HEC-RAS model will also be useful in providing information to stakeholders in planning future activities in and along the river. It is also recommended that the HEC-RAS and economic modeling be expanded to encompass the entire lower Missouri River.

Table of Contents

ACRONYMS

BSNP	Missouri River Bank Stabilization and Navigation Project
CRP	Construction Reference Plane
CWA	Clean Water Act
EIS	Environmental Impact Statement
HEC-RAS	Hydrologic Engineering Center – River Analysis System
MARC	Mid-America Regional Council
NED	National Economic Development EIS
NRC	National Research Council
O&M	Operations and Maintenance
RED	Regional Economic Development
RM	river miles
USACE	U.S. Army Corps of Engineers, Kansas City District
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey

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1 INTRODUCTION

The U.S. Army Corps of Engineers, Kansas City District (USACE), in cooperation with the Mid-America Regional Council (MARC), has conducted a study to evaluate the bed degradation problem and determine the feasibility of measures to eliminate or minimize bed degradation in portions of the lower Missouri River and its tributaries (Figure 1-1). Bed degradation is the erosion or down-cutting of the river channel. Bed degradation on the lower Missouri River is a significant problem that has caused considerable and costly damages to federal, state, and local infrastructure. Continued bed degradation has the potential to negatively impact navigation structures, levees and floodwalls, bridges, water-supply intakes, utility intakes, and a host of other features. The scope of the study extended from river mile (RM) 500 near Rulo, Nebraska to RM 0 at the confluence of the Missouri and Mississippi Rivers near St Louis, Missouri. Following an initial evaluation to identify where the problem was most severe, the study focused on the Missouri River between RM 457 near St. Joseph, Missouri and RM 329 near Waverly, Missouri. Results from this study indicate cumulative expenses (investments and repairs) in the amount of $269 million (fiscal year 2017 (FY17) dollars) would be incurred to adjust for degradation and associated low water-surface elevations over the 50–year period of analysis if the problem is not addressed. The average annual cost would be $5.3 million assuming the FY17discount rate of 2.875%.

This study was initiated after conducting a reconnaissance study to determine if there was a potential federal interest in addressing the bed degradation problem. The 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 extent of contributions to the problem by these factors was not fully evaluated at that time and additional study was recommended.

This study also addresses uncertainty described in the *Missouri River Commercial Dredging Final Environmental Impact Statement (EIS)* (USACE, 2011a) related to the effectiveness of potential modifications to the BSNP to reduce ongoing bed degradation. That EIS was prepared as part of an application by commercial sand and gravel mining companies to continue extracting material from the bed of the Missouri River in accordance with Section 10 of the River and Harbors Act of 1899 (33 United States Code [USC] 403) and Section 404 of the Clean Water Act (CWA) (33 USC 1344). The request to continue commercial sand and gravel mining was granted with limitations including the requirement that it be re-evaluated every five years based on current bed conditions. At the time the EIS was completed, it was not known if modifications to the BSNP structures could reduce or eliminate further bed degradation. This technical report also presents new information on the long-term effects of future in-channel sand and gravel mining of the Missouri River.

Figure 1-1: The study evaluated bed degradation in the lower Missouri River from near Rulo, Nebraska to its confluence with the Mississippi River.

The bed degradation study was conducted as a cost-shared project between the local sponsor, MARC, and the federal government through USACE. The specific study authority is Section 216 of the Flood Control Act of 1970 (Public Law 91-611). Section 216 provides authority to USACE to review completed civil works projects due to changed physical or economic conditions. In this case, the completed project is the BSNP. Section 216 explicitly states:

> *The Secretary of the Army, acting through the Chief of Engineers, is authorized to review the operation of projects the construction of which has been completed and which were constructed by the Corps of Engineers in the interest of navigation, flood control, water supply, and related purposes, when found advisable due to significant changed physical or economic conditions, and to report thereon to Congress with recommendations on the advisability of modifying the structures or their operation, and for improving the quality of the environment in the overall public interest.*

The *Economic and Environmental Principles and Guidelines for Water and Related Land Resources Implementation Studies* (U.S. Water Resources Council, 1983) and Engineering Regulation 1105-2-100, Planning Guidance Notebook provides requirements for conducting studies within the USACE civil works program. None of the structural plans that were evaluated in this study support a federal interest in constructing a solution to the problem. However, two non-structural plans may address the bed degradation problem and may be economically justified.

Because a federally cost-shared project was not identified that could be implemented pursuant to Section 216 authority, the decision was made to discontinue preparation of a feasibility report. Instead, this technical report has been prepared to document the methods of analysis and the findings of the study. This report also documents the development of two models that were used to evaluate alternative plans: (1) A Hydrologic Engineering Center River Analysis System (HEC-RAS) sediment model to project future water surface and bed elevations and (2) an economic model that assesses the economic damages of projected bed degradation.

As stated previously, MARC is the local cost-sharing sponsor for the study. MARC is a regional planning agency that has facilitated the engagement and funding of a stakeholder group comprised of 18 entities. The stakeholder group represents a wide range of interests including water supply, transportation (rail and highway), levee districts, commercial sand and gravel mining, and city, county, and state governments. The group also includes state and federal resource agencies including the U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service (USFWS), U.S. Geological Survey (USGS), and Missouri Department of Natural Resources. All of the participants in the stakeholder group provided financial or technical contributions to the study. See Table 1-1 for a list of all stakeholders. The extensive work of MARC, as the cost-sharing sponsor, and contributions from all of the stakeholders and agencies involved have been essential to the study and very helpful in the completion of this report.

Table 1-1: Stakeholder group for the Missouri River Bed Degradation study.

BNSF Railway Company	Kaw Valley Drainage District
City of North Kansas City/North Kansas City Levee District	Kansas City Power & Light
City of Parkville, Missouri	Leavenworth, Kansas Water Department
City of Riverside, Missouri	Mid-America Regional Council
Fairfax Drainage District	Missouri Department of Transportation
Holliday Sand & Gravel	Platte County, Missouri
Independence Water, Missouri	U.S. Environmental Protection Agency
Kansas City, Missouri Water Services	U.S. Fish and Wildlife Service
Kansas City, Missouri Water Supply	U.S. Geological Survey
Missouri Department of Natural Resources	Village of Farley/Levee District at Farley
Kansas Water Office	WaterOne of Johnson County, Kansas

Changes in riverbed elevations occur in response to imbalances in the sediment budget. Bed degradation occurs when the rate of sediment leaving exceeds the rate of sediment entering the active river bed for a reach of river. Sediment leaves a reach by transporting downstream, by depositing on the floodplain or in other areas not accessible for re-entrainment, or by leaving the river system entirely through channel mining. Sediment enters a reach from the channel immediately upstream and from tributary and bank erosion inputs.

Each reach of river is connected to the upstream and downstream reaches. The reach immediately upstream provides the majority of the sediment that enters the downstream reach. Anything that decreases the sediment transported out of the upstream reach will decrease the sediment transported into the downstream reach. Figure 1-2 illustrates this inter-connectedness.

A downstream reach can also impact the upstream reach. If the bed degrades significantly in a concentrated area (sometimes called a knickpoint or a headcut), the slope of the river (and hence the velocity and sediment transport) increases in the reach immediately upstream. This causes degradation in the upstream reach. Degradation propagating upstream in this manner is called headcutting. In large sand-bed rivers, headcuts persist more often as oversteepened reaches rather than as abrupt changes in elevations. As explained later in this report, degradation on the Missouri River in Kansas City has migrated upstream and is projected to continue migrating upstream on the mainstem Missouri River. Additionally, degradation on the mainstem Missouri River has resulted in headcuts up multiple tributaries, causing significant damage (see Section 3.3 below).

Figure 1-2: Inter-Connectedness of Missouri River Reaches. Bed elevation changes are a function of the incoming and outgoing sediment loads. Channel mining represents a

unique kind of outgoing sediment load in that the sediment leaves the system entirely rather than contributing to the sediment load downstream.

The measures considered in this study either increase the sediment entering a reach of the river, decrease the sediment transported downstream by decreasing the hydraulic forces, or decrease the sediment that leaves the river system by decreasing channel mining.

2 OPERATION OF THE MISSOURI RIVER

The Missouri River is a highly regulated and stabilized river that flows approximately 2,341 miles from southwest Montana, intersecting or bordering the states of North Dakota, South Dakota, Iowa, Nebraska, Kansas and Missouri before joining the Mississippi River near St. Louis, Missouri (Figure 2-1). The river drains an area of approximately 530,000 square miles. The Missouri River provides important social and economic benefits to the nation. These benefits are derived in part from congressionally authorized purposes of the federal projects that provide for flood control, water supply, navigation, water quality, irrigation, recreation, hydropower, and fish and wildlife. The average annual benefits from Missouri River projects designed to meet these purposes exceed $2.2 billion in fiscal year 2015 prices (USACE, 2016). Many of these benefits are derived from the Missouri River Mainstem Reservoir System and the BSNP. A basic description of the operation of the Missouri River is needed to understand the bed degradation problem.

Figure 2-1: The Missouri River is located in the central United States.

2.1 Missouri River Mainstem Reservoir System

The Missouri River Mainstem Reservoir System was authorized by the Flood Control Act of 1944 (P.L. 78-534). This act authorized a series of six dams along the middle and upper portions of the Missouri River. These dams, along with their reservoirs, are Fort Peck Dam (Fort Peck Lake) in Montana; Garrison Dam in North Dakota (Lake Sakakawea); Oahe Dam (Lake Oahe), Big Bend Dam (Lake Sharpe), and Fort Randall Dam (Lake Francis Case) and Gavins Point Dam (Lewis and Clarke Lake) in South Dakota (Figure 2-2). Construction of the dams was completed in 1964. Combined, the Missouri River Mainstem Reservoir System provides about 72.4 million acre-feet of water storage capacity and controls runoff from 279,480 square miles of the upper Missouri River basin to provide for flood-risk management and the other authorized purposes (USACE, 2006). The Mainstem Reservoir System provides flood-risk management to over two million acres of land in the Missouri River floodplain (USACE, 2006). Management of the Mainstem Reservoir System is provided in the *Missouri River Mainstem Reservoir System, Master Water Control Manual, Missouri River Basin* (USACE, 2006).

Construction and operation of the Mainstem Reservoir System inundated large portions of the upper and middle Missouri River, converting approximately one-third of the river into reservoirs. The dams have practically eliminated normal periods of high- and low-water flows in the river that existed previously. High flows, which typically occur in the springtime, are captured in the reservoirs, and then released during seasons when the flow in the Missouri River would normally be low, such as late summer and fall. Historically, in the upper portions of the river, high river flows would result from snowmelt from the Rocky Mountains and northern Great Plains from March through July. These high flows would then proceed downstream. Large or prolonged storms could cause an increase in river flows during other times of the year as well. This is particularly the case in the lower Missouri River watershed which, on average, receives a larger amount of rainfall compared to the upper and middle reaches of the watershed.

Figure 2-2: The Missouri River Mainstem Reservoir System consists of six large dams on the upper Missouri River.

Prior to the construction of the Mainstem Reservoir System, sediments that eroded from the upstream watershed and channels supplied a high-sediment load to the lower Missouri River, known historically as the Big Muddy. The upstream reservoirs have interrupted the natural sediment transport process along the length of river, immobilizing large amounts of sediment. The Missouri River Mainstem Reservoir System has caused an estimated 3.7 million acre-feet of sediment to become immobilized in the reservoirs (National Research Council (NRC), 2011). Before the dams were constructed, the Missouri River carried around 300 million tons of suspended sediment per year at Hermann, Missouri near its mouth (Jacobson et al, 2009). Today, the Missouri River only transports roughly 55 million tons of suspended sediment per year at Hermann (Meade and Moody, 2010). This reduction in sediment supply of the Missouri River is not only the result of the Mainstem Reservoir System, but also other reservoirs that have been constructed in the Missouri River watershed, such as those on the Kansas River system.

The clear-water releases from Gavin's Point Dam recruit sediment from the bed for miles downstream of the dam. Sediment is scoured from the bed until the sediment load is in equilibrium with the ability of the water to transport sediment. The clear-water, also referred to as "hungry water" picks up sediment and the degradation tapers to approximately 20 miles downstream of Omaha, Nebraska (USACE, 2010). The recent degradation experienced in Kansas City is disconnected from the upstream degradation by over 200 miles, suggesting local factors as the primary cause rather than sediment trapping by the dams.

2.2 Missouri River Bank Stabilization and Navigation Project

The Rivers and Harbors Acts of 1912, 1925, 1927, and 1945 directed USACE to construct a self-maintaining commercial-navigation channel on the lower Missouri River. The BSNP was constructed for this purpose. Prior to the BSNP, many locations of the lower Missouri River consisted of a wide braided channel that would shift back and forth across the floodplain, transporting sediment downstream as the channel meandered over time. The BSNP consists of a system of dikes and revetments that constrict the river into a single, deep, channel. A nine-foot deep and 300-foot wide navigation channel is maintained from the mouth of the river near St. Louis, Missouri to near Sioux City, Iowa; a distance of approximately 735 RM (Figure 2-3). In addition to creating a navigation channel, the BSNP also protects communities, utilities, transportation networks, and landowners from the meandering of the river. Construction of the BSNP was completed in 1981.

Figure 2-3: The BSNP extends from the mouth of the Missouri River to near Sioux City, Iowa.

The BSNP consists of a nearly continuous arrangement of river training structures to create a self-scouring channelized river in order to maintain a navigation channel and prevent the channel from moving horizontally across the floodplain. The term self-scouring channel refers to the ability of the channel to convey the incoming sediment load without persistent shoaling. Deposition of sand does occur in a self-scouring system, but it is balanced by erosion.

Today, the BSNP river training structures typically consist of rock revetments along the outside of river bends, and rock dikes and sills along the inside of river bends (Figures 2-4 and 2-5). Approximately 200 million tons of rock was placed during original construction of the BSNP. Also, the Missouri River was shortened by approximately 45 miles between Rulo, Nebraska and the mouth between 1879 and 1972, due in large part to channel cutoffs constructed as part of the BSNP (Funk and Robinson, 1974).

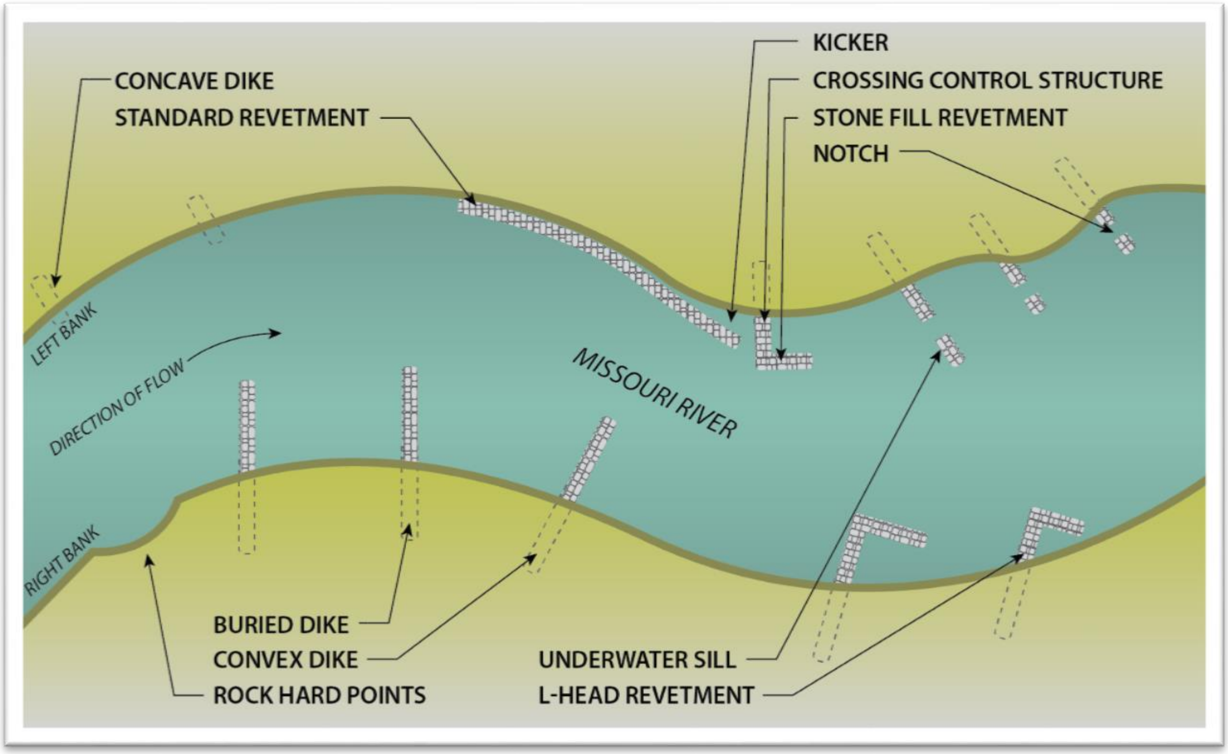

Figure 2-4: Typical arrangement of BSNP structures on the Missouri River.

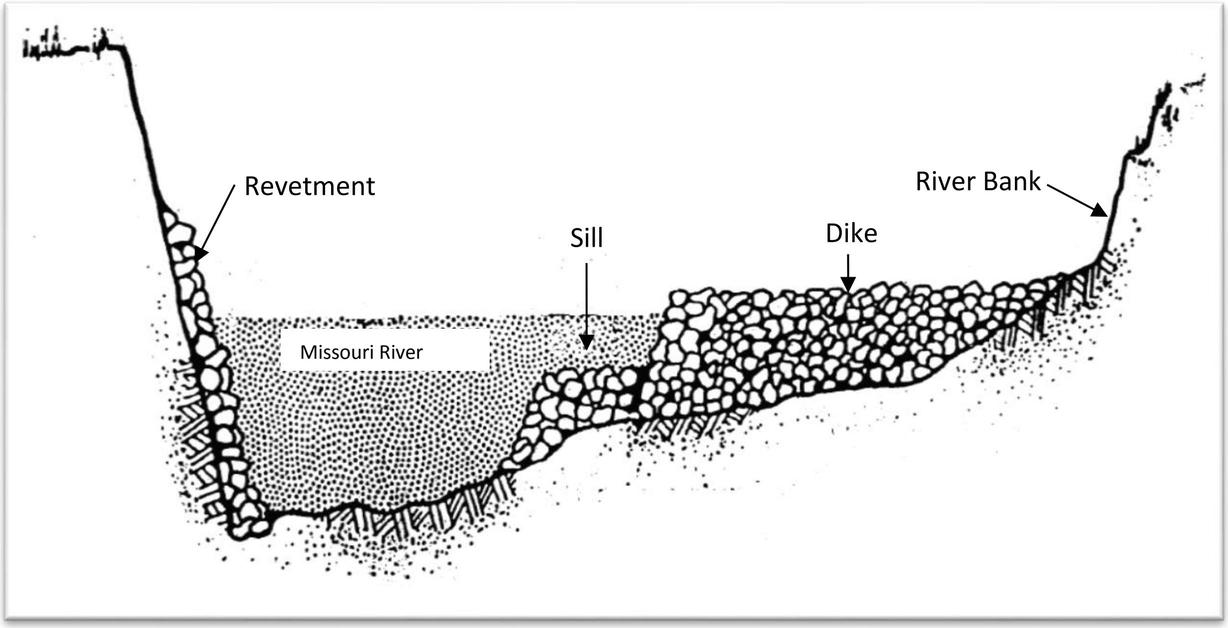

Figure 2-5: Typical cross section of the Missouri River showing the BSNP features that create a nine-feet-deep by 300-feet-wide navigation channel. Modified from Mellema, 1994.

The BSNP river training structures trapped sediment behind the dikes, converting portions of the previous river channel into accreted land and narrowing the river channel. This was particularly evident between the early 1930s and the mid-1960s. It has been estimated that approximately 45 million tons of sediment per year were trapped by the BSNP along the Missouri River between 1910 and 1981 (NRC, 2011). The accreted land became the property of adjacent landowners and is now used for a variety of land uses (i.e. farming, infrastructure development, recreation areas and other uses). In most locations, levees or floodwalls have been constructed on the accreted land to reduce the risk of impacts of flooding to both agricultural and urban areas along the Missouri River. The main period of sediment being trapped behind river structures ended in the early 1980s when construction of the BSNP training structures was considered complete. The width of the pre-BSNP river varied from 1,000 to 10,000 feet at normal flows (Schneiders 1999) while the current design widths vary from 600 to 1,100 feet.

There are two important terms to understand when discussing the BSNP and the position of the Missouri River. These are the construction-reference plane (CRP) and the rectified-channel line (Figure 2-6). The CRP is an imaginary plane that extends the length of the river used as a baseline elevation to set the height of BSNP structures. It is defined as the sloping water-surface elevation of a discharge that is exceeded 75% of the time during the navigation season. Over time, the elevation of the CRP can change if discharges change, or if the the surface elevation of the river changes due to the elevation of the bed changing. Since 1973, the CRP has been changed five times (Table 2-1). In general, these changes were an overall lowering of the CRP throughout the study reach with only a few instances of very short segments with slight adjustments (avg. 0.3 to 0.6 feet) in the upward direction.

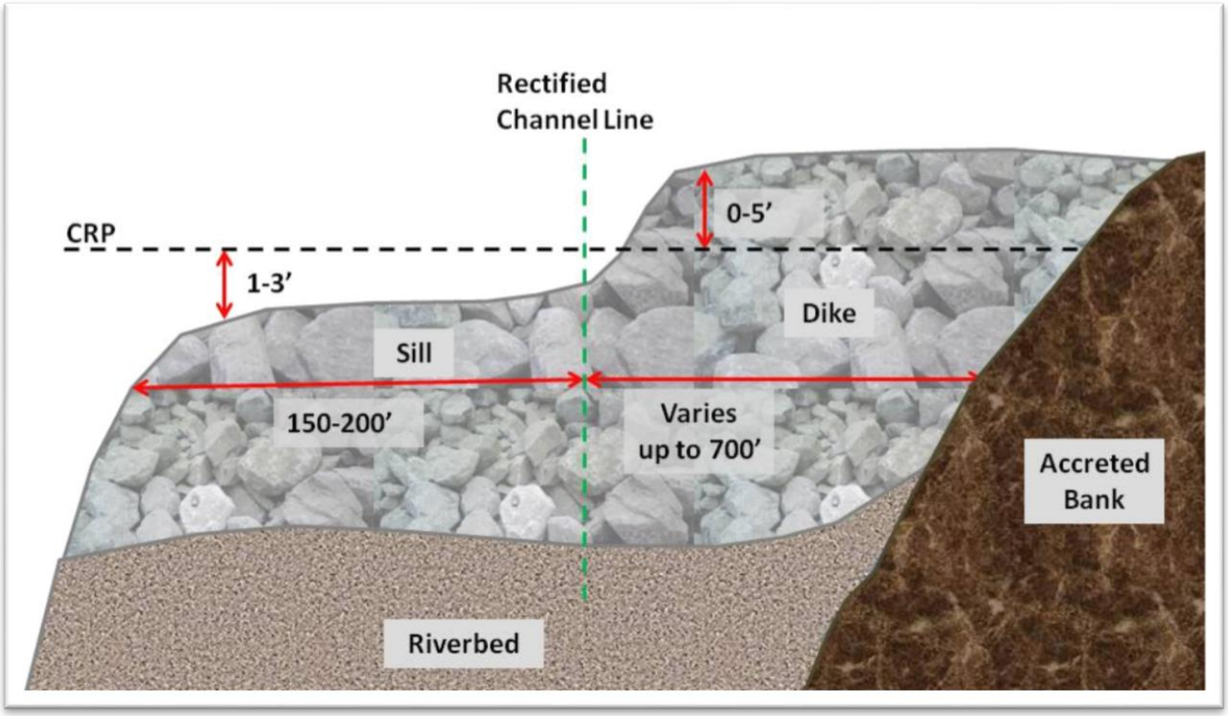

Figure 2-6: Cross section of BSNP structure showing the CRP and the rectified-channel line.

Table 2-1: History of revisions to the CRP since the 1973 revision.

Year of CRP Revision	Discharge Revised	Elevation Revised
1982		X
1990		X
2002	X	X
2005	X	X
2010		X

Figure 2-7 shows the elevations of all CRPs in use since the 1973 revision. Changes in the CRP generally follow changes in water surface profiles and bed elevations.

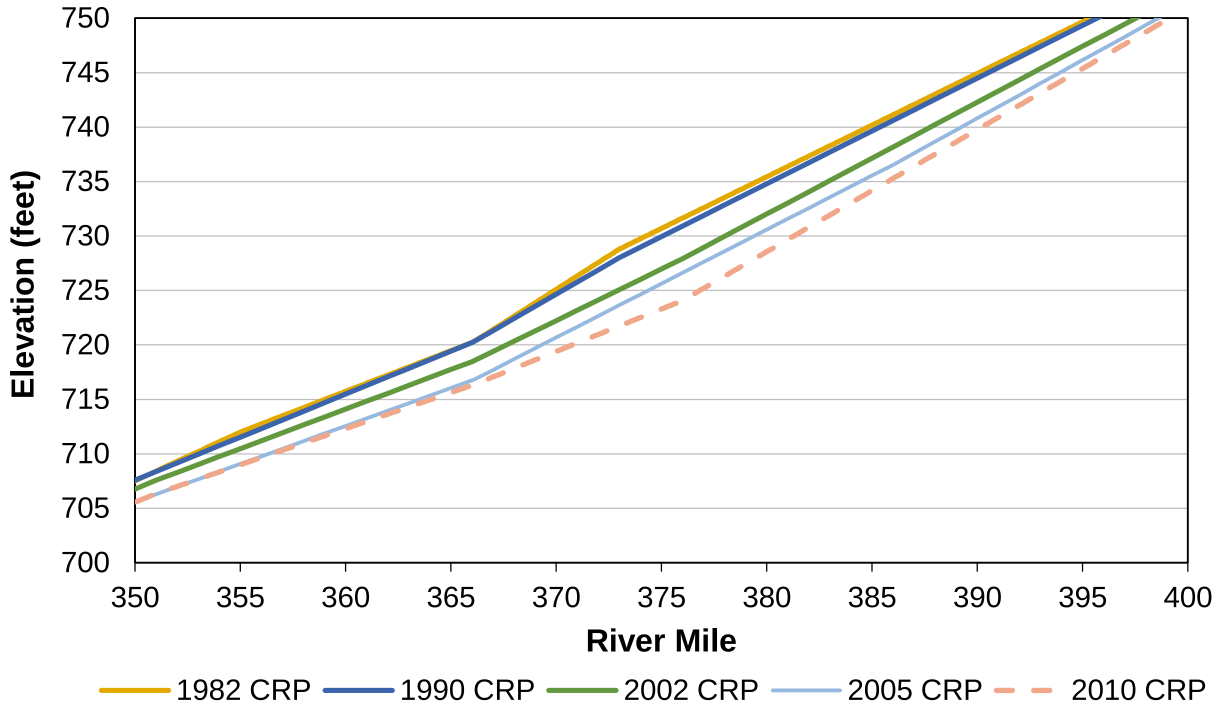

Figure 2-7: Elevations of all the CRPs in use since 1973.

Changes in the CRPs resulted in the need to modify the heights of BSNP structures. As described in Appendix A – Existing Condition of the BSNP structures, RM 330 and 400, most of the BSNP sills between RM 410 and 350 became perched when the CRP was updated in 2002. Because of the adverse impact of the perched structures on the self-scouring channel, select structures were mechanically lowered begining in 2002. In total, 127,168 cubic yards of rock was removed from structure crests between RM 390 and RM 350 over four different iterations of structure lowering. More details concerning changes to the CRP and the structure heights of the BSNP are included in Appendix A.

The rectified-channel line is used to describe the horizontal position of the portion of the river that contains the congressionally authorized navigation channel. The rectified-channel line establishes the location of revetment structures and the riverward end of dike (higher stage) portion of dike structures (Figure 2-8).

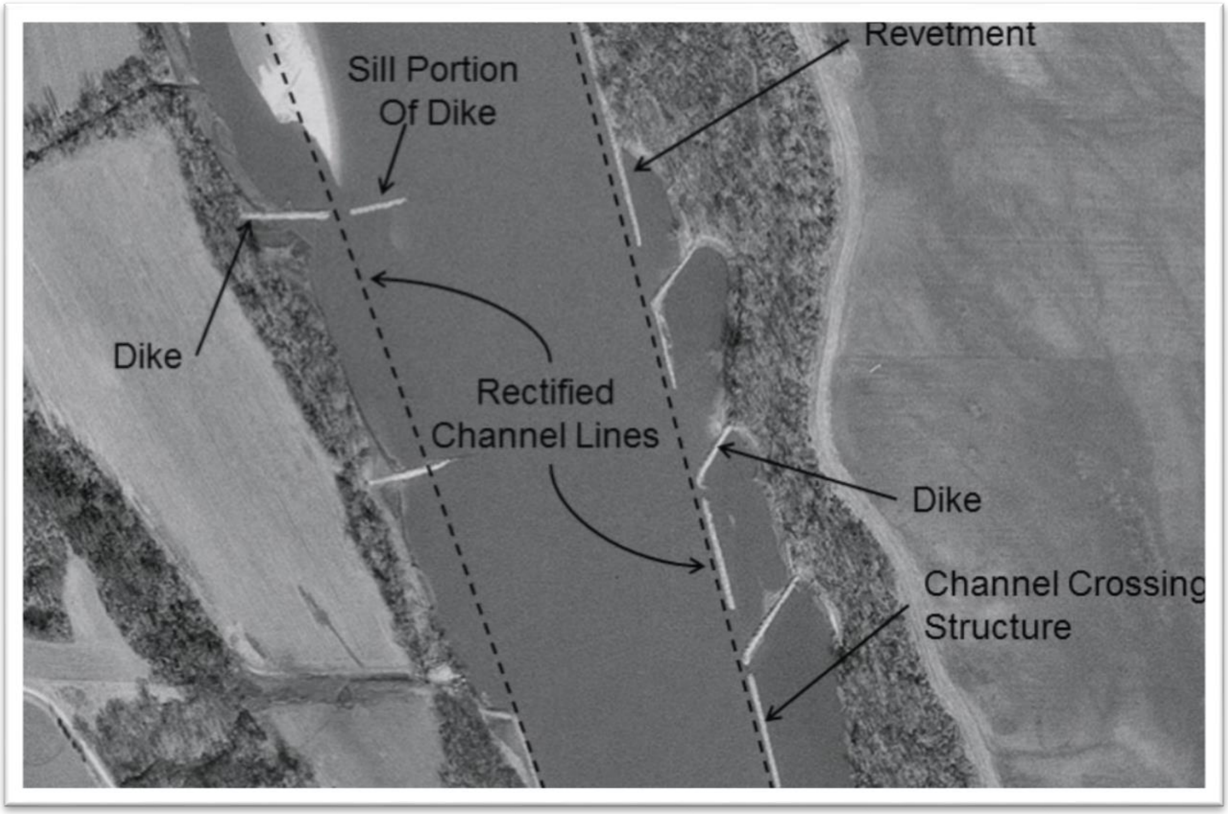

Figure 2-8: Illustration of the rectified-channel lines.

2.3 Levees and Floodwalls

The channel stabilization accomplished through the BSNP has allowed the subsequent construction of federal levees and floodwalls, and private levees 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 banks. In many locations, the small private levees contain flows with a 0.05 to 0.1 annual-chance exceedance and the top widths between levees on opposite banks are only slightly larger than the channel. Larger floods exceeding a 0.05 annual-chance exceedance are generally only contained by the federally constructed levees and 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.

3 PROBLEMS BEING EVALUATED

While this study encompasses the entire lower 500 miles of the Missouri river, from Rulo, Nebraska to the confluence with the Mississippi near St Louis, Missouri, bed degradation and associated impacts vary considerably over the 500 miles. In some stretches of the river, bed degradation is insignificant, while in other areas, bed degradation has already impacted infrastructure and necessitated expensive repairs. In addition to identifying areas where bed degradation is the most problematic, this section also describes types of impacts to infrastructure that have resulted in the past and that are reasonably expected to occur in the future if the problem is not addressed.

3.1 Water Surface Degradation and Reach Screening

Bed degradation on the Missouri River has caused a corresponding, though not necessarily equivalent drop in the water-surface elevations for low discharges. In order to better focus resources for analysis and plan formulation, readily accessible low-water-surface elevation data was used to determine the locations where systemic bed degradation was the most severe. 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 bed degradation trends over time for the lower 500 miles of the river. These low-water profiles were measured when flows fell 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).

For this evaluation, the bed degradation of the water surface was assessed from 1990 to 2009 (Figure 3-1). This timeframe was chosen because it was recent enough to represent the response of the river to the current conditions on the river; BSNP structures, reservoir management, commercial sand and gravel mining rates, etc., but still included nearly 20 years of data. This was long enough for bed degradation trends to substantially exceed yearly fluctuations. In addition, the time period included a range of high- and low-flow years and the effects of the major 1993 Missouri River Flood. The change in elevation over each RM was assessed as the elevation of the 2009 water surface minus the elevation of the 1990 water surface. A rolling five-mile average was applied. At the time of the screening, the 2011 Missouri River Flood had not yet occurred. Additional details concerning the screening procedure are included in Appendix B – Mobile-bed model Calibration Report.

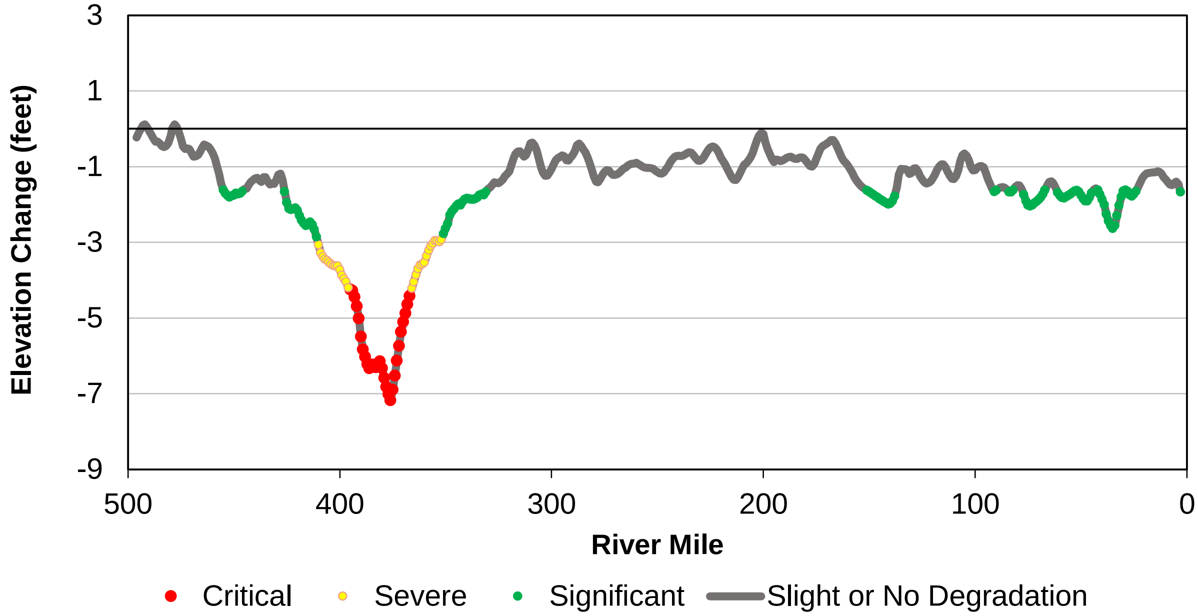

Figure 3-1: Differences in low water profiles from 1990 to 2009 normalized to a common discharge.

The critical and severe bed degradation reaches were centered on the Kansas City area. Accordingly, detailed analyses for the study was focused on the river from RM 457 to 329 (Figure 3-2). The HEC-RAS sediment model was developed to conduct detailed analyses from RM 448.89 (St. Joseph, Missouri) to RM 293.42 (Waverly, Missouri) so that it could incorporate information from USGS gaging stations at these locations. Since this original screening, recent data has shown an upstream migration of the most critical bed degradation by about 30 miles as a result of the 2011 Missouri River Flood, which is still within the modeled reach. Other portions of the river were not modeled as part of this study and results from this study should not be applied to other portions of the river without additional evaluation.

Figure 3-2: The focused study area extended from upstream of St. Joseph, Missouri to downstream of Waverly, Missouri.

3.2 Changes in Bed Elevations

Some locations of the river around the Kansas City metropolitan area have already been significantly impacted by bed degradation. Between 1987 and 2014, it is estimated that 2.3 billion cubic feet of bed material has been lost from the river between St. Joseph and Waverly, Missouri. Over these years, the five-mile reach from RM 369 to 374 degraded approximately 10.1 feet (Figure 3-3). Bed degradation of the Missouri River also induces bed degradation on tributary rivers.

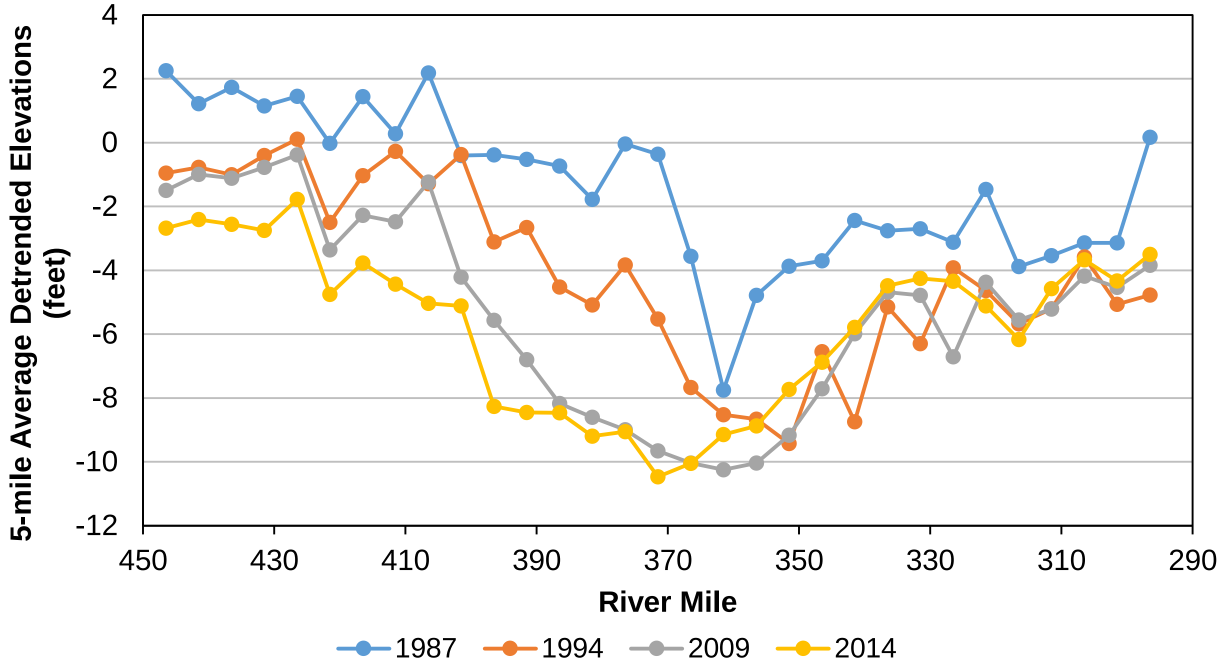

Figure 3-3: Average bed elevations from select years between 1987 and 2014. Elevations shown are longitudinally de-trended five-mile averages. (See Appendix C, Future With Project Model Projections with Risk and Uncertainty. Section 7.3 for a discussion of the de-trending procedure.)

As seen in Figure 3-3, from 1987 through 2014 the zone of bed degradation has expanded, deepened, and migrated upstream. From 2009 to 2014 specifically, the bed degradation migrated upstream and slight bed recovery was evident in Kansas City (RM 370 to 350). Reasons for this are discussed later in this document and in Appendix C – Future With-Project Model Projections with Risk and Uncertainty.

3.3 Impacts to Infrastructure

Bed degradation has adversely impacted various types of federal, state, and local infrastructure. Much of the infrastructure along the Missouri River was constructed to function at specific bed or water-surface elevations. Changes in bed and water-surface elevations have negatively impacted the BSNP structures, water-supply intakes, levees, bridges, and other resources.

Although not all costs of historical responses to bed degradation have been identified, more than $45 million in capital-construction costs and $55 million in increased-operating costs have been incurred by the major utilities since the 1990s. Examples of actions taken in response to changes in bed and water-surface elevations are shown in Table 3-1. Bed degradation on the mainstem Missouri River has induced degradation on tributaries as well. This degradation has migrated up tributaries causing damage and requiring repairs to bridges, bank stabilization, and utility crossings. This section provides examples of documented damages due to degradation. Actions taken, for which cost information is not available, includes bridge repairs, utility crossing repairs, repairs for outfall structures and bank stabilization, and other impacts on tributaries. Note that the drop in water levels has the largest impact to infrastructure when flows are low. During high-flow events bed degradation has less effect on water levels and does not contribute to flood-risk management in a substantial way.

Table 3-1: Examples of infrastructure on the Missouri River that have been impacted by bed degradation.

Stakeholder	Structure	Corrective Action
Kansas City, Missouri Highway Dept.	Local-road bridge	Repaired bridge foundation
Kansas City, Missouri Water Services Dept.	Water-supply intakes	Supplemental pump installed
Parkville, Missouri City of Parkville	Tributary Erosion	Rock/sheetpile grade control and channel lining to protect bridge and other infrastructure
Missouri Department of Transportation	Highway bridge	Increased design criteria for bridge construction
WaterOne	Water-supply intakes	Supplemental pump installed
Leavenworth Water	Water-supply intakes	Supplemental pump installed
Kansas City Board of Public Utilities	Cooling-water intakes	Supplemental pump installed
Kansas City Board of Public Utilities	Cooling-water intakes	Cooling tower constructed
Levee Districts/Drainage Districts	Flood-control structures	Levee and floodwall reconstructed
USACE	Flood-control structures	Levee and floodwall reconstructed
USACE	BSNP structures	Repaired and modified

3.3.1 Missouri River Bank Stabilization and Navigation Project

The BSNP was constructed to create a self-maintaining commercial-navigation channel on the lower Missouri River. A continuous series of structures consisting of rock revetments and dikes were constructed along 735 miles of river to maintain a nine-foot-deep by 300-foot-wide navigation channel. See Section 2.2 for a more detailed description of the BSNP. Bed degradation impacts the stability of rock revetments and the functionality of dikes structures.

Bed degradation near the toe of rock revetments causes slope instability and sloughing of the rock fill. When this occurs, new rock needs to be placed on the structures to maintain bank stabilization and channel alignment.

Bed degradation causes an associated drop in the water-surface elevation, which leaves the dike structures perched above their design elevations. These perched structures are overtopped less frequently than intended, which can result in land accretion, potential loss of high-flow conveyance, and loss of aquatic habitat. Perched structures require mechanical lowering.

At the time of this report, most of the sill and dike structures have been lowered in response to bed degradation, but only a few revetments have been repaired resulting in a deferred-maintenance cost. See Appendix A – Existing Condition of the Bank Stabilization and Navigation Project Structures, RM 330 and 400.

3.3.2 Water Intakes

In the past, utility providers have constructed water intakes along the Missouri River at fixed elevations to provide access to water. The elevations of the intakes were designed to allow for water to be obtained during periods of low river flow. River bed degradation has caused the low-flow water-surface elevations to decrease, forcing utilities to make modifications to their intake structures to obtain water. Water supply and power utilities have needed to augment water intakes with auxiliary pumps to reach farther into the river at an added cost for utility operators that is ultimately passed on to users. There are limits to the distance that the water can be accessed with auxiliary pumps and other stop-gap measures before permanent infrastructure modifications are needed. If the water-surface elevation continues to decrease, very costly modifications will be necessary.

In 2003, a power plant along the Missouri River had to construct a cooling tower because the auxiliary intake pumps installed four years earlier were no longer able to provide sufficient cooling water. In Kansas City, Missouri emergency modifications were made to its primary water intake facility in order to obtain water during periods of low flow. WaterOne, a public water supplier to the Johnson County, Kansas area, and Leavenworth Water in Leavenworth, Kansas have also had to utilize auxiliary pumps.

3.3.3 Levees

Performance of levees adjacent to areas of degradation can be compromised due to undercutting of the foundations reducing stability, or loss of foreshore reducing seepage lengths. This can result in expensive repairs that typically involve placing large quantities of rock along the foundation of levees that have been damaged, or moving the levee further away from the river. In 2009, non-federal levees in Wyandotte County, Kansas were damaged when bed degradation migrated from the Missouri River up a small tributary (Figure 3-4). In this case, the levee had to be moved further away from the creek in order for it to be repaired. The large and critical federal-levee systems have also been impacted by the degradation problem, necessitating costly and urgent repairs in some cases. Costly repairs were needed to the Missouri River Levee System L-385 levee in Riverside, Missouri as bed degradation migrated up Line Creek from the Missouri River (Figure 3-5). During the 2011 Missouri River Flood, the bed further degraded in the Kansas City area and undercut the slope of the Jersey Creek floodwall. USACE placed rock along the foundation of the slope as an emergency action to protect the floodwall (Figure 3-6). Since that time, this bend has been the site of a major construction project to stabilize the bank and floodwall. Similar emergency repairs were made to the North Kansas City Levee at a location underlying the 169 Highway, a major highway that crosses the Missouri River in the Kansas City area. Similar types of impacts are expected to occur in other locations if bed degradation is not addressed.

Figure 3-4: Bed degradation from the Missouri River moved up a small tributary in Wyandotte County, Kansas contributing to damage on a non-federal levee in 2009.

Figure 3-5: Bed degradation from the Missouri River moved up Line Creek in Riverside, Missouri causing damage to a major-federal levee. Note the rock toe of the levee at the top of the eroded bank.

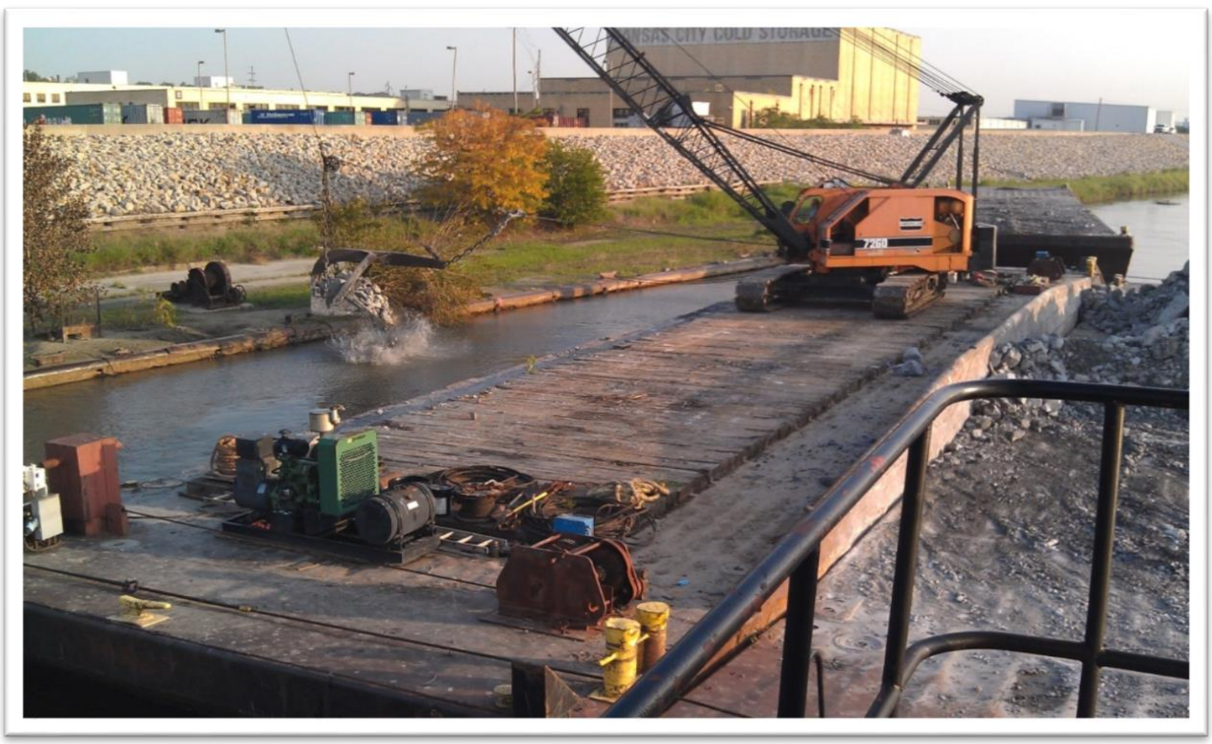

Figure 3-6: Rock being placed along the foundation of the Jersey Creek floodwall in 2011. Since that time, this bend has been the site of a major-construction project to

stabilize the bank and floodwall. Similar emergency repairs were made along the North Kansas City Levee.

3.3.4 Bridges

Bridges have been impacted by bed degradation. As the river bed degrades, piers that support bridges become undermined, or a widened channel cause additional piers which were never designed to be exposed to river flow to be located in the main channel. One example of bridge pier undercutting is the Argosy Parkway Bridge, which crosses Line Creek in Platte County, Missouri and had to be shut down when the foundation became unstable due to bed degradation that migrated up the creek from the Missouri River (Figure 3-7). Repairs had to be made to the foundation before the bridge could be reopened (Figure 3-8). Bridges within the study reach were analyzed by establishing critical elevations based on the owner's scour action plan, or, in the absence of a plan, the elevation at the bottom of footings. Several recently constructed bridges (Christopher Bond I-29/35 and Hwy 59) were constructed with foundations to bedrock, such that they could accommodate any degree of future degradation.

Figure 3-7: Bridge piers were damaged along a tributary to the Missouri River that was subject to bed degradation in Platte County, Missouri.

Figure 3-8: The same bridge as shown in previous figure (3-7) following repairs.

3.3.5 Potential Future Impacts to Infrastructure

Over the next 50 years, up to an additional five and one half feet of bed degradation on average are projected to occur within some portions of the study area. Localized areas may degrade more. This will result in continued impacts to infrastructure along the river. For some types of infrastructure, actions consistent with historical levels of effort to repair or restore infrastructure performance will not be sufficient to address future bed degradation. Far greater actions, such as abandonment of existing intakes, development of alternative water sources, or the use of alternative cooling systems will be required in some instances. The most likely (base-case) evaluation of future costs for repair or replacement of major infrastructure along the river from St. Joseph to Waverly, Missouri over the next 50-year period of analysis could exceed $269 million (FY 2017 dollars) if bed degradation is not addressed. The present value of these damages is estimated to be $139 million. These values could be higher if all smaller infrastructure costs, such as pipe crossings at tributaries were included. Details concerning future impacts are discussed more extensively in Section 8.2 Future Without-Project Economic Analysis.

4 FACTORS INVESTIGATED

The Missouri River is a highly altered system. Numerous factors have influenced the current condition of the river, including the construction of the mainstem and tributary dams, the BSNP, large flood events, droughts, and commercial sand and gravel mining of the river bed. While the river is continuing to degrade over time due to sediment being trapped in the mainstem and tributary dams, measured data and model results indicate the increased bed degradation experienced since 1990 in the St. Joseph to Waverly reach is caused by the level of commercial dredging which occurred in and around Kansas City. This degradation migrated upstream as a response to the 2011 Missouri River Flood (USACE, 2011a; Appendix C – Future Without-Project Model Projections with Risk and Uncertainty).

4.1 Missouri River Bank Stabilization and Navigation Project

The BSNP created a system that maintains a balance between the force of the water and the sediment transport which prevents excessive deposition of material within the channel and eliminates the need for maintenance dredging to maintain the navigation channel. The heights of the BSNP structures are critical to maintain a self-scouring channel. The elevations at which the BSNP structures are intended to be in relation to the CRP are referred to as the design criteria (USACE, 1980). For example, the design criteria may be for the top of a dike to be constructed to a height of two feet above the CRP, or a sill to a height of two feet below the CRP. Notwithstanding the general design criteria, the system has been adaptively managed, with individual structures being raised or lowered to alleviate site-specific problems.

As described previously, bed degradation and the associated lowering of the CRP can leave river training structures perched at elevations above their design criteria. This confines the river flow to the narrow, active channel over a greater range of discharges. This can increase the velocity of the water, which increases the bed erosion and could exacerbate the bed degradation problem. However, the timing of bed degradation and structure heights suggests that the perched structures are a result of bed degradation rather than a principle cause (see Appendix A – Existing Condition of the Bank Stabilization and Navigation Project Structures, RM 330 and 400). On the other hand, if the heights of the BSNP structures are too low, then the active channel will have decreased velocities which may allow sediment to accumulate, negatively impacting the navigation channel. A balance needs to be maintained in order to prevent excessive sediment from either eroding or accumulating along the bed of the river. Many of the previously perched BSNP structures have been lowered in response to changes to the CRP. Large-scale lowering of these structures is not considered part of normal operation and maintenance of the system, and some structures remained perched to heights of six feet higher than the design criteria. One of the purposes of this study was to evaluate the effects on the long-term bed degradation trend of large scale lowering of dike and sill elevations.

4.2 Flood and Drought Events

Historically, during major flood events the Missouri River would capture new sediment through meander erosion from a wide accessible floodplain. Now, the BSNP structures constrain the river to a considerably narrower width along a fixed alignment. This induces high water velocities and limits the input of bank and floodplain sediments to the river bed. Major floods speed the upstream migration of degradation. This was evidenced in the 1993 and 2011 floods. High water events and major floods also cause temporary degradation followed by rebound. This was observed in 1951, 1952, 1987, 1993, 2007, and 2011 and is examined further in Appendix C – Future Without-Project with Risk and Uncertainty.

Two additional factors added to the bed degradation during the 2011 Missouri River Flood. First, the flood was dominated by prolonged high-flow releases of sediment-starved water from the mainstem reservoirs with relatively little contribution of sediment from any downstream tributaries because of less than normal precipitation in the lower watershed. This resulted in significantly lower sediment concentrations than normal for similar flows. Second, the flood included numerous levee breaches, which resulted in significant sand deposition on the floodplain (Alexander et. al, 2013).

Exponentially less sediment movement occurs during low flows, which slows the upstream migration of existing bed degradation but exacerbates degradation due to channel mining. During low-flow years, channel mining constitutes a larger proportion of the incoming sediment load, and local degradation has less opportunity to attenuate by spreading out. Furthermore, lower flows increase the establishment of vegetation on channel margins, which results in channel narrowing. The Missouri River exhibited lower flow years from 2002 to 2006.

4.3 Commercial Sand and Gravel Mining

Records indicate that sand and gravel has been mined from the Missouri River since at least 1935. However, this activity likely occurred prior to the start of available records. Today, sand and gravel is mined from the Missouri River using hydraulic dredges (Figure 4-1). This activity is regulated through the River and Harbors Act Section 10 and the CWA Section 404. The permits, dated December 2015, and issued in January 2016, allow for 5.8 million tons of sand and gravel to be mined annually from the Missouri River downstream of Rulo, Nebraska to the confluence of the Missouri River with the Mississippi River near St. Louis, Missouri.

Figure 4-1: A commercial sand and gravel mining operation. Material is mined from the riverbed using a hydraulic dredge.

The primary uses for the sand and gravel from the Missouri River are for the local construction and manufacturing industries. Sand and gravel are used to make concrete, asphalt, brick mortar, tile grout, and landscape materials (USACE, 2011a). Most of the sand and gravel mined from the Missouri River is used in communities located near the river. Of the 5.8 million tons/year permitted to be mined from the Missouri River, approximately two million tons/year are permitted between RM 498 and 250. The permitted quantity allowed to be mined each year will steadily increase to approximately 2.6 million by the year 2020 (Table 4-1).

Table 4-1: Current and future quantities of sand and gravel permitted to be mined from the Missouri River between RM 498 and 250.

River Reach	Quantity (tons/year)				
	Year 2016	**Year 2017**	**Year 2018**	**Year 2019**	**Years 2020**
St. Joseph (RM 391 to 498)	330,000	330,000	330,000	330,000	330,000
Kansas City (RM 357 to 391)	540,000	540,000	540,000	540,000	540,000
Waverly (RM 250 to 357)	1,109,500	1,264,733	1,419,965	1,575,198	1,730,431
Annual Total	**1,979,500**	**2,134,733**	**2,289,965**	**2,445,198**	**2,600,431**

Figure 4-2 shows the quantities of sand and gravel mined from the Missouri River in the Kansas City metropolitan area, RM 350 to 400, from 1974 to 2014. Quantities increased sharply in the early 1990s and remained at that level through the mid to late 2000s. The dredging in 2002 includes 1.7 million tons mined by USACE for the construction of the L-385 unit of the Federal Missouri River Levee System. The increase in the early 1990s was a result of regulatory restrictions on mining in the nearby Kansas River that began in 1990 that caused a shift of mining activity to the Missouri River and an increase in local demand for construction materials due to strong economic conditions. The restrictions on the Kansas River were implemented because of substantial economic impacts to utilities and infrastructure along the river, especially in the lower 22 miles of the river (USACE, 1990). Many of the economic impacts that existed on the Kansas River prior to the restrictions were related to bed degradation and are similar in nature to the impacts on the Missouri River identified in this report. The decrease in extraction over the past decade is attributed to decreased demand as a result of the economic downturn that began in 2007, and a reduction in the amount that was permitted to be mined from the river beginning in 2011. In the EIS prepared in 2011 as part of the Section 10 of the River and Harbors Act of 1899 (33 USC 403) and Section 404 of the CWA (33 USC 1344) permitting process, it was noted that there is a correlation between commercial sand and gravel mining and the most degraded areas of the Missouri River (USACE, 2011a).

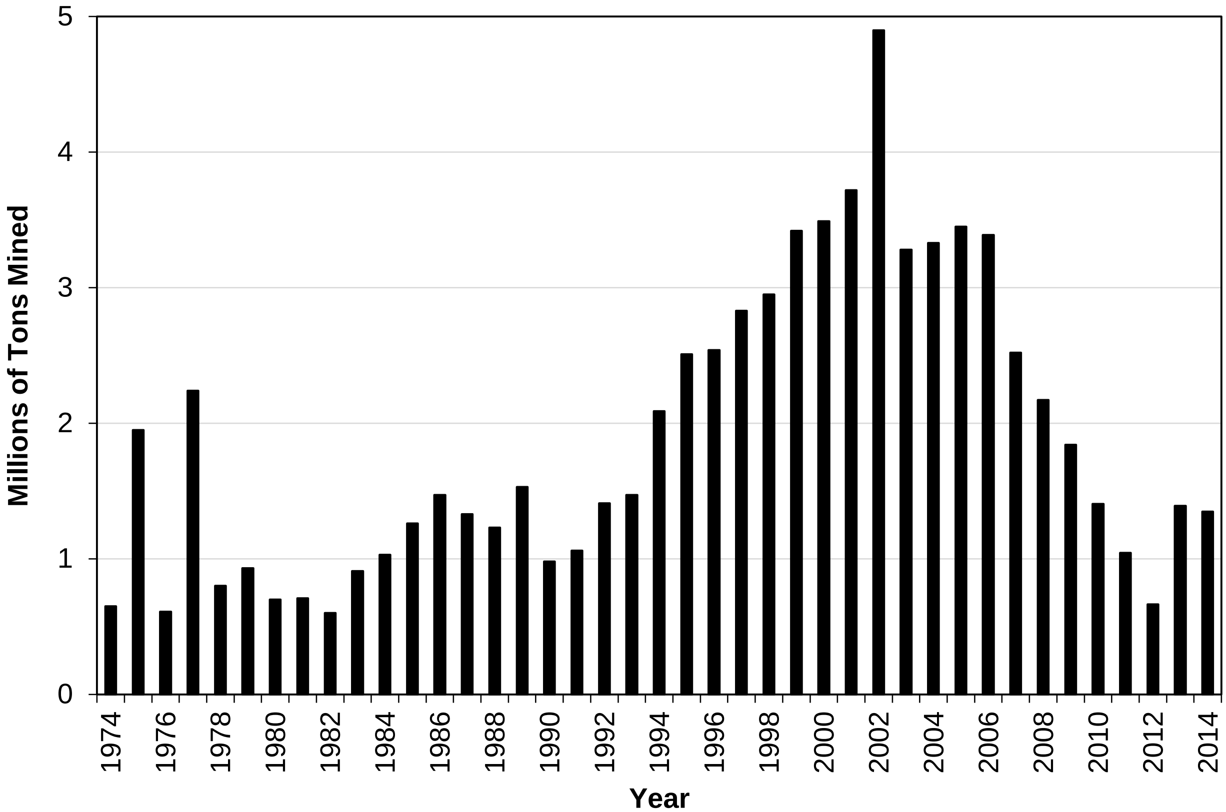

Figure 4-2: Quantities of sand and gravel mined from the bed of the Missouri River from the metropolitan Kansas City area (RM 350 to 400).

Commercial sand and gravel mining can impact large alluvial rivers in several ways. The most obvious impact is that removal of bed material lowers the elevation of the river bed in the immediate vicinity of the extraction location, forming deep pits or holes on the bottom of the river. In high-sediment systems like the Missouri River, these holes quickly spread in the upstream and downstream direction while filling with incoming sediments. Bed degradation migrates upstream of the mining site due to an increase in slope caused by degradation in and downstream of the mine pit. Sediment-starved water leaves the mining site which can erode the channel bed downstream of the mined area (Kondolf, 1994). Over time, the volume mined from the river bed is dispersed from a deep pit in a localized dredging area to a small incremental drop in elevation that can extend miles upstream and downstream of the original pit location (Scott, 1973; Stevens et al, 1990; Rinaldi, Wuzga, and Surian, 2005). Because of known impacts associated with in-river mining, this practice has been banned in many other countries (Kondolf, 1997).

The initial design of the BSNP did not anticipate the large quantities of commercial sand and gravel extraction seen in recent years. From 1994 to 2014, approximately 61 million tons of bed material was mined from the bed of the Missouri River from St. Joseph, Missouri to Waverly, Missouri with the majority mined in the Kansas City metropolitan area. Bathymetric surveys indicate approximately 38 million tons of bed degradation in the active channel (from the tip of the sill to the opposite bank or revetment) over the same time period, suggesting that commercial sand and gravel extraction prevented what would otherwise have been a bed recovery trend following the 1993 flood. Model results support this conclusion (Figure 8-3, and Appendix C – Future Without-Project Model Projections with Risk and Uncertainty).

5 PUBLIC SCOPING

USACE and MARC solicited public input for the study in February and March 2014. Public scoping provided an opportunity for the general public, non-governmental organizations, government agencies, and other stakeholders to learn about the bed degradation problem, potential solutions to address the problem, and provide comment on what should be considered during the study.

Input was received from nineteen entities. Five commenters were unaffiliated, or did not identify themselves as representing a particular organization. Three commenters represented federal agencies. Two commenters represented state agencies. One commenter represented a county. One commenter represented a municipality. Five comments represented business interests. One commenter was from a charitable organization. Comments pertained to the National Environmental Policy Act (NEPA) process and stakeholder representation, technical comments on the HEC-RAS sediment transport model, local interest and concerns, and the BSNP and federal interest. This input helped inform issues to be considered by USACE. Detailed information concerning the public scoping process, including copies of original comments received, is included in Appendix D – Missouri River Bed Degradation Public Scoping Report.

6 STUDY OBJECTIVES AND CONSTRAINTS

Objectives for the study were refined during a charrette with stakeholders in November 2012. See Appendix E – Report Synopsis Following Planning Charrette for details. Specific objectives of the study were to develop a plan to achieve the following within the refined study area:

- Eliminate or minimize additional bed degradation of the Missouri River
- Eliminate or minimize bed degradation on Missouri River tributaries induced by further degradation on the main stem Missouri River
- Prevent or minimize projected increases to future operation, repair, and replacement costs of federal, municipal, and private infrastructure as a result of bed degradation
- Minimize impacts to infrastructure reliability as a result of bed degradation
- Reverse bed degradation where beneficial

- Improve or maintain desirable habitat conditions for fish and wildlife along the Missouri River

For this study, the following constraints were identified:

- Missouri River authorized purposes – Any plan identified for implementation must be consistent with congressionally authorized purposes of the Missouri River. This includes flood control, navigation, water supply, recreation, hydropower, fish and wildlife, and irrigation.

- Missouri River Master Water Control Manual – Plans must be consistent with the existing operations of the Missouri River Mainstem Reservoir System as described in the Master Water Control Manual (USACE, 2006)

- Biological Opinion – In accordance with the Endangered Species Act, in 2000 the USFWS prepared a *Biological Opinion on the Operation of the Missouri River Mainstem Reservoir System, Operation and Maintenance of the Missouri River Bank Stabilization and Navigation Project, and Operation of the Kansas River Reservoir System*. This document was amended in 2003. The biological opinion provided a recommended and prudent alternative to avoid jeopardy to the federally endangered pallid sturgeon. Alternatives must be consistent with the recommended and prudent alternative.

7 EVALUATION METHODS

The federal objective is to make positive net contributions to National Economic Development (NED) as described in the *Principles and Guidelines* and ER 1105-2-100. Net contributions to NED (i.e., net benefits) are the primary criteria used in the evaluation of alternative plans. Regional Economic Development (RED) benefits were also considered in the evaluation of alternative plans using publically available information. Environmental and social considerations, which are typically used in feasibility studies to evaluate alternative plans, were not fully developed because the economic criteria indicated that no plan would be recommended for implementation as a cost-shared project under the Section 216 authority.

At the start of the study, suitable tools to evaluate alternatives for the study did not exist. Because of this, the Missouri River Mobile-bed model and the Missouri River Economic Model were developed. The Mobile-bed model is described in Section 7.1 and the Economic Model is described in Section 7.2. The Economic Benefits Model is dependent on inputs from the Mobile-bed model.

7.1 Missouri River Mobile-bed model

The Missouri River Mobile-bed model is a HEC-RAS 5.0 sediment model that was developed to predict future bed degradation if no remedies are undertaken (future without project) and to screen and evaluate potential solutions (future with project). The model starts at RM 448.89, less than one mile upstream from the St. Joseph, Missouri USGS gaging station (RM 448.2). The model ends at RM 293.421, near the Waverly, Missouri USGS gaging station (RM 293.4). The downstream boundary is a historically stable location on the river. The model extents were chosen to encompass the critical-degradation, severe-degradation, and adjacent significant-degradation reaches determined during the river-reach-screening process. The model design and cross section resolution allows testing of reach-scale effects, e.g. the effect on bed change of lowering all dikes over several miles and the reach-averaged effects of commercial dredging. The model setup and calibration are summarized here. See Appendix B – Mobile-bed model Calibration Report for detailed documentation. See Appendix F – Mobile-bed model Review Documentation for Agency Technical Review and Independent External Peer Review of the model.

7.1.1 Model Setup and Calibration

The model contains 287 cross-sections which span approximately 155 RM of the Missouri River with six to 12 cross sections per river bend. Elevations for model setup and calibration used National Geodetic Vertical Datum 1929. Flow and sediment loads from the upstream Missouri River, the Platte River (in Platte County, Missouri), and the Kansas River are derived from USGS gage measurements. Bed sediment sizes are based on a 1994 bed sediment survey. Locations and quantities of sand and gravel mining were based on historic data reported to the Kansas City District Regulatory Branch as part of the conditions for Rivers and Harbors Act Section 10 and CWA Section 404 permits.

The model was calibrated to replicate measured water surfaces, sediment loads, velocities, bed elevation changes, and volume of bed degradation from 1994 to 2014. The principle calibration period was from 1994 to 2009, which included both low- and high-flow years and was considered more representative for long-term conditions. The model was additionally calibrated against measured data from 2009 to 2014. This second calibration period included unique boundary conditions which are most likely not representative for long-term simulations. The model calibrated well during both time periods. See Appendix B – Mobile-bed model Calibration Report for complete documentation. Examples of calibration metrics are provided here.

The average absolute discrepancy between the modeled and measured water surfaces from 1994 to 2009 is 0.60 feet at the Kansas City gage and 0.49 feet at the St. Joseph gage. Figure 7-1 plots the modeled water surface and USGS-measured water surface from 1994 to 2002 at the Kansas City gage. Additional graphs are provided in Appendix B – Mobile-bed model Calibration Report.

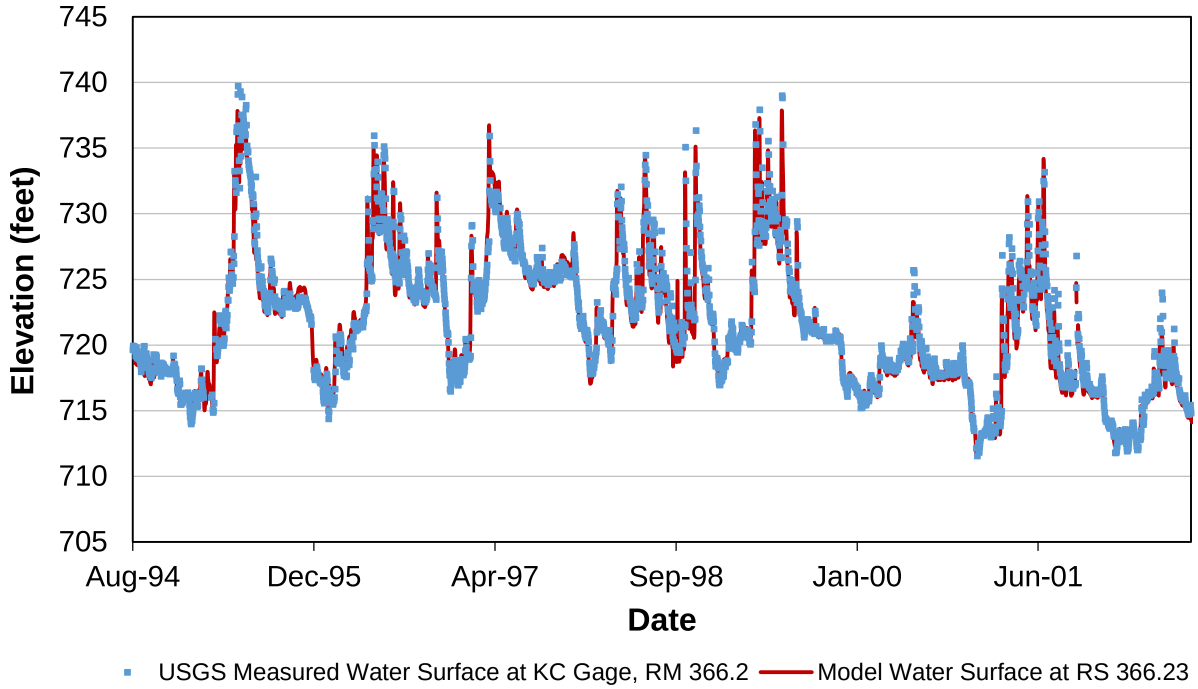

Figure 7-1: Example of modeled vs. measured water-surface elevation at the Kansas City Gage from 1994 to 2002.

Figures 7-2 and 7-3 display the modeled- and measured-average-bed elevation change between 1994 and 2009 and between 2009 and 2014. Although the bed of the river is highly variable, the model reproduces the trends, magnitude, and locations of bed degradation well in both time periods.

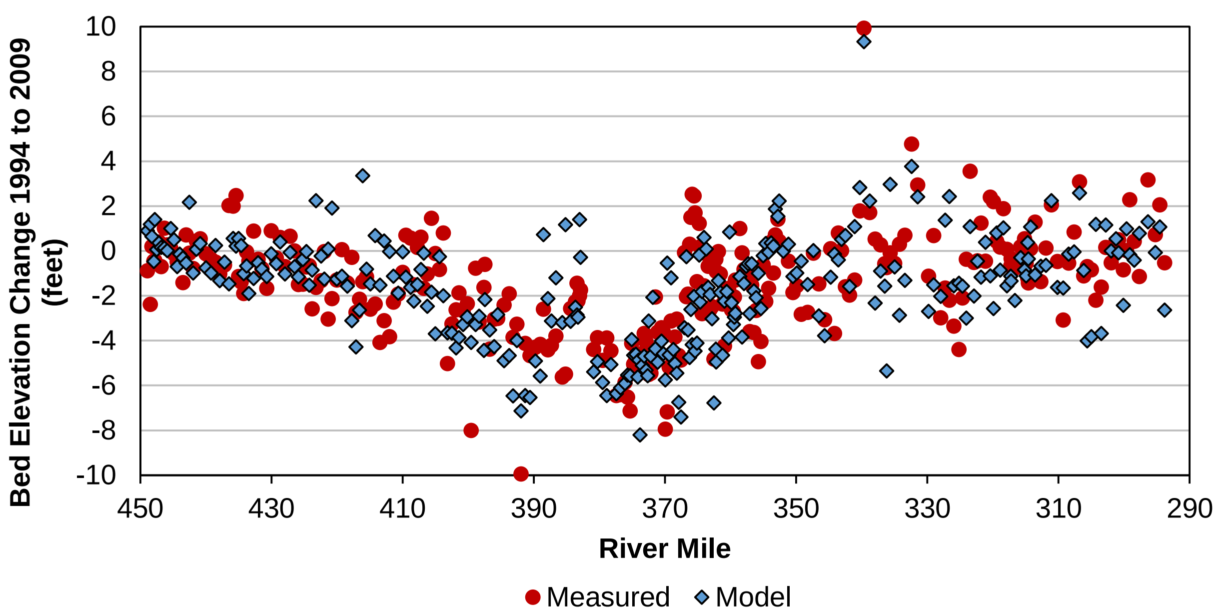

Figure 7-2: Modeled vs. measured bed elevation change from 1994 to 2009.

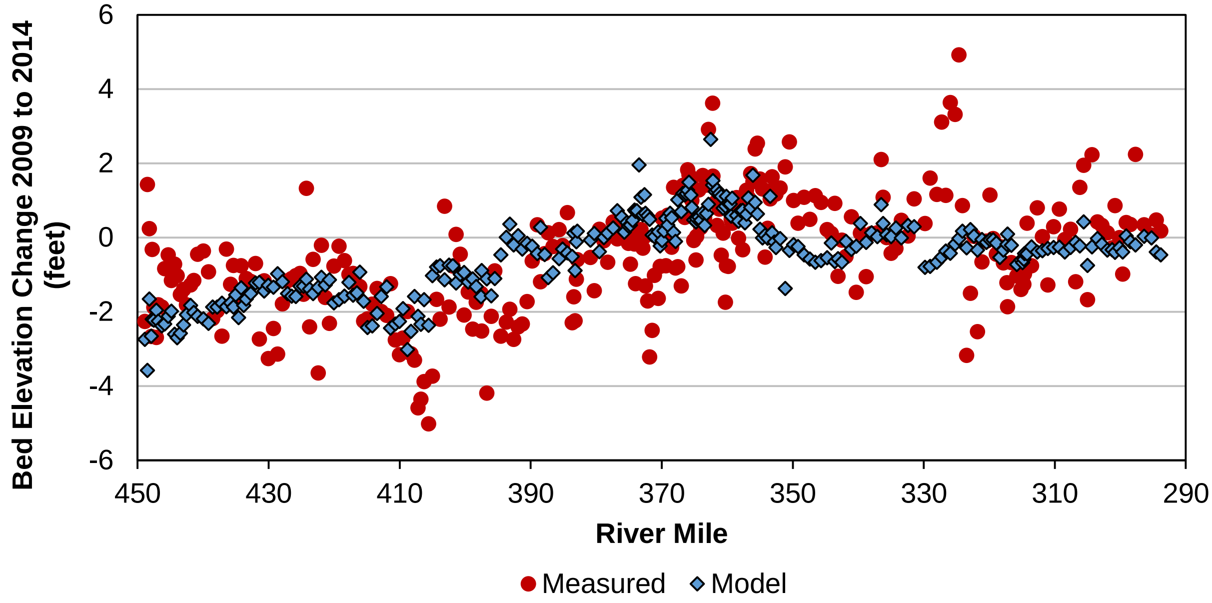

Figure 7-3: Modeled vs. measured bed elevation change from 2009 to 2014.

Figures 7-4 and 7-5 display the longitudinal-cumulative-mass curves for 1994 to 2009 and 2009 to 2014 for measured and modeled data. Longitudinal-cumulative-mass curves smooth out fluctuations caused by individual cross sections. Again, the model reproduces the magnitude and locations of bed degradation well, particularly demonstrating the upstream migration of degradation over time.

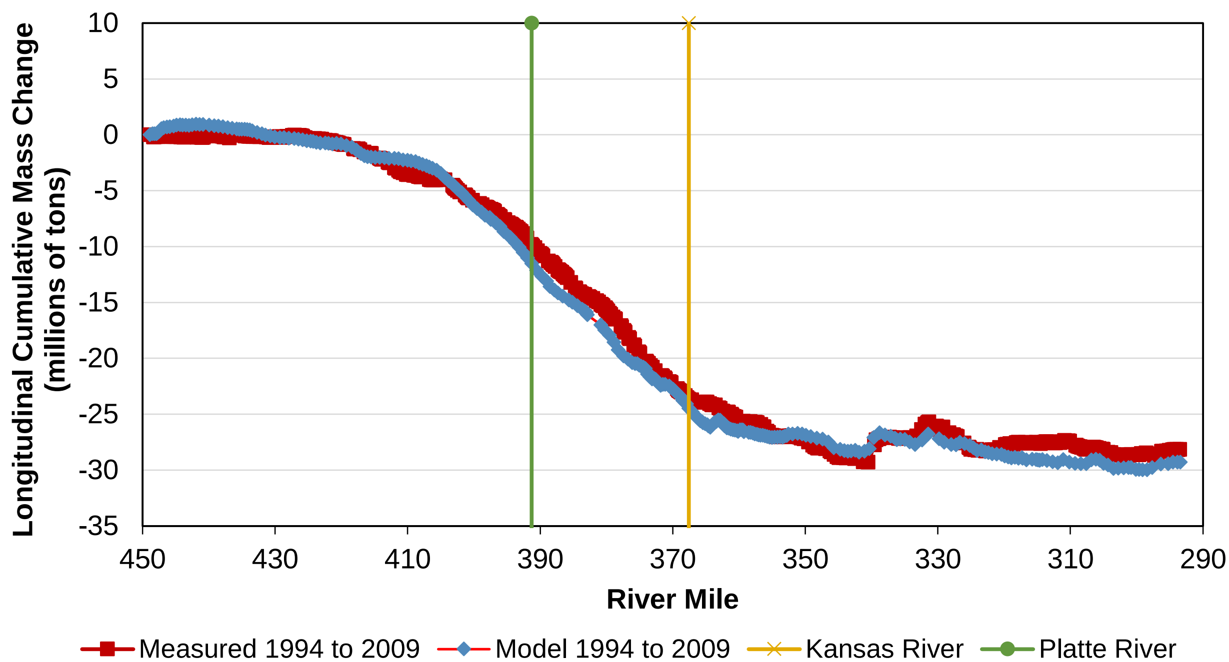

Figure 7-4: Modeled vs. measured-mass change from 1994 to 2009.

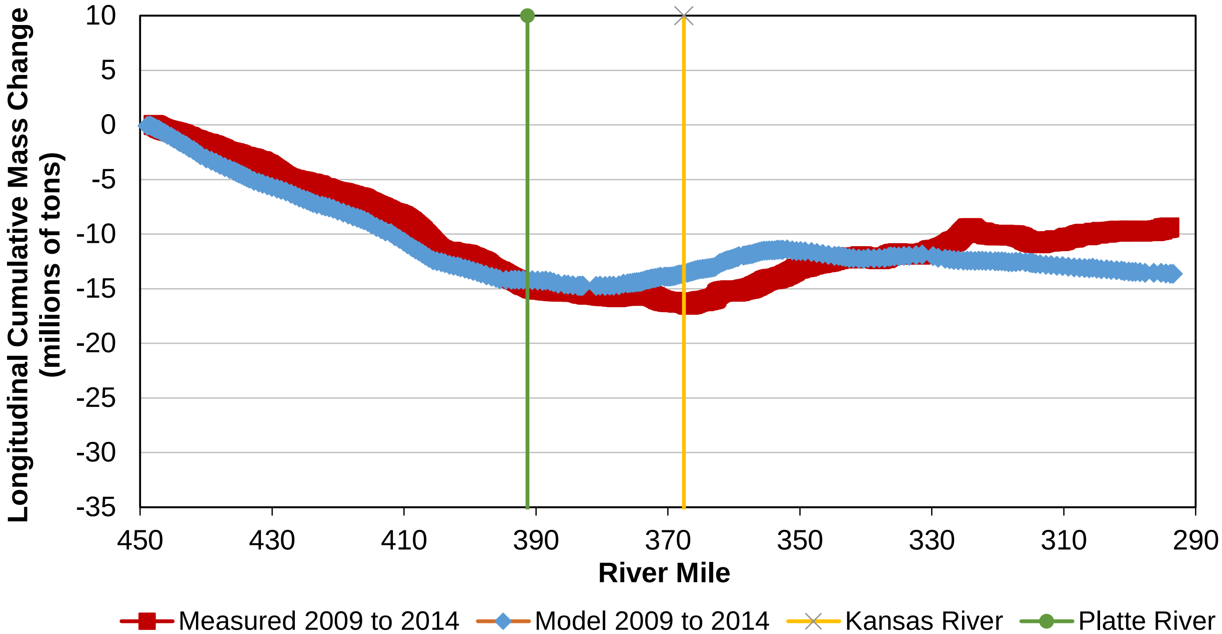

Figure 7-5: Modeled vs. measured-mass change from 2009 to 2014.

7.2 Economic Analysis and Modeling

USACE follows procedures from the United States Water Resources Council's *Principles and Guidelines*. Identification of a tentatively selected plan for Section 216 studies is based on the NED objective. The purpose of NED objective is to maximize the net benefits to the nation from a project. Net benefits are calculated by subtracting total economic costs from total economic benefits. The NED plan must also be consistent with national environmental statutes.

For this study, NED benefits result from avoiding future damages due to the impacts of bed degradation within the study area. Future damages that fall within the NED category are the repair and replacement costs for at-risk infrastructure, owned and maintained by federal, state, and local governments, and by private entities when suitable information is made available.

The major outputs of concern related to Missouri River bed degradation include power generation, municipal and industrial water supply, highway transportation, flood damage risk reduction, bank stabilization, and navigation. It is assumed that the future provision of these outputs will not be reduced by projected future bed degradation because of the national and local importance of these fundamental outputs. The nearly 2.6 million people residing within the Kansas City Metropolitan Statistical Area will continue to receive power, water, transportation, and flood-damage-risk-reduction services regardless of bed degradation because specific entities exist which were chartered to provide these services, such as utility companies, levee districts, and state departments of transportation. Additionally, USACE is mandated by Congress to maintain the authorized project purposes of the BSNP. Although the economic analysis assumes that repairs would be performed prior to any catastrophic failure of infrastructure, there is a small amount of risk associated with this assumption. If a catastrophic failure were realized, the impacts would be much greater than those described.

Although projected future bed degradation will not affect the provision of these fundamental outputs, the costs of providing these outputs will be substantially affected by the damage caused by projected future bed degradation. Alternative plans that reduce future damages to the infrastructure and hence reduce the future cost of providing these outputs, contributing to NED by increasing the net value of the outputs. The future costs avoided by alternative plans are the NED benefits of the individual plans. These avoided costs will be compared to plan implementation costs in the benefit-cost evaluation of alternative plans.

The Missouri River Bed Degradation Economic Model is a study-specific model developed to estimate future costs to infrastructure due to bed degradation. Model inputs include the associated change to water-surface elevations and bed elevations from the Mobile-bed model, infrastructure-repair costs due to changes in water and bed elevations, and geographic information system (GIS) program outputs, which identify physical characteristics of the infrastructure. The economic model takes and inputs the minimum model elevation at each feature for the year.

The model is used to generate average annual costs over a 50-year period of analysis with the current FY17-discount rate of 2.875% for each of the alternatives. Detailed information concerning the economic evaluation is located in Appendix O – Economic Analysis. Detailed information concerning the model review and approval is located in Appendix G – Economic Model Documentation. The model has been approved for single-use for this study in accordance with Engineering Circular 1105-2-412 – Assuring Quality of Planning Models.

7.2.1 Economic Data Collection and Data Inputs

This section discusses data collection and data inputs for non-federal and federal economic analysis. All costs are planning-level estimates. Actual costs could be greater than those described.

7.2.1.1 Non-Federal Costs

Information concerning potential future responses to continuing bed degradation, including potential plans of stakeholders and their costs, was gathered from local utilities and municipalities. This confidential information includes potential future actions which may be taken in the near term and other actions which are long term. The scheduling of these actions will be determined by the perceived extent of future degradation at each facility. High-flow events in the near term with associated bed degradation would likely cause a facility operator to initiate plans that would otherwise be scheduled farther into the future. Similarly, high-flow events in the near term with associated bed degradation may cause a larger, more expansive response from a facility operator than would be executed under conditions of more gradual bed degradation.

For the base-case (Future Without-Project Condition) economic scenario, which is based on the average bed degradation projections from the Mobile-bed model, the entire infrastructure re-construction or repair cost is entered into the model in the year that the critical bed elevation is achieved. However, municipalities and utilities are averse to risks, which may impact the provision of fundamental services such as water and power. Responses to perceived future bed degradation would likely be proactive so that service provision continues with minimal disruption. It would likely be years between planning, construction, and operation of a large, capital intensive response to bed degradation, such as development of an alternative water source or switching to a recirculating cooling system. It would not be unreasonable to assume that a facility operator may begin the planning process five years or more prior to the critical level of bed degradation being achieved. This assumption has been confirmed in interviews. Incorporating this long lead time into the planning process, the facility operator can ensure that the new structure will be in operation prior to the failure of the existing structure. A sensitivity analysis was performed in which the economic model was adjusted to account for a three year lead time (See Section 12 Risk and Uncertainty). In the sensitivity analysis, the capital costs are incurred three years prior to the year that the critical bed elevation is achieved.

In order to maintain the confidentially under which potential future plans and projected future costs were disclosed, the potential future costs of plans to address the effects of future bed degradation are grouped into categories (Table 7-1). Projected future costs for municipal infrastructure include capital-construction costs and annual additions to operations and maintenance (O&M) costs. All major infrastructure was evaluated for inclusion into Table 7-1; however, only a sub-set of this infrastructure was projected to be impacted in the bed degradation modeling. Therefore, not all costs identified in Table 7-1 are projected to be incurred during the 50-year planning horizon because the projected degradation at some facilities is not sufficient to achieve the critical elevation for that structure. The base-case bed degradation model results in $269 million in damages with a present value of $139 million.

Table 7-1: Potential future municipal infrastructure costs due to bed degradation. All values are in FY17 dollars.

Structure Type	**Capital Costs**
Auxiliary Intake Equipment	$23,400,000
New Intake Construction	$244,800,000
Alternative Water Supply Sources	$135,600,000
Alternative Cooling Systems	$342,000,000
Bridge Repairs	$20,800,000
Levees and Floodwalls	$18,300,000
Total Structure Capital Costs	**$785,500,000**
Increased Annual O&M Costs – Utilities	**$29,000,000**

Bed degradation in the main channel of the Missouri River causes degradation in tributary streams. Bed degradation that migrates up tributaries can impact bridges, culverts, buried pipelines and other infrastructure. The most economical way to prevent bed degradation from migrating up tributaries is to construct grade-control structures near the most downstream end. To project future economic impacts to protect infrastructure up tributaries, all tributaries between RM 293 and 498 were identified using aerial photography. Elevation data from representative cross-sections of the tributaries were extracted from 10-meter LiDAR data collected in 2013. The economic analysis only included the costs to construct grade-control structures to protect against future degradation, not current degradation which may have been induced by past Missouri River bed degradation. Construction of a grade-control structure is only included for tributaries with associated Missouri River bed degradation projected to be two feet or more from 2015 to 2065. At two feet of degradation costs for grade-control structure construction range from a low of $42,000 to a high of $462,000 based on the quantity of material needed. At four feet of degradation a new grade-control structure would be combined with bank protection. The costs at four feet of degradation range from $480,000 to $2,100,000. See Appendix L – Cost Estimate to Construct Rock Grade-Control Structures on Tributaries to the Missouri River.

7.2.1.2 Federal Costs

Bed degradation can impact a number of federal projects including the BSNP, levees and floodwalls, and constructed fish and wildlife habitat. River bed degradation adversely affects the BSNP in two ways; river training structures become perched above their design elevation and outside bend revetments become undermined resulting in an over-steepened slope along the face of the revetment. The cost of revetment reinforcement is estimated to be $320,000 per RM per foot of degradation. The cost of lowering river training structures is estimated to be $25,000 per RM per foot of degradation. See Appendix H – Analysis of the Cost of Degradation of the Bed of the Missouri River to the Missouri River Bank Stabilization and Navigation Project.

Assumptions related to impacts to flood damage risk reduction structures such as levees and floodwalls are included in Appendix I – Geotechnical Analysis of Flood-Risk Management Projects. The analysis considers failure during flood events, which could cause direct economic damages and possible loss of life, and failure during non-flood events which would require repair. These impacts and associated costs were considered in the economic analysis. Assumptions related to the impacts of bed degradation to bridges are included in Appendix J – Structural Analysis of Independent Structures.

USACE provides and maintains fish and wildlife habitat improvements along the Missouri River. Side channels, also called chutes, have been constructed in some locations along the Missouri River as a part of the Missouri River Recovery Program effort to avoid jeopardy of the endangered pallid sturgeon and to mitigate for the construction of the BSNP. Because these side channels were built to target specific flow and depth criteria, river bed degradation has the potential to adversely affect the function of the side channels in the vicinity of main channel degradation. For this analysis, all side channels within the Kansas City District above RM 290 are considered to be potentially impacted by bed degradation. This includes the following side channels:

- Dalbey Bottoms Chute C; RM 415.0-415.9;
- Dalbey Bottoms Chute B; RM 416.0-418.0;
- Dalbey Bottoms Chute A; RM 418.0-419.3;
- Benedictine Bottoms Independence Creek Chute; RM 424.1-424.6;
- Benedictine Bottoms Chute; RM 425.6-427.5; and
- Worthwine Island Chute; RM 456.9-458.9

If bed degradation and a corresponding drop in water-surface elevation in the target flow condition occurs in the vicinity of the side channel it will be necessary to lower the rock control structures that maintain the design flow relationships and biological access of the side channels (commonly referred to as chutes). Modifications of the rock control structures would be needed when the bed degradation near the chute reaches three feet and again at six feet. At each of these points, the control structures in each of the chutes would need to be lowered or, in some instances, entirely rebuilt. The control structure in Worthwine Island Chute cannot be lowered because the rock is not thick enough. The existing rock would need to be removed and a new control structure built. The control structures in the other chutes could be lowered up to five feet before needing to be replaced. Costs to modify the chutes at three feet of degradation range from approximately $29,000 to approximately $59,000, with the exception of Worthwine Island Chute which requires more extensive modifications at an estimated cost of $843,000. Costs to rebuild the control structures at six feet of degradation range from approximately $325,000 to approximately $650,000, with the exception of Worthwine Island Chute which requires less extensive modifications estimated at a cost of $88,000. See Appendix K – Analysis of the Cost of Degradation of the Bed of the Missouri River to the Missouri River Recovery Program Side Channel Chutes for Shallow Water Habitat.

8 FUTURE WITHOUT-PROJECT CONDITION

Future bed elevations and potential economic impacts are summarized for a 50-year period of analysis for the Future Without-Project Condition. Average annual costs are derived using the current FY17 federal interest rate of 2.875%.

8.1 Future Without-Project Degradation Modeling

The calibrated Mobile-bed model was used to develop the Future Without-Project Condition. The modeling included the parameters and conditions listed in Table 8-1.

Table 8-1: Conditions used for the Mobile-bed model Future Without-Project Condition.

Parameter	**Condition**
Cross Section Geometry	Updated to 2014 bed and dike elevations. Vertical Datum NAVD 88.
Flow Series	Flows that generate cumulative bed material transport with a 50% probability of exceedance at the end of 5, 10, 25, and 50 years.
Sediment Load	Flow-load relationship as calibrated during the first calibration time period (1994 to 2009).
Floodplain Deposition	Floodplain deposition scaled from the 2011 deposition according to days above a significant flood threshold. The 2011 floodplain depositional volume was determined by two feet times the areal extent of sand deposition.
Mining	As permitted in the December 2015 decision. Locations based on 2010 to 2015 locations.
Flood-Related Degradation	Model reproduces long-term trend, not short-term degradation and rebound. Temporary scour and rebound based on cross sectional measurements from the 2011 flood were added to model results.

Figure 8-1 displays projected bed elevation change in select years over the 50-year period of analysis compared to 2015. As seen, the Future Without-Project Condition projects continued degradation upstream of RM 400 and downstream of RM 367 compared to 2015 elevations. In the Kansas City area (RM 350 to 390), bed recovery is predicted in the near term, followed by a return of degradation. Over time, the new degradation that starts downstream of Kansas City migrates upstream causing degradation in the Kansas City area.

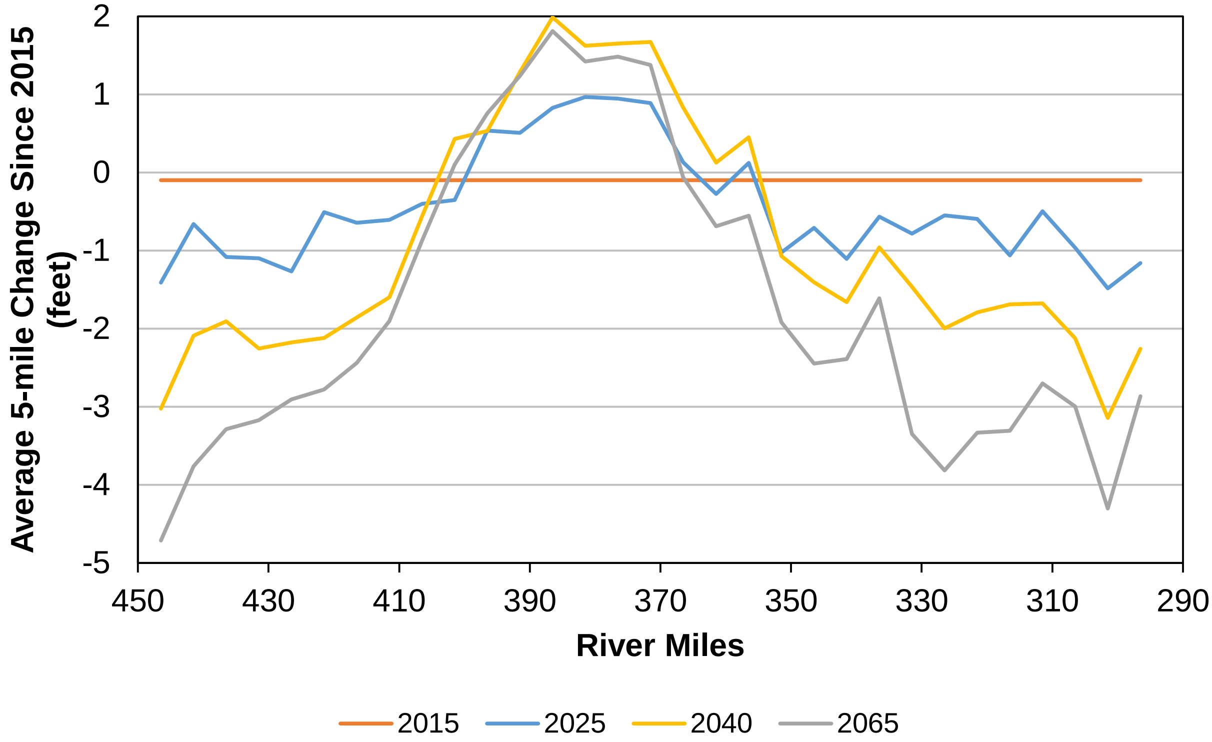

Figure 8-1: Five-mile reach average degradation since 2015 for the Future Without-Project Condition.

These projections are best understood in the historical context of degradation over the past two decades. Figure 8-2 plots the longitudinally de-trended bed elevations in 1987 (the oldest digitized survey), 1994 (the start of the model calibration time period), 2014 (the most recent river-wide survey), and in the future without-project years of 2025, 2040, and 2065. As seen, the levels of degradation expected at the upstream end of the model (near St. Joseph, Missouri) are similar to the levels that have been previously observed in the Kansas City area. In Kansas City, the bed elevations still remain significantly degraded, despite slight recovery in the short-term.

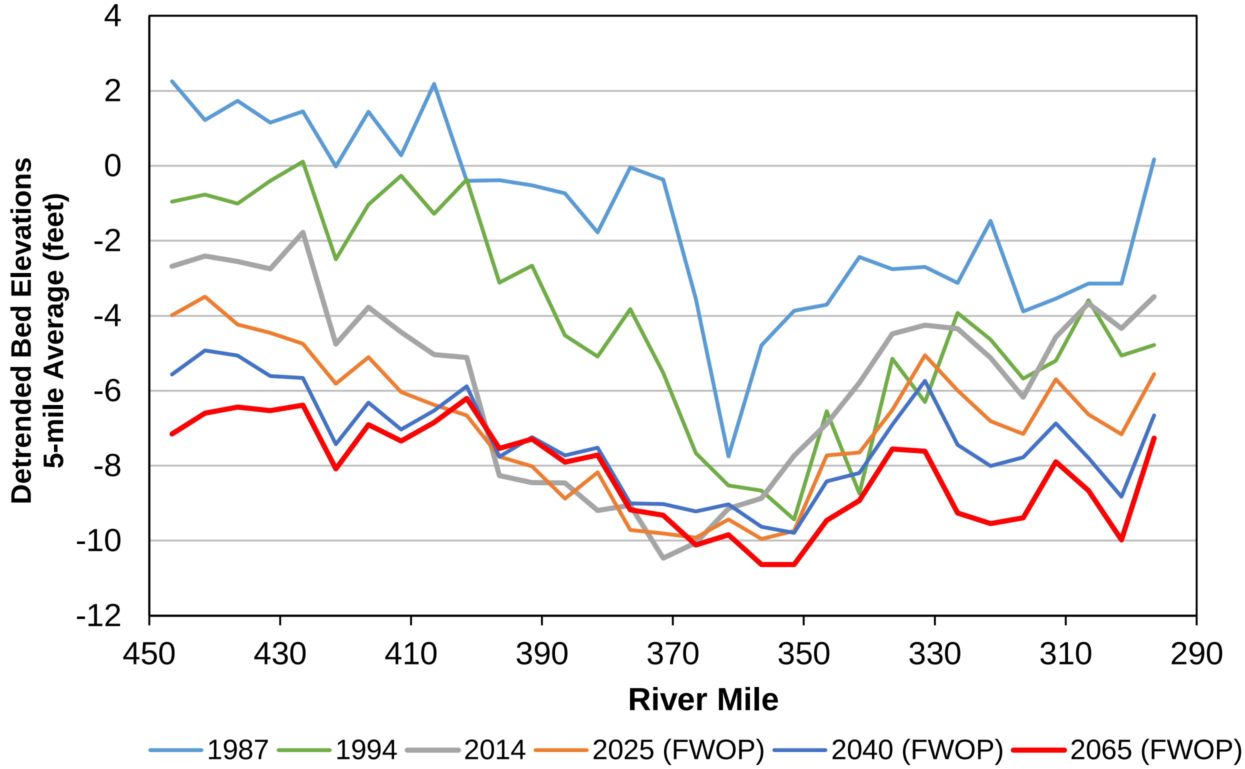

Figure 8-2: Five-mile reach average bed elevations for the Future Without-Project Condition.

The Mobile-bed model provides degradation projections for both bed elevations and associated low flow water-surface elevations for individual infrastructure features on the river. Average parameters as specified in Table 8-1 were used to generate the Future Without-Project Condition. The parameters in Table 8-1 were also varied to generate future scenarios with more or less degradation for risk and uncertainty analysis. See Section 12 of this report and Appendix C – Future Without-Project Model Projections with Risk and Uncertainty for detailed information concerning sensitivity tests and risk and uncertainty analyses.

Among the findings of the risk and uncertainty analysis was that the degradation in Kansas City would not have occurred if commercial sand and gravel mining was absent from the channel. This was determined by running the calibrated model from 1994 to 2014 with and without the commercial sand and gravel mining (Figure 8-3). In the absence of commercial sand and gravel mining, the Missouri River in the Kansas City area would have been in a recovery phase following the 1993 Missouri River Flood. However, the area upstream of Kansas City would still have experienced slight degradation as pre-1994 degradation in the Kansas City area migrated upstream and as a result of the 2011 Missouri River Flood.

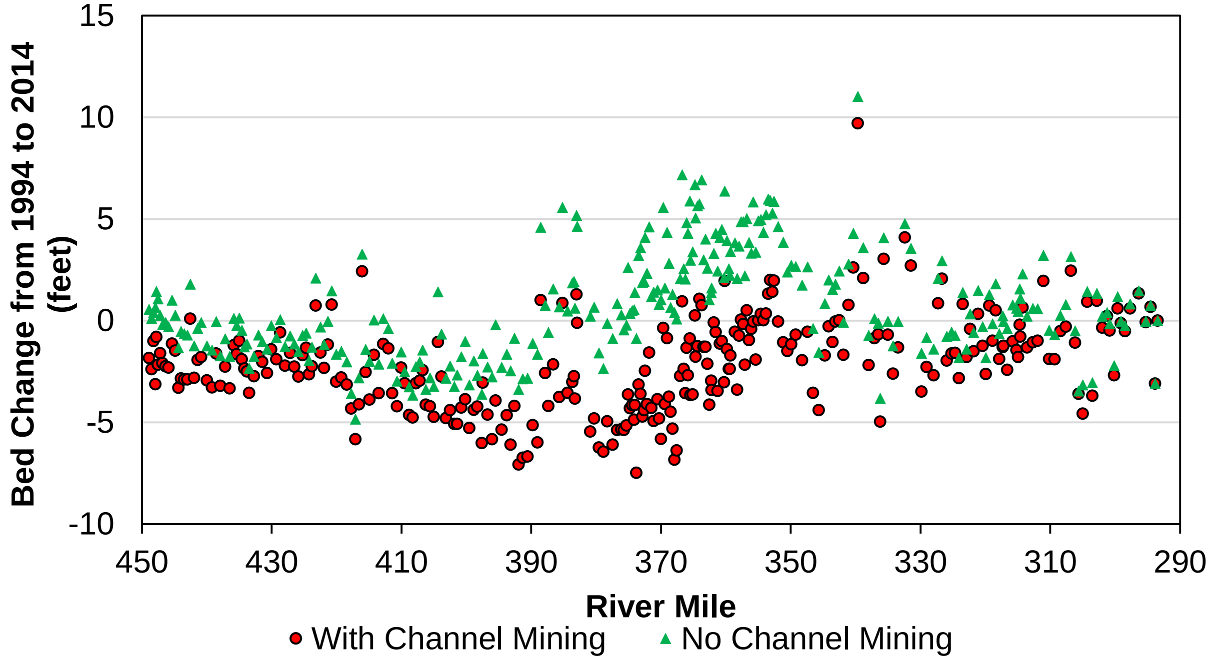

Figure 8-3: Modeled bed degradation with and without commercial dredging from 1 August 1994 to 29 July 2014.

8.2 Future Without-Project Economic Analysis

Under without-project conditions, the base-case bed degradation model indicates that federal costs to maintain the BSNP and fish and wildlife habitat will increase by $82.9 million dollars in present value over the 50-year planning time period. The costs to municipal water and electric utilities will increase by $34.6 million in present value and the cost to maintain tributary structures will increase by $21.4 million in present value over the 50-year planning time period. In total, over the 50-year planning time period, the present value of additional costs due to bed degradation are estimated to be $139 million, with an average annual cost of $5.3 million (evaluated using the FY17-discount rate of 2.875%) (Table 8-2).

Table 8-2: Projected future costs to existing infrastructure that may occur over the next 50 years if bed degradation is allowed to continue. Values were calculated over 50 years using the FY17 2.875% discount rate.

	Present Value	Average Annual Value
Federal Projects		
BSNP	$82,200,000	$3,120,000
Fish and Wildlife Habitat	$760,000	$30,000
Subtotal	**$82,960,000**	**$3,150,000**
Non-Federal		
Utilities	$34,580,000	$1,310,000
Tributaries	$21,400,000	$810,000
Subtotal	**$55,980,000**	**$2,120,000**
Total	**$138,940,000**	**$5,270,000**

Reducing or avoiding these projected future costs would contribute to NED. The future costs avoided by alternative plans are the NED benefits of those plans. These avoided costs will be compared to plan implementation costs in the evaluation of alternative plans.

9 ALTERNATIVE PLANS

Alternatives are developed following plan formulation procedures described in ER 1105-2-100 – Planning Guidance Notebook.

9.1 Plan Formulation

Management measures were identified that met at least one of the project objectives. A management measure is a feature, a structural element that requires construction or assembly on-site, or an activity, a non-structural action. Input received from a Value Engineering Study (Appendix M – Value Engineering), and the pubic scoping process (Appendix D – Missouri River Bed Degradation Scoping Report) were used to develop a wide range of measures. Structural measures that could be recommended for implementation pursuant to Section 216 authority as well as non-structural measures that could be considered as part of the Section 10 of the River and Harbors Act of 1899 and Section 404 of the CWA or Section 14 of the Rivers and Harbors Act of 1899, 33 USC 408 (Section 408) permitting process were considered in this study. Non-structural measures that could be implemented under Section 10 and Section 404 and/or Section 408 decision processes were not optimized to identify a recommended plan as those actions are outside the implementation authority under which the study was undertaken. This approach demonstrated the effectiveness of structural and non-structural measures across a range of conditions. It also allowed for the evaluation of a full range of alternatives as required in Engineering Regulation 1105-2-100, Planning Guidance Notebook and the Council of Environmental Quality's NEPA implementing regulations (40 CFR Part 1502.14(c)). Measures that did not meet the project objectives or that violate study constraints were screened out from further evaluation. Alternatives were developed from individual management measures and by combining various management measures together when possible in a logical manner. The alternatives were evaluated using the criteria required by the *Principles and Guidelines* that consist of completeness, effectiveness, efficiency, and acceptability.

9.2 Management Measures

Management measures were identified that had the potential to meet at least one of the project objectives. These included modifying BSNP structures, widening channel banks, installing grade-control structures, augmenting the river with gravel, bypassing sediment around Gavin's Point Dam, and modifying quantities of sand and gravel removed from the river by commercial channel mining activities. These measures were then evaluated using the project objectives and the project constraints.

These measures operate by influencing the sediment budget, as shown in Figure 9-1. The measures either increase the sediment entering a reach of the river (gravel augmentation, sediment bypass), they decrease the sediment transported downstream by decreasing the hydraulic forces (modify BSNP structures, channel widening, grade control, abandon BSNP structures) or they decrease the amount of sediment that is removed from the river system by reducing channel mining. Because the river is connected, any decrease in the amount of sediment leaving one reach (outgoing sediment) in turn causes an equivalent decrease to the incoming sediment for the downstream reach.

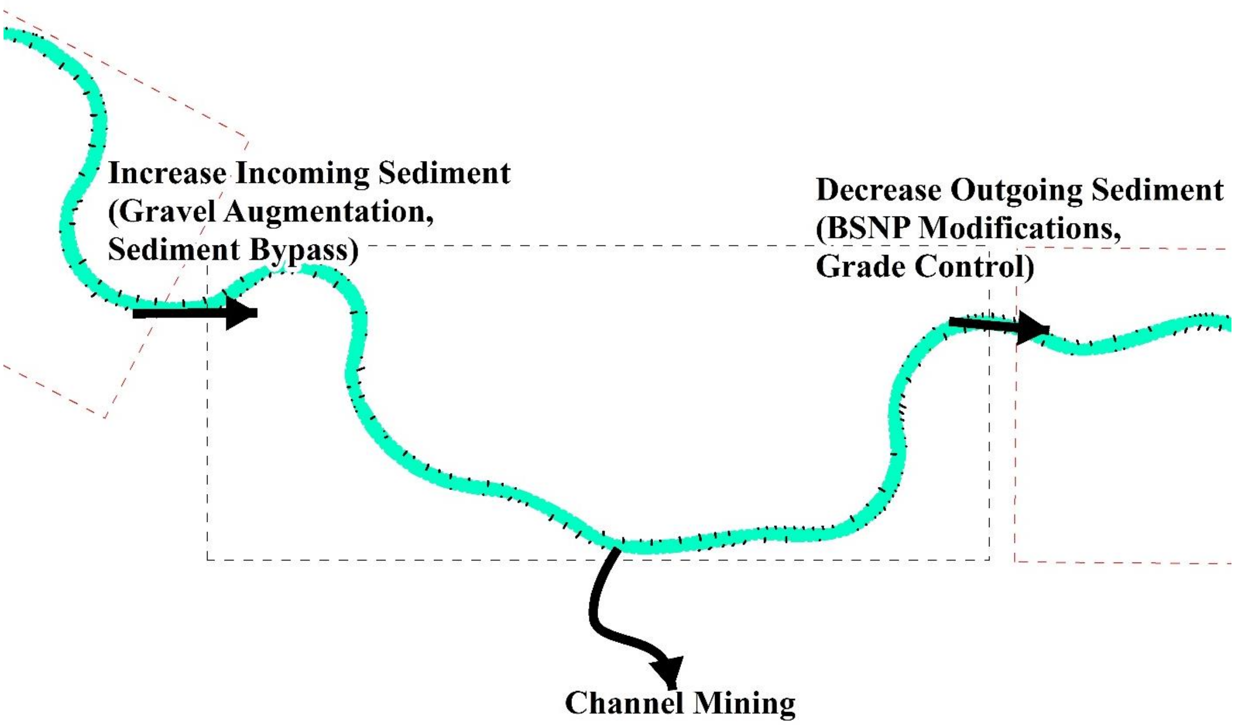

Figure 9-1: Conceptual sediment budget showing sources and sinks of sediment affected by management measures. Measures decrease bed degradation by increasing the incoming sediment, decreasing the outgoing sediment, or decreasing the channel mining.

9.2.1 Modification of BSNP Structures

Lowering the elevations of the BSNP dikes and sills increases the effective size of the channel. This would result in slower water velocities and some decrease in sediment transported out of a reach to the downstream reach. Various options exist for modifying these structures to maximize benefits from this measure. These include lowering the elevation of dikes only, lowering the elevations of sills only, and lowering both the elevations of dikes and sills. The amount that the structures could be lowered would also be considered. This measure could be implemented independently or in combination with other measures. Locations where this measure could be implemented could also be evaluated in order to maximize benefits. Multiple variations in BSNP adjustments were evaluated over the course of the study, including deeper and shallower excavations, wider and narrow excavations, and shifted locations of RM. Excavation depth was limited by the constraint of not lowering the low flow water-surface elevation. Excavation width was limited by space constraints and navigation concerns. The River mile locations of lowering were selected to coincide with the zone of projected location of degradation based on the future without-project condition. This measure was carried forward for further evaluation.

9.2.2 Widening Channel Banks

Widening the channel banks reduces water velocities, resulting in less sediment transported to the downstream reach. The channel banks could be widened mechanically using either land based construction equipment or from a combination of land based equipment and a hydraulic dredge. Alternatively, the channel banks could be widened by only excavating around and removing part of the buried portions of BSNP structures. Then, with time, the force of the river would erode away a portion of the banks between the dikes. The location where the channel banks could be widened could also be evaluated to maximize benefits from this measure. As the channel width is controlled via dike structures, this measure was combined with modifications of BSNP structures and carried forward for further evaluation.

9.2.3 Install Grade-Control Structures

New rock grade-control structures could be constructed perpendicular to the flow of the river using rip rap. Grade-control structures reduce the hydraulic forces transporting sediment out of a reach to the downstream reach by decreasing the slope of the river. The location and dimensions of the grade-control structures could be modified to maximize benefits. One factor must be evaluated when considering grade-control structures is that they can contribute to downstream-degradation problems, effectively moving the problem downstream. Additional measures or future-channel modifications would be needed to offset downstream impacts. This measure was carried forward for further evaluation.

9.2.4 Sand and Gravel Augmentation

Sand and gravel could be mined from the floodplain and placed into the Missouri River to increase bedload material and reduce bed degradation. This would require major pit-mine operations to provide sufficient suitable material. This measure was screened out because it would be inefficient and would not provide a sustainable solution.

9.2.5 Sediment Bypass

The construction of dams on the upper Missouri River prevents the downstream movement of sediment from the upper Missouri River to the lower Missouri River, including those locations within the study area. This measure would involve moving sediment from behind Gavins Point Dam, the dam farthest downstream, to a location below the dam where it would be transported downstream by the force of the river. However, USACE (2013) finds that drawdown flushing of Gavins Point Dam would only pass silts and clays from the reservoir to the downstream channel, not sands or gravels. These silts and clays would not help alleviate bed degradation in the focus reach of this study. Sands and gravels are located much further upstream in the reservoir and the distance to these sources does not make this an efficient option. Sediment augmentation from other sources (fish and wildlife habitat construction, excavated sediments from top width widening, etc.) would have a small positive effect but would be extremely limited at addressing the problem because of the relatively small amount of material that would be contributed to the system. Also, large scale changes to the Mainstem Reservoir System, such as removing dams, were not considered to be a reasonable measure to evaluate in detail because of the large amount of socioeconomic benefits they provide to the nation and the effect on the authorized purposes of the Missouri River. For these reasons, this measure was not carried forward for further evaluation.

9.2.6 Abandon Maintenance of BSNP Structures

As recommended for consideration by the U.S. Environmental Protection Agency, this measure would consist of no longer maintaining any of the BSNP structures within the study area. Over time the BSNP structures would degrade and the banks of the river would erode and widen, reducing water velocities and the amount of sediment transported out of reach to the downstream reach. All of the land and infrastructure adjacent to the river would be at risk of becoming damaged or experience catastrophic failure. Specific items at risk include, but are not limited to, flood-risk management structure such as levees and floodwalls, water intakes, bridges, roads, railroads, docking facilities, agricultural land, pipelines and utilities, and numerous residential, commercial, and industrial buildings. It would no longer be possible to maintain navigation, a congressionally authorized purpose of the river. Because of the expected increase of risk to life, health, and safety, and unacceptable adverse economic impacts that would result from this measure, it was not carried forward for further evaluation.

9.2.7 Modifications to Commercial Sand and Gravel Mining

In-river commercial sand and gravel mining is regulated through the River and Harbors Act Section 10 and the CWA Section 404. Implementing any modifications to permits issued for commercial sand and gravel mining is not within the Section 216 authority. However, NEPA requires the evaluation of a full range of reasonable alternatives, even those that may not be within the jurisdiction of the action agency. In the case of this particular study, modifications to in-river mining practices are within the jurisdiction of the agency, but not implementable within this study authority. Rather they are subject to Section 10 of the River and Harbors Act of 1899 (33 United States Code [USC] 403), Section 404 of the CWA (33 USC 1344) and Section 14 of the Rivers and Harbors Act of 1899, 33 USC 408 (Section 408). Information generated from this study could be useful to inform future agency decisions. For these reasons, this measure was carried forward for further evaluation. Initially, modifications to commercial sand and gravel mining were considered as a sensitivity analysis. See Appendix C – Future Without-Project Model Projections with Risk and Uncertainty. Based on the results of the sensitivity analysis, modifications to commercial sand and gravel mining were incorporated as a measure for the formulation of alternatives. To consider this measure, the study used a range of sand and gravel mining levels conditions as follows:

Condition A is the Future Without-Project scenario based on the currently permitted level of commercial sand and gravel mining, as defined by the 2015 permit record of decision (USACE 2015b) which became effective in January 2016.

Condition B is a reduced level of sand and gravel mining based on the stable dredging rate computed via the sediment budget analysis provided in USACE 2015. USACE (2015) analysis suggests a river-wide annual limit of 2.4 million tons per year over the lower 498 miles of river. Using the same tons/mile rate equates to 753,133 tons from St. Joseph to Waverly. In dredging condition B, the St. Joseph tonnage is shifted to Kansas City which minimizes degradation in St. Joseph.

Condition C eliminates sand and gravel mining in all three modeled reaches, starting in year 2021.

Further details regarding the assumptions may be found in Appendix C – Future Without-Project Conditions with Risk and Uncertainty and Appendix N – Future Without-Project Model Projections

Table 9-1: Range of Sand and Gravel Mining Scenarios and Conditions.

Sand and Gravel Mining Conditions (tons/year)			
	A- Baseline Sand and Gravel Mining	B- Reduced Sand and Gravel Mining	C- No Sand and Gravel Mining
St. Joseph* (RM 391 to 450)	330,000	0	0
Kansas City (RM 357 to 391)	540,000	451,367	0
Waverly** (RM 294 to 357)	1,730,430	305,765	0

Total (RM 450 to 294)	2,600,430	757,133	0
*All the St. Joseph dredging is assume to occur within the model space.			
** The full Waverly reach extends to RM 250. The dredging amounts in this table correspond to the model space only.			

9.3 Value Engineering Recommendations

Value Engineering Study was conducted after early identification of management measures. This study contributed further toward the development of the measures carried forward for adjustments to the BSNP structures, channel widening, and grade-control structures discussed above in Section 9.2. The Value Engineering study also proposed measures for modifications to commercial sand and gravel mining to be considered and this recommendation was adopted. Several additional measures were proposed for consideration through the Value Engineering Study process but not adopted. These are described briefly described below. A copy of the Value Engineering Study is included as Appendix M – Value Engineering Study.

9.3.1 Increase River Flow Length and Sinuosity through Restoration of River Channel Cutoffs.

The Value Engineering Study proposal identified river bends that were cut off from the river during construction of the BSNP. The measure would reconnect the cutoff bends to the navigation channel. The project delivery team determined that costs were underestimated and based on conceptual costs determined the cost for implementation would be unlikely to provide project benefits.

9.3.2 Construct Small Side Chute Channels.

The proposal was to construct secondary side channels similar to the shallow-water-habitat chutes rather than excavating the bank. This measure was not adopted for further consideration as it would be less efficient than widening the river.

9.3.3 Consider a Wider Floodway with the Flood Plain

This proposal recommended relocating levees and floodwalls landward in order to expand the floodway and reduce flow velocities during floods. A significant amount of floodway would need to be opened for either conveyance or floodplain storage in order to change flood depths. The levees identified for relocation would provide little storage and no flow conveyance because immediately downstream of the locations Kansas City's Levee System would constrict flow back to the channel. Social acceptance of setting back levees would be limited due to requirements and costs for relocation of industries. This measure was not adopted for further consideration.

9.4 Description of Alternatives

Alternatives were developed from the management measures that met the screening criteria. In total, 15 alternative plans were developed (Table 9-2). This included a No-Action Alternative as required by the Council on Environmental Quality's NEPA implementing regulations.

Table 9-2: Alternatives for the Missouri River Bed Degradation Study.

ALTERNATIVE	STRUCTURAL MEASURES				MINING VOLUME MEASURES		
	Lower Sills to -5 feet CRP	Lower Dikes to -5 feet CRP	Lower Sills & Dikes to -5 feet CRP	Grade-Control Structures	Currently Permitted Commercial Sand & Gravel Mining*	Reduced Commercial Sand & Gravel Mining	Eliminate Commercial Sand & Gravel Mining
Alternative 1A: Future Without-Project Condition					X		
Alternative 1B						X	
Alternative 1C							X
Alternative 2A	X				X		
Alternative 2B	X					X	
Alternative 2C	X						X
Alternative 3A		X			X		
Alternative 3B		X				X	
Alternative 3C		X					X
Alternative 4A			X		X		
Alternative 4B			X			X	
Alternative 4C			X				X
Alternative 5A				X	X		
Alternative 5B				X		X	
Alternative 5C				X			X

*Assumes that the permitted quantity that will be allowed to be mined each year will steadily increase from 1,979,500 tons/year in 2016 to approximately 2,600,431 tons/year by 2020 and stay at this level for the remainder of the period of analysis.

BSNP Modification Alternatives: The BSNP modification alternatives included lowering just the sill portion of the structure, lowering the dike portion of the structure with top-width widening, and lowering both the sill and the dike portion with top-width widening. See Figure 9-2.

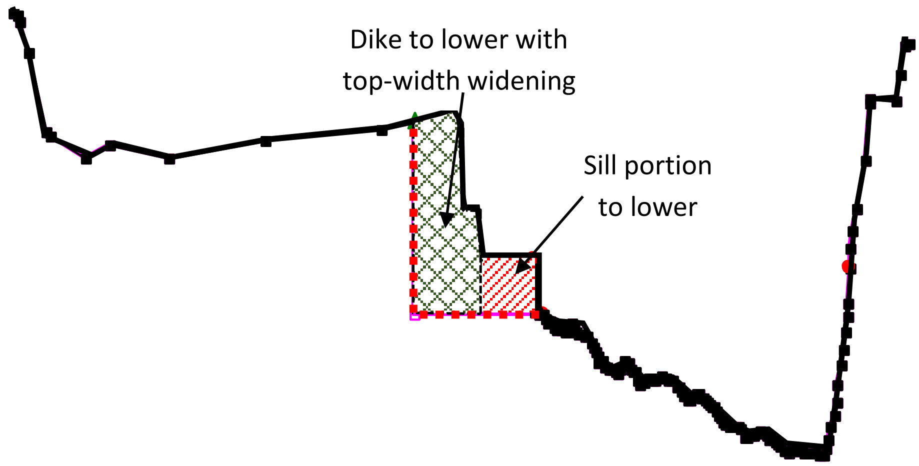

Figure 9-2. Example cross-section illustrated sill lowering (Alts 2A, 2B, 2C) and dike lowering with top-width widening (Alt 3A, 3B, 3C). Alternatives 4A, 4B, and 4C include both sill and dike lowering with top-width widening.

In the initial engineering and modeling analyses, it was determined that the most robust modifications to the BSNP (sill lowering combined with dike lowering and top-width widening), Alternatives 4A, 4B, and 4C were only marginally effective at reducing degradation. It was clear that alternatives involving dike or sill lowering individually (2A, 2B, 2C and 3A, 3B, 3C) would be even less effective. Accordingly, the alternatives involving dike or sill lowering individually were not evaluated in detail using modeling or quantity and cost calculations. The subsequent descriptions and assessments reflect this screening decision.

Alternative 1A – No-Action/Future Without-Project Condition: The No-Action Alternative incorporates the Future Without-Project Condition as required by ER 1105-2-100 for USACE planning studies. It provides the basis from which alternative plans are formulated and impacts are assessed over a 50-year period of analysis beginning in 2015. With the No-Action Alternative, no federal action would be taken to address the bed degradation problem through the Section 216 authority. However, it incorporates other actions that would be reasonably expected to occur in the future, including actions that would be taken by public and private entities in response to bed degradation. Details concerning the Future Without-Project Condition were described in Section 8.1. See Appendix C – Future Without-Project Model Projections with Risk and Uncertainty for additional information including a detailed discussion concerning assumptions.

Alternative 1B – Reduced Commercial Sand and Gravel Mining: This alternative would reduce the amount of commercial sand and gravel mining to 757,000 tons/year within the focused study area starting in year 2021. USACE (2015a) previously estimated that a river-wide annual limit of 2.4 million tons/year over the lower 498 miles of river would have resulted in a stable mining rate from 1994 to 2014. Using the same tons/mile rate equates to 753,133 tons from St. Joseph to Waverly. With Alternative 1B, the St. Joseph tonnage is shifted to Kansas City which minimizes degradation in St.

Joseph. It is assumed that the mining rates currently permitted through the year 2020 would remain in effect until that time. This alternative assumes that a sufficient supply of commercially available sand and gravel would be available from other sources, such as land-based pit-mine operations in combination with channel mining. Assumptions associated with this are discussed in Section 11.1.

Alternative 1C – Eliminate Commercial Sand and Gravel Mining: Alternative 1C would eliminate commercial sand and gravel mining from the focused study area starting in the year 2021. It also assumes that the mining rates currently permitted through the year 2020 would remain in effect until that time. This alternative assumes that a sufficient supply of commercially available sand and gravel would be available from other sources, such as land-based pit-mine operations. Assumptions associated with this are discussed in Section 11.1.

Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining: Alternative 4A would lower the BSNP sills and dikes between RM 391 to 449 to five feet below the CRP (Figure 9-3). It is assumed that approximately 28 acres of land would need to be cleared and grubbed, 180,000 cubic yards of material would need to be removed from buried portions of the BSNP dikes, and nearly 60,000 cubic yards of material would need to be removed from unburied portions of the BSNP dikes and sills. Preliminary estimates are that total project cost would be approximately $53 million dollars. Alternative 4A would use the same assumptions for future commercial sand and gravel extraction as Alternative 1A – No-Action/Future Without-Project Condition.

Alternatives 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining: Alternative 4B would lower the BSNP sills and dikes to five feet below the CRP between RM 391 to 449, identical to alternative 4A (Figure 9-4). It is assumed that approximately 28 acres of land would need to be cleared and grubbed, 180,000 cubic yards of material would need to be removed from buried portions of the BSNP dikes, and nearly 60,000 cubic yards of material would need to be removed from unburied portions of the BSNP dikes and sills. Preliminary estimates are that total project cost would be approximately $53 million dollars. It would also include a reduced level of commercial sand and gravel mining to 757,000 tons/year within the focused study area as described for Alternative 1B – Reduced Commercial Sand and Gravel Mining. This alternative assumes that a sufficient supply of commercially available sand and gravel would be available from other sources, such as land-based pit-mine operations in combination with channel mining. Assumptions associated with this are discussed in Section 11.1.

Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining: Alternative 4C would lower the BSNP sills and dikes to five feet below the CRP between RM 391 to 449, identical to alternative 4A (Figure 9-3). It is assumed that approximately 28 acres of land would need to be cleared and grubbed, 180,000 cubic yards of material would need to be removed from buried portions of the BSNP dikes, and nearly 60,000 cubic yards of material would need to be removed from unburied portions of the BSNP dikes and sills. Preliminary estimates are that total project cost would be approximately $53 million dollars. It would eliminate commercial sand and gravel mining from the refined study reach starting in the year 2021, as described for Alternative 1C – Eliminate Commercial Sand and Gravel Mining. This alternative assumes that a sufficient supply of commercially available sand and gravel would be available from other sources, such as land-based pit-mine operations. Assumptions associated with this are discussed in Section 11.1.

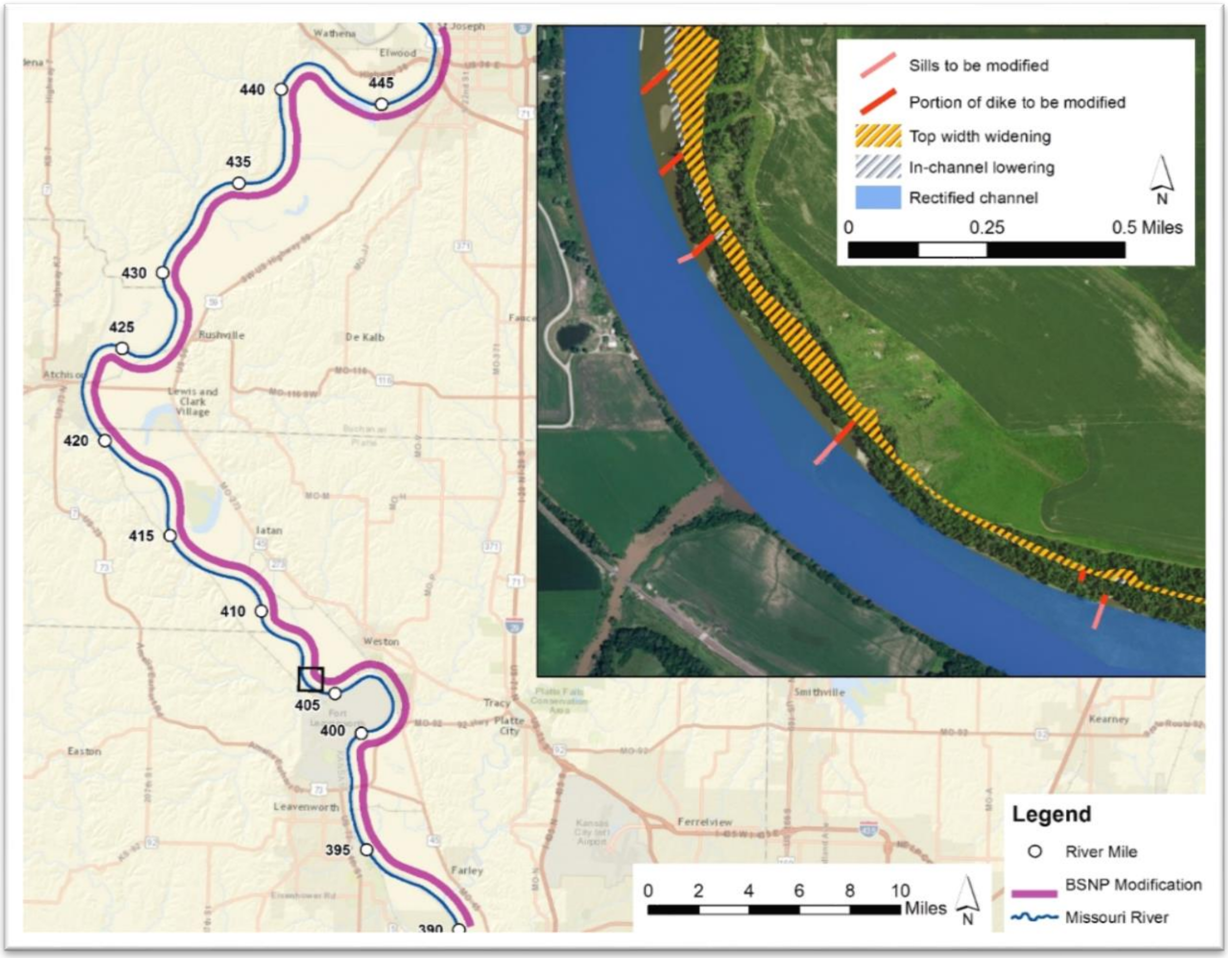

Figure 9-3: Alternatives 4A, 4B, and 4C would result in lowing the BSNP sills and dikes to five feet below the CRP between RM 391 and 449.

Alternative 5A – Install New Rock Grade-Control Structures & Maintain Existing Commercial Sand and Gravel Mining: Alternative 5A would result in 38 rock grade-control structures being constructed between RM 394 to 443 to address bed degradation (Figure 9-4). The top of the grade-control structures would be 11 feet below the 1973 CRP. The structures are designed to return the low-water surface profile to pre-degradation levels and prevent further upstream migration of the river bed degradation. The channel constriction allows nine feet of depth over the structures at navigation discharges. See Figure 9-5 for an example of a cross-section. The gentle slope on the downstream side of the structure would allow for fish passage and reduce impacts on navigation (Figure 9-6). Alternative 5A would use the same assumption for

future commercial sand and gravel extraction as Alternative 1A – No-Action/Future Without-Project Condition
Model results indicated that as few as six grade-control structures would be effective for stopping degradation. However, these structures would adversely impact navigation by drops in water-surface elevations ranging from 1.2 to 3.8 feet over each of the structures after they would be constructed. By the end of the 50-year period of analysis in 2065, there would be a drop of up to 6.6 feet at the most downstream structure. To offset this impact by maintaining a maximum one-foot drop in water-surface elevation over any single structure, additional grade-control structures would need to be constructed. In total, 38 grade-control structures would need to be constructed between RM 394 to 443. This would fundamentally change the character of the river to a series of slack-water pools and rapids when discharges are at or below minimum navigation flows. Approximately five million tons of rock would be needed to construct the grade-control structures. Preliminary estimates are that total project cost would be close to $300 million dollars, not including O&M, which would be substantial. In addition, more rigorous analysis of flood effects would be needed were this alternative selected.

Alternative 5B – Install New Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining: Alternative 5B would result in 37 rock grade-control structures being constructed from RM 394 to 443 to address bed degradation similar to Alternative 5A (Figure 9-4). It would also reduce the level of commercial sand and gravel mining to 757,000 tons/year within the focused study area as described for Alternative 1B – Reduced Commercial Sand and Gravel Mining. This alternative assumes that a sufficient supply of commercially available sand and gravel would be available from other sources, such as land-based pit-mine operations in combination with channel mining. Assumptions associated with this are discussed in Section 11.1.

As with Alternative 5A, it was determined that this alternative would perform with fewer structures but then would adversely impact navigation. Thirty-seven grade-control structures would need to be constructed between RM 394 to 443 to offset this impact, fundamentally changing the nature of the river. Approximately 4.8 million tons of rock would be needed to construct the grade-control structures. Preliminary estimates are that total project cost would be approximately $275 million dollars, not including O&M, which would be substantial. In addition, more rigorous analysis of flood effects would be needed were this alternative selected.

Alternative 5C – Install New Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining: Alternative 5C would result in 37 rock grade-control structures being constructed from RM 394 to 443 to address bed degradation similar to Alternatives 5A and 5B (Figure 9-3). It would eliminate commercial sand and gravel mining from the focused study area starting in the year 2021, as described for Alternative 1C – Eliminate Commercial Sand and Gravel Mining. This alternative assumes that a sufficient supply of commercially available sand and gravel would be available from other sources, such as land-based pit-mine operations. Assumptions associated with this are discussed in Section 11.1.

As with Alternatives 5A and 5B, it was also determined that this alternative could perform with fewer structures but would adversely impact navigation. Thirty-seven grade-control structures would need to be constructed between RM 394 to 443 to offset this impact, fundamentally changing the nature of the river. Approximately 4.8 million tons of rock would be needed to construct the grade-control structures. Preliminary estimates are that total project cost would be approximately $275 million dollars, not including O&M, which would be substantial. In addition, more rigorous analysis of flood effects would be needed were this alternative selected.

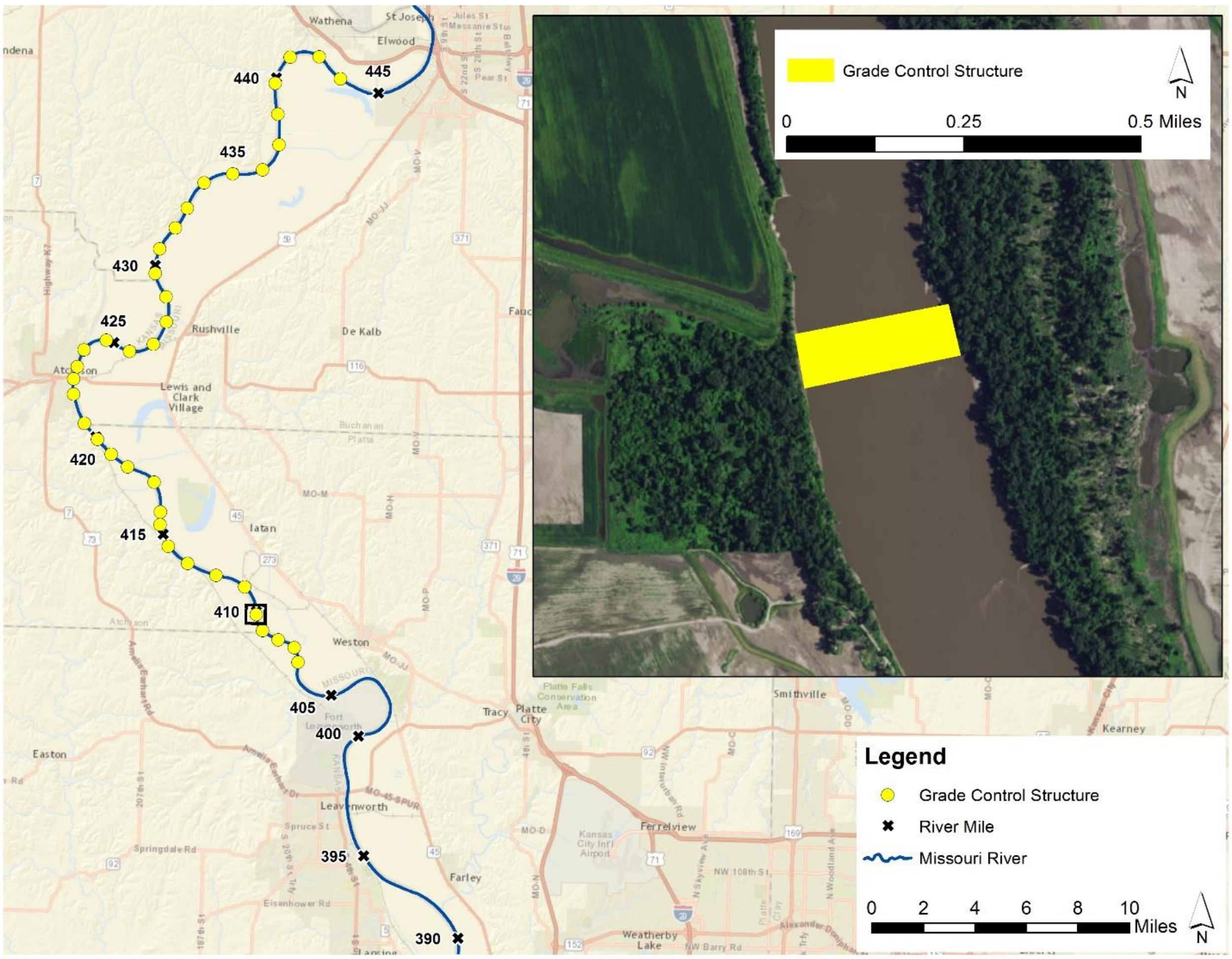

Figure 9-4: Alternatives 5A, 5B, and 5C would result in 37 to 38 grade-control structures between RM 394 to 443.

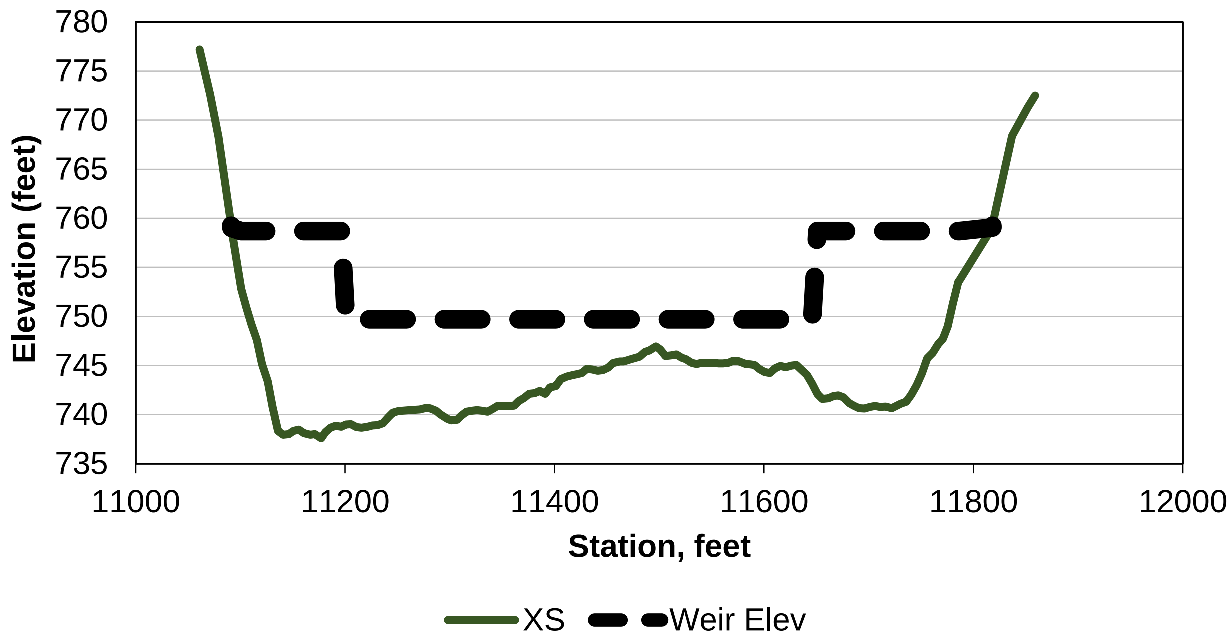

Figure 9-5: Cross-section and profile of grade-control structure at RM 407.19. The top of rock indicated by dashed line.

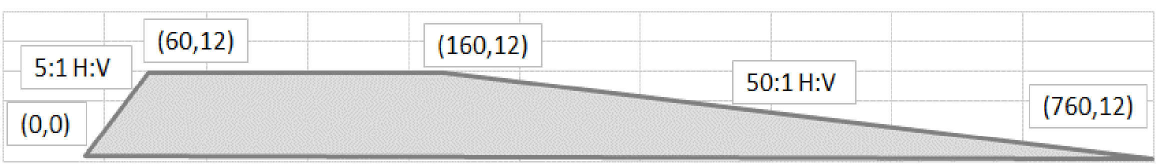

Figure 9-6: Grade-control structure profile. River stations correspond to structure at RM 407.19.

10 EVALUATION OF ALTERNATIVES

This section evaluates the physical and economic performance of the alternatives.

10.1 Physical Evaluation of Alternatives

Nine of the 15 alternatives were assessed in more detail using the Mobile-bed model. These included the following:

- Alternative 1A – No-Action/Future Without-Project Conditions,
- Alternative 1B – Reduced Commercial Sand and Gravel Mining,
- Alternative 1C – Eliminate Commercial Sand and Gravel Mining,

- Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining,

- Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining,

- Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining,

- Alternative 5A – Install New Rock Grade-Control Structures & Maintain Existing Commercial Sand and Gravel Mining,

- Alternative 5B – Install New Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining, and

- Alternative 5C – Install New Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining.

As indicated previously, six of the 15 alternatives with lowering of sills or dikes individually were screened out because they were less effective than those with combined sill and dike lowering, which were marginal. These included the following:

- Alternative 2A – Lower BSNP Sills & Maintain Existing Commercial Sand and Gravel Mining,

- Alternative 2B – Lower BSNP Sills & Reduce Commercial Sand and Gravel Mining,

- Alternative 2C – Lower BSNP Sills & Eliminate Commercial Sand and Gravel Mining,

- Alternative 3A – Lower BSNP Dikes & Maintain Existing Commercial Sand and Gravel Mining,

- Alternative 3B – Lower BSNP Dikes & Reduce Commercial Sand and Gravel Mining, and

- Alternative 3C – Lower BSNP Dikes & Eliminate Commercial Sand and Gravel Mining.

Figures 10-1, 10-2, 10-3, and 10-4 present projected bed elevations using the Mobile-bed model at the end of the 50-year simulation. These projections are given with respect to the projected bed degradation with 2015 as the start year. Figure 10-1 compares alternatives with the currently permitted quantities of commercial sand and gravel mining at the end of the 50-year simulation.

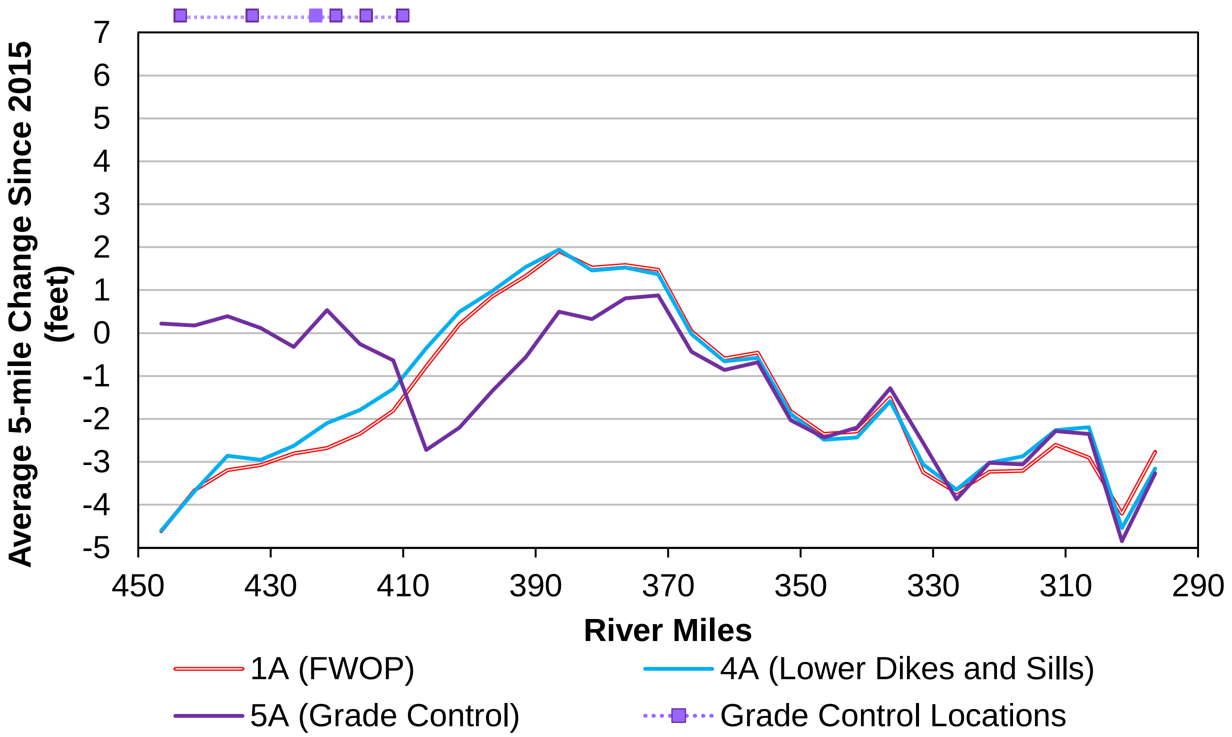

Figure 10-1: Projected bed elevations for year 2065 for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining, and Alternative 5A – Rock Grade-Control Structures & Maintain Existing Commercial Sand and Gravel Mining. Changes in elevation are in relation to the 2015 bed elevations (0 on y-axis).

As shown in Figure 10-1, Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining would only be slightly better than Alternative 1A – No-Action/Future Without-Project Condition in terms of long-term degradation. Because this was the most robust BSNP structural modification and is only marginally effective, alternatives with less robust BSNP structural measures were not modeled (Alternative 2A, 2B, 2C, 3A, 3B and 3C). This also confirmed that not dynamically adjusting dikes over the model calibration time period introduces only minor error in the model.

Alternative 5A – Install New Rock Grade-Control Structures & Maintain Existing Commercial Sand and Gravel Mining would effectively stabilize the bed in the vicinity of St. Joseph, Missouri. It would shift the degradation downstream. This effect decreases with increased distance downstream. However, it would induce a more degraded condition in the Kansas City area when compared to Alternative 1A – No-Action/Future Without-Project Condition. To offset this impact, over 30 additional grade-control structures would need to be constructed along the length of the river below the original set of structures to address the problem.

Figure 10-2 compares alternatives with reduced quantities of commercial sand and gravel mining at the end of the 50-year simulation. As shown, Alternative 1B – Reduced

Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, and Alternative 5B – Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining result in substantially less degradation compared to Alternative 1A – No-Action/Future Without-Project Condition due to the reduction in commercial sand and gravel mining. Alternative 4B is only slightly better than Alternative 1B – Reduced Commercial Sand and Gravel Mining. Alternative 5B – Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining shifts degradation downstream compared to Alternative 1B – Reduced Commercial Sand and Gravel Mining. The effect is offset by the reduced commercial sand and gravel mining level such that Alternative 5B – Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining exhibits less degradation or more bed recovery than Alternative 1A – No-Action/Future Without-Project Condition.

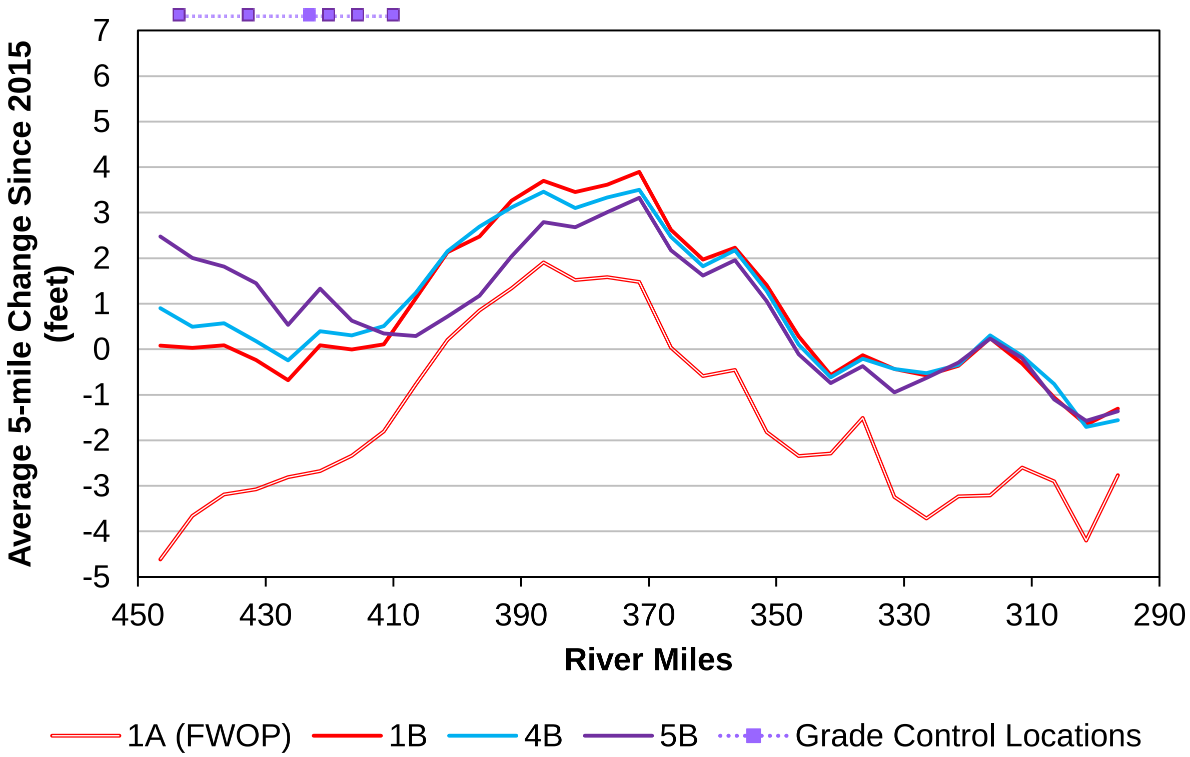

Figure 10-2: Projected bed elevations for year 2065 for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, and Alternative 5B – Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining. Changes in elevation are in relation to the 2015 bed elevations (0 on y-axis).

Figure 10-3 compares the alternatives at the end of the 50-year simulation with no commercial sand and gravel mining. As shown, Alternative 1C – Eliminate Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining, and Alternative 5C – Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining result in substantially less degradation for most of the modeled area compared to Alternative 1A – No-Action/Future Without-Project Condition. Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining is only slightly better than Alternative 1C – Eliminate Commercial Sand and Gravel Mining. Alternative 5C – Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining shifts degradation downstream compared to Alternative 1C. The effect is offset by the eliminated commercial sand and gravel mining, such that Alternative 5C – Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining exhibits less degradation and in some locations more bed recovery than Alternative 1A – No-Action/Future Without-Project Condition.

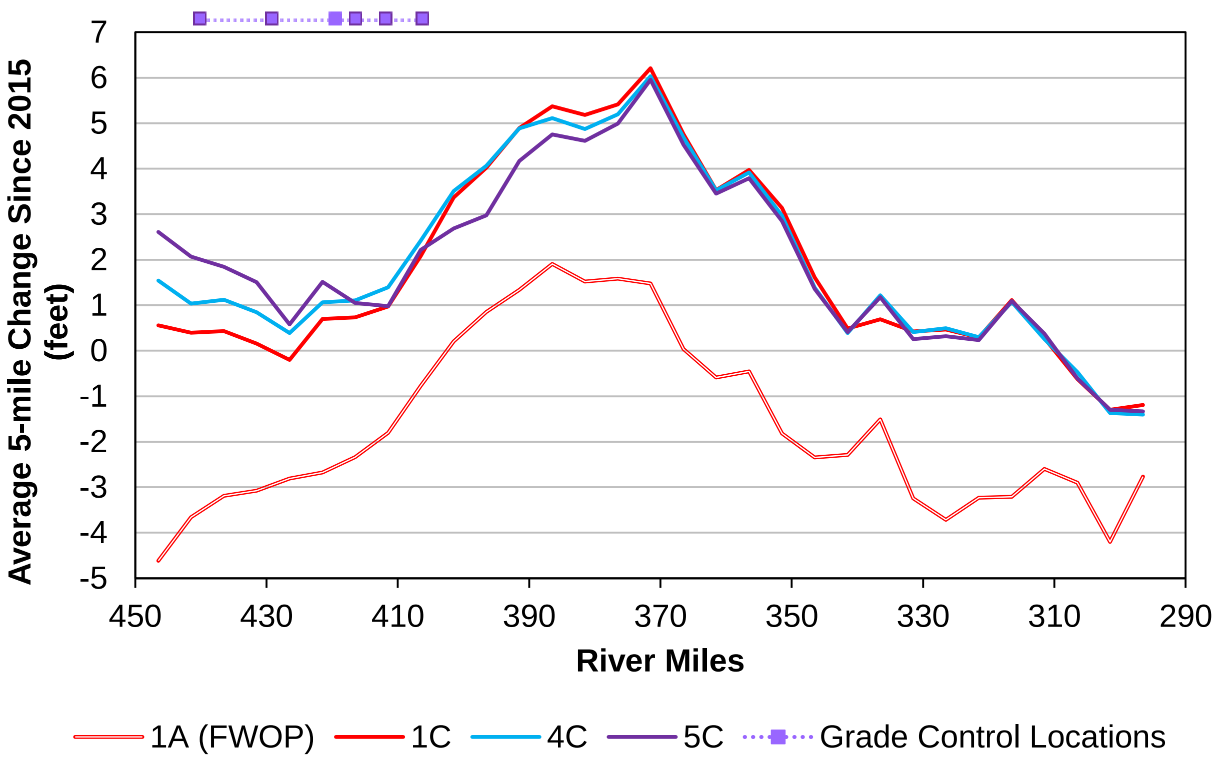

Figure 10-3: Projected bed elevations for year 2065 for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1C – Eliminate Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining, and Alternative 5C – Install New Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining. Changes in elevation are in relation to the 2015 bed elevations (0 on y-axis).

When considered collectively, Figures 10-1, 10-2, and 10-3 demonstrate the ineffectiveness of lowering BSNP sills and dikes to prevent degradation over the long term. They also demonstrate that rock grade-control structures effectively protect infrastructure in St. Joseph by shifting the degradation downstream towards Kansas City.

Figure 10-4 presents model projections for the Future Without-Project Condition and the two alternatives that include modification of commercial sand and gravel mining without any other structural measures. These are Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining. Alternative 1B and Alternative 1C are sufficient to substantially reduce degradation and in some locations increase bed recovery in the focused study area. The overall level of bed degradation and bed recovery is strongly a function of the level of commercial sand and gravel mining. As explained in Section 9.2.7, the reduced commercial sand and gravel mining measure includes the complete cessation of commercial sand and gravel mining in the St. Joseph reach, a slight reduction in the Kansas City reach, and a large reduction in the Waverly reach compared to the currently permitted quantities.

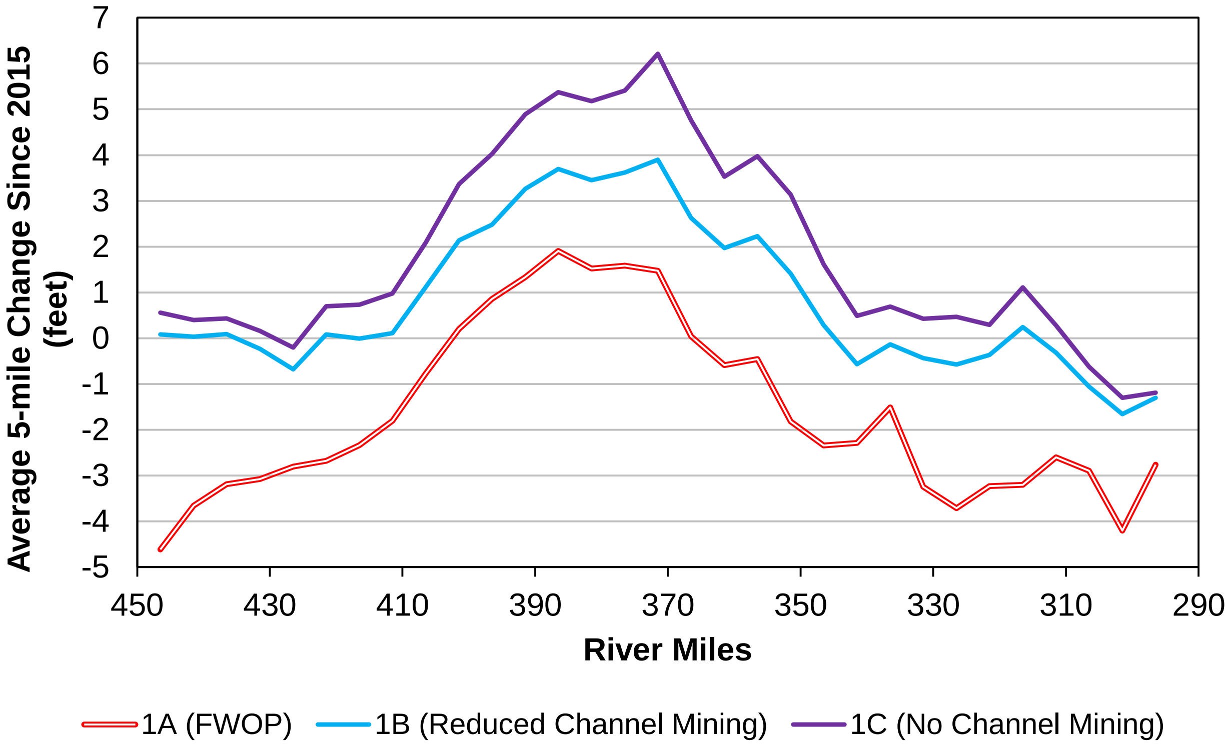

Figure 10-4: Projected bed elevations for year 2065 for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining. Changes in elevation are in relation to the 2015 bed elevations (0 on y-axis).

Figure 10-1 to 10-4 presented bed-elevation projections compared to 2015 conditions and indicate some bed recovery, particularly from RM 370 to 391. However, as demonstrated in Figures 3-1 and 3-3, the Missouri River had already degraded substantially in Kansas City from RM 350 to 391 and especially from RM 370 to 391.

Figures 10-5 to 10-7 present model projections for three different reaches of the study area over time including both historic bed elevations dating from 1987, and modeled projections of future conditions using the Mobile-bed model. The three reaches included the area from RM 392 to 448 (upstream of Kansas City area to St. Joseph), RM 350 to 391 (Kansas City area), and RM 294 to 349 downstream of Kansas City area to Waverly). The projections depict averages on a broad scale. Localized reaches will experience more or less degradation compared to the bed elevations shown in the figures. Note that the commercial sand and gravel mining measure is equal to the currently permitted quantities through year 2020 for all the alternatives. The Mobile-bed model indicates that none of the alternatives would result in bed elevations returning to 1987 levels, although, bed elevations in the Kansas City area have recovered closer to the 1987 elevations than the other two reaches.

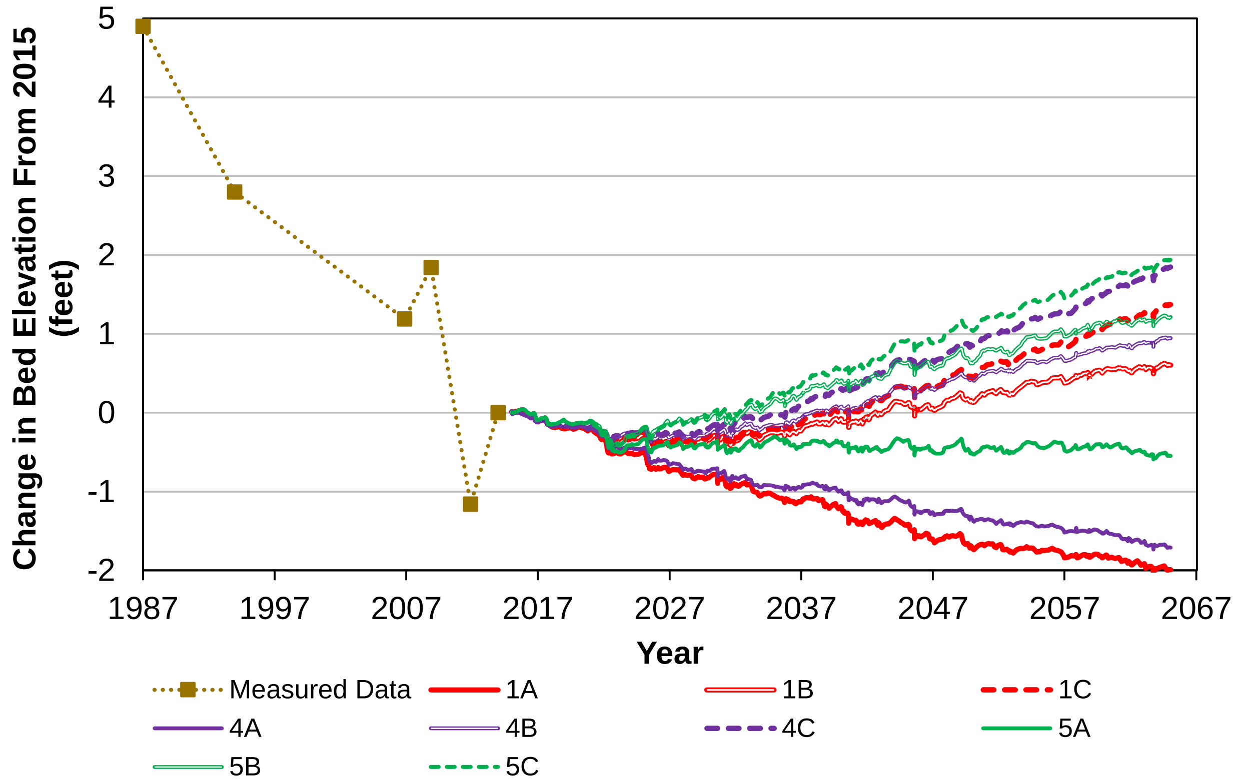

Figure 10-5: Bed elevations changes over time for RM 392 to 448 over a 78-year period showing measured elevations from 1987 to 2015 and modeled projections from 2015 to 2065 for alternatives evaluated in detail. See Section 9.4 for a description of the alternatives.

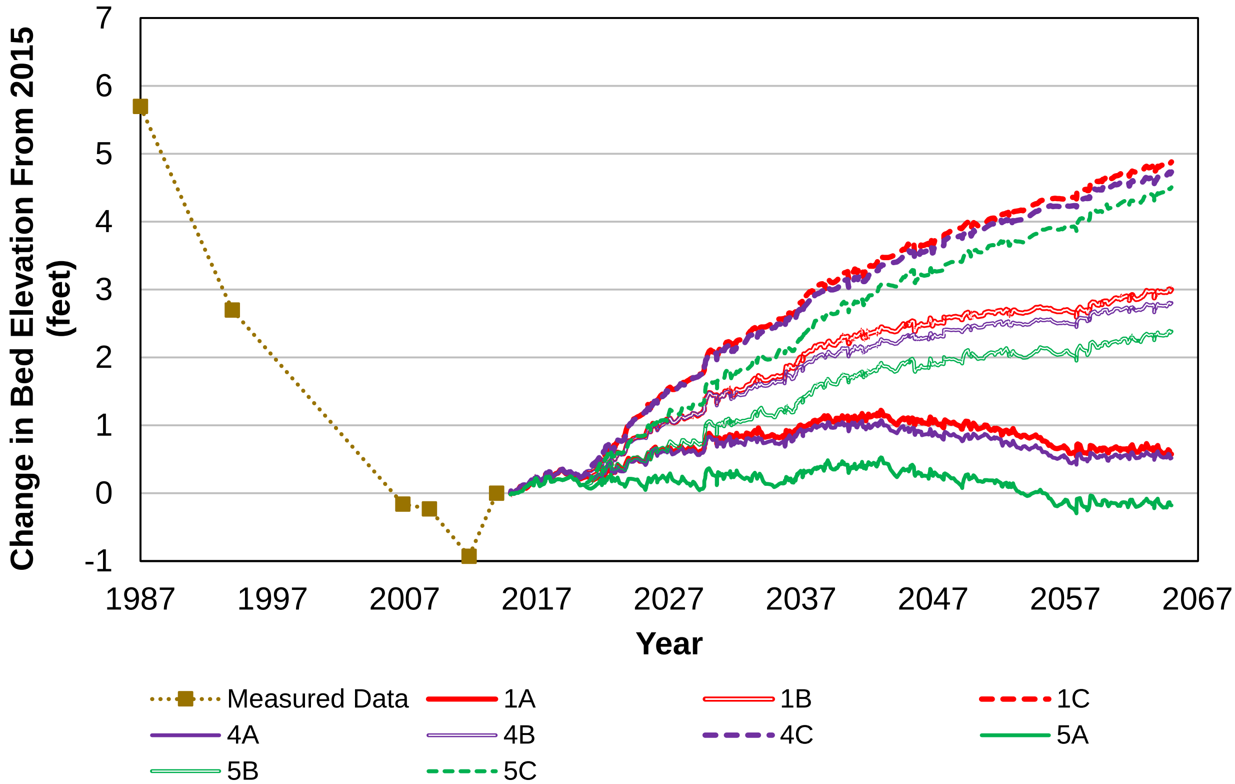

Figure 10-6: Bed elevations changes over time for RM 350 to 391 over a 78-year period containing measured elevations from 1987 to 2015 and modeled projections from 2015 to 2065 for alternatives evaluated in detail. See Section 9.4 for a description of the alternatives.

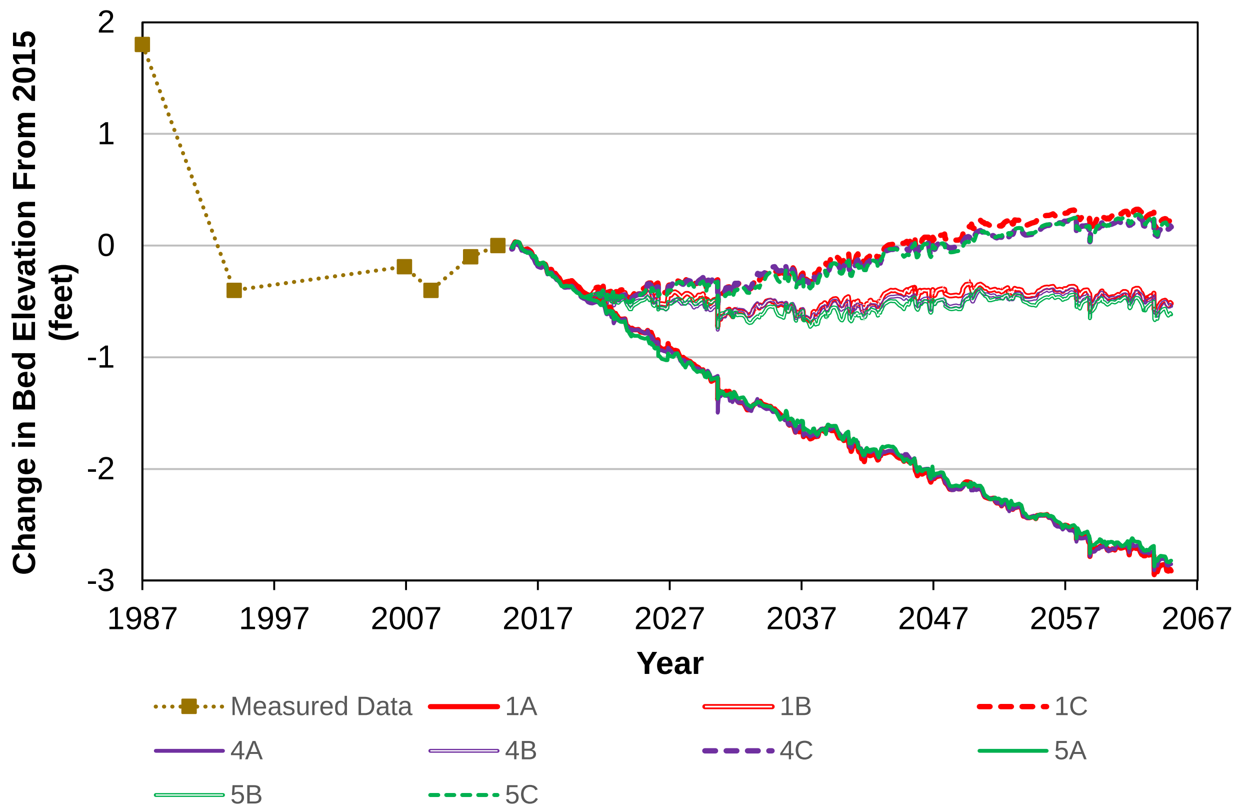

Figure 10-7: Bed elevations changes over time for RM 294 to 349 over a 78-year period containing measured elevations from 1987 to 2015 and modeled projections from 2015 to 2065 for alternatives evaluated in detail. See Section 9.4 for a description of the alternatives.

In summary, an evaluation of alternatives using the Mobile-bed model indicated the following:

- Lowering dikes and sills would be largely ineffective,
- Structural measures that would prevent degradation in St. Joseph would decrease bed recovery in Kansas City, and have essentially no effect on the reach downstream of Kansas City.
- The reach encompassing Kansas City is expected to continue on a recovery trend for the near term. At the currently permitted commercial sand and gravel mining quantities, degradation in the reach downstream of the Kansas City area will migrate upstream over time. A new degradation trend is expected in the Kansas City area around year 2043.
- Reductions in commercial sand and gravel mining substantially reduce bed degradation. Elimination of commercial sand and gravel mining results in bed recovery for almost the entire focused study area.

- None of the alternatives cause the bed elevations to fully recover to the 1987 elevations by the end of 50 years.

Table 10-1 summarizes the nine alternatives evaluated in detail using the Mobile-bed model. All sill and dike lowering alternatives were eliminated from consideration due to a lack of effectiveness. All alternatives that contained grade-control measures were eliminated from further consideration because they would shift the degradation from St. Joseph to Kansas City. Over 30 additional grade-control structures would need to be constructed downstream of the St. Joseph area to address this problem. This would not be economically viable as further discussed in Section 10.2. Also, while not analyzed in detail, it is likely that a large number of grade-control structures would result in significant adverse environmental impacts that may make them unacceptable. This is discussed further in Section 11.2. Additional details concerning the physical evaluation of alternative plans are provided in Appendix N – Future With-Project Model Projections.

Table 10-1: Physical evaluation of alternatives.

Structural Measures	**Currently Permitted Mining Quantities (A)**	**Reduced Mining Quantities (B)**	**No Mining (C)**
1 – None Measure	1A – No Action	1B[1]	1C[1]
2 – Lower Sills	2A[2]	2B[2]	2C[2]
3 – Lower Dikes	3A[2]	3B[2]	3C[2]
4 – Lower Sills and	4A[2]	4B[2]	4C[2]
5 – Rock Grade-Control Structures	5A[3]	5B[3]	5C[3]

Subscripts: 1 = Demonstrated effectiveness
2 = Demonstrated lack of effectiveness
3 = Not effective due to shifting degradation towards Kansas City

10.2 Economic Evaluation of Alternatives

The primary economic criterion for the evaluation of alternatives is the NED net benefit of the alternative. The net benefit is calculated as the difference between the damages avoided by the alternative and the cost of implementing the alternative. The damages avoided are the avoided future costs due to bed degradation of providing future power generation, municipal and industrial water supply, highway transportation, flood damage risk reduction, bank stabilization, navigation, and fish and wildlife habitat constructed as part of the Missouri River Recovery Program. The economic evaluation of alternatives is performed using average annual equivalent values. The total without-project condition damages over the 50-year period of analysis are $269 million in FY17 dollars. The present value of these damages using the FY17-discount rate (2.875%) is $139 million. The average annual equivalent value of these damages over the 50-year period of analysis using the FY17-discount rate of 2.875% is $5.3 million (Table 10-2).

The economic evaluation of alternatives shows that the alternative that would provide the greatest net benefits is Alternative 1C – Eliminate Commercial Sand and Gravel Mining (Table 10-2). Also, Alternative 1B – Reduced Commercial Sand and Gravel Mining would provide a very similar amount of net benefits to Alternative 1C (Table 10-2).

The BSNP modification alternative at the 2015 permitted dredging level (Alternative 4A) does not provide positive-net-benefits in the base-case analysis. Residual damages under Alternative 4A are greater than the without-project condition damages because this alternative shifts the degradation toward reaches of the river where higher value impacts occur. Alternatives 4B and 4C provide only nominal positive net benefits. (Table 10-3). Alternatives that include measures for grade-control structures (Alternatives 5A, 5B, and 5C) do not result in any positive-net-economic benefits (Table 10-4).

Table 10-2: Net benefits for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	**Alternative 1A**	**Alternative 1B**	**Alternative 1C**
FWOP Damages	$5,270,000	$5,270,000	$5,270,000
Residual Damages	$5,270,000	$2,200,000	$2,170,000
Damages Avoided (Benefits)	$0	$3,080,000	$3,100,000
Alternative Implementation Cost	$0	$0	$0
Net Benefits	**N/A**	**$3,080,000**	**$3,100,000**

Table 10-3: Net benefits for Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	Alternative 4A	Alternative 4B	Alternative 4C
FWOP Damages	$5,270,000	$5,270,000	$5,270,000
Residual Damages	$5,420,000	$2,360,000	$2,310,000
Damages Avoided (Benefits)	($150,000)	$2,920,000	$2,960,000
Alternative Implementation Cost	$2,840,000	$2,840,000	$2,840,000
Benefit/Cost Ratio	-0.1	1.0	1.0
Net Benefits	**($2,990,000)**	**$80,000**	**$120,000**

Under Alternative 4A, the damages avoided (benefits) are negative because this alternative shifts the degradation toward reaches of the river where higher value impacts occur.

Table 10-4: Net benefits for Alternative 5A – Install New Rock Grade-Control Structures & Maintain Existing Commercial Sand and Gravel Mining, Alternative 5B – Install New Rock Grade-Control Structures & Reduce Commercial Sand and Gravel Mining, and Alternative 5C – Install New Rock Grade-Control Structures & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).. Costs do not include O&M.

Average Annual Economic Results	Alternative 5A	Alternative 5B	Alternative 5C
FWOP Damages	$5,270,000	$5,270,000	$5,270,000
Residual Damages	$2,140,000	$880,000	$840,000
Damages Avoided (Benefits)	$3,130,000	$4,400,000	$4,430,000
Alternative Implementation Cost	$12,780,000	$11,750,000	$11,750,000
Benefit/Cost Ratio	0.2	0.4	0.4
Net Benefits	**($9,650,000)**	**($7,350,000)**	**($7,320,000)**

Based on the economic analysis, the alternatives that would result in the greatest positive NED benefits would include a reduction or elimination of commercial sand and gravel mining within the focused study area. As discussed in Section 9.2.7, making modifications to the quantity of sand and gravel that is permitted under other authorities is not within the Section 216 authority. As there are no other alternatives with positive net benefits at the permitted level of mining, the economic evaluation does not find a federal interest in a structural solution to the problem. Additional information concerning the economic analysis is found in Appendix O – Economic Analysis.

11 OTHER CONSIDERATIONS

In addition to the evaluation of the completeness, effectiveness and efficiency of the alternatives plans, evaluations of potential impacts to RED and potential environmental consequences of alternative plans were conducted to help determine the acceptability. Because the study did not recommend an alternative plan for implementation, these items were not evaluated to the level of detail that is typical for a feasibility study or a NEPA document such as an environmental assessment or EIS. Only publically available information was used to conduct the RED analysis. The single commercial sand and gravel mining operation within the St. Joseph and Kansas City reach did not make information available in sufficient time to meet the schedule for completing this report. In addition, no new direct operational information from any other providers of commercially available sand and gravel, either from the second entity operating in the Waverly reach of the Missouri River or land-based providers, was obtained.

11.1 Regional Economic Development

The RED account registers changes in the distribution of regional economic activity that result from each alternative plan. Regional income and regional employment are the metrics that are typically evaluated for a RED analysis. The RED analysis focuses on the local impacts of reducing or eliminating commercial sand and gravel mining from the focused study area. Note that the primary economic evaluation criterion (changes to NED) is based on a national perspective without differentiation of which sector of the economy or which region of the country benefits. The RED analysis, on the other hand, is necessarily a local analysis of shifts in employment and income.

In addition to an evaluation of the completeness, effectiveness and efficiency of the alternatives plans, evaluations of potential impacts to RED were conducted to help determine acceptability. Because the study did not recommend an alternative plan for implementation under the study authority, these items were not evaluated to the level of detail that is typical for a feasibility study. Only a cursory-RED analysis was performed for this study. Therefore, it should be noted that RED impacts were not fully examined as part of this study.

RED impacts that would include a boost to the local economy based on project implementation (construction of a new project) were not considered since there was not a structural plan recommended.

For alternatives with reduced and eliminated commercial sand and gravel mining on the river, it is assumed that the reduction in the quantity of material mined from the river would be replaced with an equivalent quality and quantity of material from a floodplain pit mine. Investigation into pit-mine operation indicate that material excavated from a local floodplain pit mine is tested in accordance with industry standards as is material mined from the river. Materials from both sources meet the industry standard for common applications such as concrete and asphalt production. Numerous floodplain pit mines currently operate in the area and the undelivered price of material is similar from floodplain and river sources.

Publicly available information, regarding detailed industry operation information as well as information regarding distances from pit mine and dredged material stockpiles were used in this evaluation. Additional information was gathered from regional price quotes. No new direct operational information from industry operators providing commercially available sand and gravel was obtained.

There are numerous concrete and asphalt plants located throughout the Kansas City metropolitan area. Material is trucked from stockpiles near the material source to the various concrete and asphalt production facilities. The specific location where sand and gravel would be stockpiled from either river operations or floodplain pit operations is unknown, but was assumed to be within the Kansas City metropolitan area. Likewise, the exact locations of various users are also unknown but are also assumed to be within the Kansas City metropolitan area. Regardless of where the stockpiles are located, they are likely to be closer to some users and further away from other users. Therefore, given the impossibility of projecting exact future locations, it can reasonably be assumed that there is no appreciable overall change in total distance traveled to deliver sand and gravel from either floodplain or river sources.

Changes in employment resulting from replacing river dredging operations to pit mining operations are projected to be marginal. Both operations require skilled machinery operators, although different skills would be required for the different operations. For example, dredge operators would be replaced by earth moving equipment operators. The number of employees for each operation is relatively small. A dredge, for example, may have a crew of eight to twelve workers, and typically only a single dredge is working within the Kansas City reach at a time. Up to three dredges may be operating at times in the modeled reach as this encompasses the St. Joseph reach upstream of Kansas City and the upper portion of the Waverly reach just downstream of Kansas City.

Overall, the RED effects of reducing or eliminating commercial dredging from this reach of the Missouri River would be marginal and any employment and income losses would be largely offset by employment and income gains to pit mining operations.

11.2 Environmental Considerations

This technical report is not intended to include a complete evaluation of potential environmental impacts of the alternatives in accordance with NEPA (42 U.S.C 4321-4347). However, it does provide an abbreviated description of the affected environment and discusses potential environmental concerns that were recognized during the development of alternative plans. It also provides a brief discussion of potential cumulative impacts. Lastly, it documents initial coordination with the USFWS pursuant to the Fish and Wildlife Coordination Act (16 U.S.C. 661 et seq), NEPA, and the ESA (16 U.S.C. 1531-1544). See Appendix P – USFWS Planning Aid Letter.

The affected environment of the Missouri River, including the area included within this study, has been described in detail in numerous public documents. See the *Final*

Supplemental EIS for the Missouri River Fish and Wildlife Mitigation Project (USACE, 2003), the *Missouri River Commercial Dredging Final EIS* (USACE, 2011a), and more recently, the *Draft Missouri River Recovery Management Plan and EIS* (USACE, 2016). A general discussion of the operation of the Missouri River Mainstem Reservoir System and the BSNP was provided in Section 2, and infrastructure was discussed in Section 3 of this report. Economic analysis of the alternatives was provided in Section 10 and Section 11.1. The resource categories in this section were identified because it was believed that they would be the most likely to be impacted if any of the alternatives identified in this report were implemented. The resource categories discussed here are not intended to be a comprehensive list that would be evaluated in a NEPA document. Potential environmental consequences of alternatives are broadly discussed in a qualitative manner.

11.2.1.1 River Geomorphology

Prior to the construction of the Missouri River Mainstem Reservoir System and the BSNP, the channel geometry of the Missouri River varied widely. The width of the main channel ranged from roughly 1,000 to 10,000 feet during normal-flow periods and 25,000 to 35,000 feet during floods (Schneiders, 1999). Because the Missouri River is a sand-bed river, the channel geometry continuously changed as varying flows and sediment loads in the river resulted in frequent erosion and deposition. Most of these changes occurred during flood events (USACE, 2016).

Today, as a result of the Mainstem Reservoir System and the BSNP, the river planform is comparatively static. Bed elevations fluctuate considerably from hour to hour and year to year, in part due to the presence of large migrating sand dunes. As explained earlier in this report, bed degradation trends exist in specific portions of the river. These trends are presented in Figures 3-1 and 3-3 of this report, and in more detail in Appendix A – Existing Condition of the Bank Stabilization and Navigation Project Structures, RM 330 and 400, and Appendix B – Mobile-bed model Calibration Report.

Major flood events on the Missouri River result in short-term bed scour that recovers to levels nearly consistent with the long-term trend of bed degradation. The Missouri River exhibited this behavior during the 1951, 1952, 1987, 1993, 2007, and 2011 flood events (USACE, 2009; USACE, 2015b). Typically, bed recovery lagged behind the end of the flood hydrograph by several months, i.e. the flood waters receded but the bed remained degraded. In less than six months, the bed had recovered to the three-year average bed elevation. The 2011 Missouri River Flood was unique in that during and post-flood, the watershed downstream of the dams contributed little water or sediment, which slowed bed recovery. See Appendix C – Future Without-Project Model Projections with Risk and Uncertainty for more information. This effect is assumed to continue under all the alternatives. Floods and other high-flow events accelerate the upstream migration of bed degradation. In the Missouri River, these upstream migrations of bed degradation take the form of over-steepened reaches more than an abrupt change in slope that often occurs in smaller streams. This effect is evident between the 2009 and 2014 surveys as seen in Figure 3-3 presented earlier in this report. The effect of upstream migration of bed degradation is included in the model results and bed elevation summaries listed above.

Exponentially less sediment movement occurs during low flows, which slows the upstream migration of existing bed degradation but exacerbates degradation due to channel mining. During low flow years, channel mining constitutes a larger proportion of the incoming sediment load, and local degradation has less opportunity to attenuate by spreading out. Alternatives that reduce or eliminate channel mining reduce or eliminate bed degradation during low flows. The effect this has on bed degradation is included in the model results.

Although not comprehensive of all potential impacts, major impacts of the alternative plans to the geomorphology of the river were previously discussed in Section 8.1 Future Without-Project Degradation Modeling and Section 10.1 Physical Evaluation of Alternatives. Refer to these sections for detailed discussions of impacts to the geomorphology of the river.

11.2.1.2 River Hydrology and Flood Heights

Over the past several years, discretionary winter releases from the Mainstem Reservoir System have been made to supplement water-surface elevations in Kansas City during the non-navigation season. These releases have been necessary due to the substantially degraded existing condition of the Missouri River. Bed recovery in the Kansas City reach will decrease the reliance of public utilities on discretionary releases and decrease the risk of interrupted water and power service should water not be available for release. The value of bed recovery in reducing the need for or magnitude of discretionary winter releases and of decreased risk is recognized but has not been quantified.

Bed degradation and bed recovery primarily impact low-water elevations and do not impact flood heights to the same extent. During floods, the active channel conveys a relatively smaller proportion of flow, which decreases the impact of bed elevation changes on flood elevations. In the longer term, a degrading bed induces geomorphic changes such as channel narrowing and vegetation recruitment on exposed areas which somewhat offset conveyance gains from bed degradation. The reverse is also true. Bed recovery causes a small decrease in hydraulic conveyance in the short term. In the long term, incised channels may re-widen and any new vegetation may be inundated, die, and eventually erode away, which offsets the conveyance loss. Historically, flood heights have increased despite the lowering of the bed, which makes it difficult to correlate changes in flood heights with changes in the elevation of the active bed using measured data.

This Mobile-bed model was developed to project long-term trends for bed and low-flow water-surface elevations. For long-term bed-degradation projections, levee over toppings, timing of tributary inputs, and other unsteady flow effects during large floods are insignificant. These factors become important, however, for predicting flood heights. The Kansas City District has developed additional modeling tools which include these effects and would be appropriate for assessing future flooding scenarios. An assessment of flood heights or flood damages has not been undertaken for this study.

11.2.1.3 Water Quality

Individual states have jurisdiction for managing water quality within their states. Section 303(d) of the CWA requires each state to identify waters for which existing required pollution controls are not stringent enough to meet state water quality standards. States are required to establish total maximum daily loads for these waters (see 40 CFR 130.7). The State of Missouri has placed the Missouri River on the 303(d) List of Impaired Water Bodies for bacteria from Atchison through Chariton counties, and from St. Charles through St. Louis counties. Also, the Missouri River along its entire length in Missouri has a total maximum daily loads approved by the U.S. Environmental Protection Agency for aquatic-life impairments due to chlordane and polychlorinated biphenyls. Historically, the water quality of the Missouri River was much different than it is today. Prior to the 1930’s when major river modifications began, the Missouri River contained 70 – 80 times as much suspended sediment as it does currently (Blevins, 2006). Consequently, the Missouri River is no longer as turbid as it was previously (Blevins, 2006).

A detailed evaluation of potential impacts to water quality for each of the alternatives was not conducted. Implementation of alternatives described in this technical report may or may not result in impacts to water quality. It is believed that modifications to unburied BSNP structures would result in minor short-term construction related impacts to water quality. This would result in localized increases in turbidity related to construction. Modifications to buried BSNP structures to widen the channel banks would have similar but somewhat larger impacts because of land and channel disturbance. Further evaluation would be needed to assess these impacts with regard to context and intensity. Grade-control structures would have the potential to result in even greater impacts to water quality. These structures would change the flow dynamics of the river. Potential impacts to water quality parameters such as suspended sediment and water temperature would also need to be evaluated further. Modifications to commercial sand and gravel mining impacts would not be significant based on the *Missouri River Commercial Dredging Final EIS* where it was concluded that there would not be any significant impacts to water quality from commercial sand and gravel mining. The states of Missouri and Kansas issued CWA 401 Water Quality Certifications.

11.2.1.4 Wetlands

Wetlands are lands that are transitional between terrestrial and aquatic systems (Cowardin et al., 1979). Wetlands serve a variety of important functions, including wildlife habitat, fish breeding and foraging habitat, nutrient/sediment trapping, flood control, and recreation. Prior to the construction of the BSNP and levees along the Missouri River, wetlands were a common feature of the floodplain due to the dynamic nature of the river. The BSNP stabilized the river and allowed accreted land to form in the old active channel and created a narrow channel with few islands, backwaters, or side channels. As a result, the number of wetlands has been significantly reduced along the Missouri River. Hesse et al. (1988) estimated that there was a 39% decline in the amount of wetlands within the Missouri River floodplain between 1892 and 1982. In 1995, it was estimated using Landsat satellite images that nearly 75,000 acres of wetlands were present in Missouri River floodplain within the Kansas City District (USACE, 2003). The majority of the wetlands were classified as either forested or emergent.

Many of the wetlands that remain along the Missouri River are dependent on alluvial aquifers to create the necessary hydrologic conditions. The depth of the water in the aquifers is dependent on the water-surface elevation of the Missouri River. Bed degradation lowers the depth of alluvial aquifers adjacent to the river. As part of the feasibility study, a study was initiated by the U.S. Geologic Survey to model potential changes to alluvial aquifers and wetlands of alternatives that were described in this report. This evaluation was discontinued when it was determined that the study would not result in any recommendation for implementation of a structural plan pursuant to the Section 216 authority. It is expected that reductions in water-surface elevations associated with bed degradation would adversely impact wetlands adjacent to the Missouri River. The extent of these impacts are not known at this time.

11.2.1.5 Fish and Wildlife

There are approximately 90 fish species that are currently found in the lower Missouri River (USACE, 2003). Impoundment, channelization, bed degradation, and unnatural hydrologic conditions have changed the fish species composition in many rivers. Along the Missouri River, construction of dikes and revetments has narrowed and deepened the channel into a fixed location. The ecological impact of these river changes has negatively impacted native riverine fishes (NRC, 2002).

The increases in agriculture, along with the effects of bank stabilization and channelization, have also reduced the wildlife habitat in the floodplain. However, remnant riparian areas and agricultural fields provide habitat for mammals such as gray squirrel, fox squirrel, cottontail rabbit, red fox, gray fox, and coyote. Common furbearers along river banks include mink, muskrat, beaver, otter, and raccoon. White-tailed deer is a common big game species found in the floodplain.

Many reptile and amphibian species have also been negatively impacted as a result of the reduction of wetland habitat within the floodplain. Amphibian species such as eastern tiger salamander, smallmouth salamander, Great Plains toad, Woodhouse’s toad, and Plains spadefoot toad require ephemeral wetland habitats to successfully reproduce. Wetlands within the floodplain also support numerous reptilian species such as diamondback water snake, northern water snake, and the western hog-nosed snake and eastern hog-nosed snake in certain geographic reaches. The floodplain also provides important habitat for turtles, such as false map turtles, smooth softshell turtles, and spiny softshell turtles. Additionally, the Missouri River floodplain provides habitat for the western massasauga rattlesnake.

The Lower Missouri River is located within the Central and Mississippi North American migratory waterfowl flyway. Waterfowl use the Missouri River and its floodplain for resting, feeding, and nesting. Numbers of waterfowl are greatest during the spring and fall migration seasons. Common dabbling-duck species include mallard, wood duck, northern shoveler, northern pintail, gadwall, blue-winged teal, green-winged teal, and American widgeon. Wood ducks are probably the most common nesting species in the study area (USFWS, 1999). Common species of diving ducks are ring-necked, lesser scaup, ruddy, redhead, common golden-eye, and bufflehead (USFWS, 1999). Other waterfowl in the study area include hooded merganser, common merganser, red-breasted mergansers, Canada geese, snow geese, and white-fronted geese. During migration stops, dabbling ducks and geese rest on islands and sandbars and forage in grain fields, whereas diving ducks use large open water areas for loafing and foraging. Other migratory birds that can be found in the study area include wading birds, shorebirds, passerines, and raptors. Wading birds such as the great blue heron, black-crowned and yellow-crowned night heron, and green heron use the river corridor to forage for fish, amphibians, and invertebrates (USFWS, 1999). Shorebirds that are regular breeders in the area include killdeer and American woodcock. Passerines are the largest group of migratory bird species within the study area and include thrushes, warblers, flycatchers, vireos, hummingbirds, swallows, wrens, tanagers, orioles, sparrows, as well as others (USFWS, 1999). Floodplain forests and wetlands are important breeding and migratory habitats for passerines. Hawks, falcons, eagles, vultures, and owls are also found in floodplain habitats. Within the Kansas City District, most migratory-bird-nesting activities occur during the period of 1 April to 15 July. Bald eagles have become increasingly common within much of the Kansas City District. They utilize riparian woodlands along rivers, lakes, and streams for nesting, perching, and roosting sites. Bald eagles are no longer listed as a federally threatened species. However, bald eagles are still protected by the Bald and Golden Eagle Protection Act.

A detailed evaluation of potential impacts to fish and wildlife for each of the alternatives was not conducted. However, implementation of alternatives described in this technical report may result in impacts to fish and wildlife. The USFWS provided a Planning Aid Letter in accordance with the Fish and Wildlife Coordination Act after reviewing an initial array of alternatives that were an early iteration of those described in this report (Appendix P – USFWS Planning Aid Letter). In the Planning Aid Letter, USFWS recommended that USACE consider alternatives that would prohibit commercial sand and gravel mining on the Missouri River to avoid impacts to fish and wildlife. Alternative 1C – Elimination of Commercial Sand and Gravel Mining fits the description of the recommendation in the Planning Aid Letter.

Changes in inundation of fish and wildlife habitat can influence the amount, quality, distribution, and variety of habitats available to fish and wildlife. Flows, channel geometry, and other physical components of the river can adversely or beneficially impact the availability of habitat. The implementation of any of the grade control alternatives would change the flow dynamics of the river and would likely impact aquatic species. Changes in bed elevation and water-surface elevation could also impact existing water depths and flow velocities resulting in indirect impacts to aquatic species. Diverse-river-channel morphology and channel dimensions provide conditions necessary for many species' life processes. Reduction in channel morphology and channel dimension diversity would reduce the amount of variation in depth and water velocity in the river resulting in less habitat for aquatic species. Any changes in water-surface elevations would impact riparian vegetation along the channel, having indirect effects on wildlife species that utilize this habitat type, such as many species of birds. A detailed evaluation would be necessary before implementing any of the proposed alternatives. It should be noted that there may be impacts to fish and wildlife if bed degradation continues under the No-Action/Future Without-Project Condition. Impacts from commercial sand and gravel mining are described in the *Missouri River Commercial Dredging Final EIS* (USACE, 2011a).

11.2.1.6 Threatened and Endangered Species

Federally listed threatened and endangered species known to occur within the study area include the pallid sturgeon (*Scaphirhynchus albus*), Indiana bat (*Myotis sodalis*), and northern long-eared bat (*Myotis septentrionalis*). The federally endangered pallid sturgeon is primarily found in the Missouri River and the Mississippi River downstream of the confluence with the Missouri River. Modification of the natural Missouri River hydrograph, habitat loss, fish migration blockage, pollution, hybridization, and overharvesting are some of the possible causes for pallid sturgeon decline (USFWS, 1993).

The Indiana bat is a federally listed endangered species. This species population has declined due to habitat loss and human disturbance. The Indiana bat is a temperate, insectivorous, migratory bat that occurs in 20 States in the eastern half of the United States, including portions of Missouri. The Indiana bat hibernates colonially in caves and mines during winter. In spring, reproductive females migrate and form maternity colonies where they bear and raise their young in wooded areas, specifically behind exfoliating bark of large, usually dead, trees. Both males and females return to the caves and mines in late summer or early fall to mate and enter hibernation.

The northern long-eared bat has recently been listed as a threatened species under the Endangered Species Act. Northern long-eared bats have been experiencing rapidly declining populations due to white-nose syndrome, a fungal pathogen. During winter this species of bat is known to hibernate in caves and abandoned mines. Summer habitat is not well defined, but it is believed that roosting habitat includes dead or live trees and snags with cavities, peeling or exfoliating bark, split tree trunk and/or branches. Foraging habitat includes upland and lowland woodlots and tree lined corridors. Occasionally, they may roost in structures like barns and sheds.

It is uncertain if any of the alternatives described in this report would impact pallid sturgeon. As described in the *Draft Missouri River Recovery Management Plan and EIS* (USACE, 2016), there are a number of hypotheses related to factors that may be impacting the pallid sturgeon population in the Missouri River. Any modifications to the

BSNP structures, channel widening, or large scale grade-control structures have the potential for beneficial or adverse impacts to this species. A detailed evaluation would be needed before implementing any of the alternatives to understand any potential impacts. Impacts from commercial sand and gravel mining are described in the *Missouri River Commercial Dredging Final EIS* (USACE, 2011a).

All of the alternatives have the potential to have indirect impacts on Indiana and northern long-eared bats. Each alternative described in this report could result in changes to woody vegetation along riparian corridor that may provide desirable habitat for these species. As with the pallid sturgeon, a more detailed evaluation would be needed before implementing any of the alternatives to understand if and to what degree there may be any impacts to Indiana and northern long-eared bats.

11.2.1.7 Land Use

Land use within the Missouri River floodplain has changed drastically since the construction of the BSNP. The BSNP stabilized the previously meandering river into a single channel. This caused large areas of new land to accrete. The accreted land was then used for a variety of purposes including agricultural production. A recent evaluation of land use within the Missouri River floodplain is provided in *Draft Missouri River Recovery Management Plan and EIS* (USACE, 2016). Between Rulo, Nebraska and the mouth of the Missouri River, approximately 63.2% of land cover is used for agriculture, 18% is forests, wetlands, grasslands, and scrublands, 10.5% is open water, and 8.3% is developed. Much of this land is in private ownership.

Alternatives that include modifications to BSNP structures would not be expected to have any impacts on adjacent land. Alternatives that include channel widening may have impacts on adjacent land use. In some locations, land would need to be acquired to widen the channel to the desired width. A more detailed evaluation would be needed to determine the significance of these impacts. Construction of grade-control structures would likely have short-term construction-related impacts to land adjacent to the structures. The structures would need to be anchored into the riverbank to prevent flanking. Although construction easements may need to be obtained, it is not expected that these impacts would be long term or significant. Impacts from commercial sand and gravel mining on land use are described in the *Missouri River Commercial Dredging Final EIS* (USACE, 2011a).

11.2.1.8 Cultural Resources

Cultural resources are a broad pattern of material and non-material sites or objects that represent contemporary, historic, and pre-historic human life ways or practices. These locations represent social, spiritual, and shared cultural heritage, and contribute to community cohesion. The Missouri River floodplain contains a variety of cultural resource types that span from the earliest Native American inhabitants of North America to the present time. Common cultural resource sites include prehistoric Native American archeological sites, historic archeological sites, ship wrecks, and historic structures such as bridges and buildings. It is unknown if bed degradation in the past has adversely impacted any cultural resources.

Potential impacts to cultural resources were not evaluated for any of the alternatives. It is uncertain if continued bed degradation would adversely affect cultural resources. A detailed evaluation would be needed to assess the extent of impacts for each of the alternatives.

11.2.1.9 Cumulative Impacts

The Council on Environmental Quality Regulations defines cumulative impacts as “the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time” (Council on Environmental Quality, 1997). The cumulative impacts addressed in this document consist of the impacts of multiple actions that result in similar effects on the natural resources. The geographical areas of consideration are actions located within/along the lower Missouri River.

The *Draft Missouri River Recovery Management Plan and EIS* (USACE, 2016) provides a thorough discussion of cumulative impacts to a wide range of resource categories that have occurred within the Missouri River. The cumulative actions that are identified include bed degradation. According to the *Draft Missouri River Recovery Management Plan and EIS*, when combined with other past, present, and reasonably foreseeable actions, bed degradation has the potential to result in cumulative impacts to river infrastructure, hydrology, fish and wildlife habitat, threatened and endangered species, water quality, cultural resources, land use, commercial sand and gravel mining, flood-risk management, navigation, recreation, thermal power, water supply, wastewater, tribal interests, environmental justice, and ecosystem services.

In the *Missouri River Commercial Dredging Final EIS* (USACE, 2011a) it was determined that commercial sand and gravel mining cumulatively affected geomorphology (river geomorphology and sediment), water quality, aquatic resources including fish and wildlife habitat and diversity of habitat, threatened and endangered species, economics, cultural resources, infrastructure, and greenhouse gas emissions and climate change. River geomorphology was the primary cumulatively affected resource. The *Record of Decision for Authorization of Commercial Sand and Gravel Dredging on the Lower Missouri River* (USACE, 2011b) states that there are no significant adverse environmental effects related to commercial sand and gravel mining on the Missouri River at the permitted quantities. This determination was made using the 2009 bed elevations as the baseline condition.

Numerous conditions were associated with the decision including the need for a monitoring and adaptive management framework to allow for no more than slight degradation. It concluded that moderate to substantial bed degradation would be contrary to the public interest. At the time the *Missouri River Commercial Dredging Final EIS* was prepared, there were not adequate tools to project future bed elevations. The monitoring and adaptive management is dependent on an evaluation of past bed conditions (*a posteriori*) rather than on future projections (*a priori*) based on a sediment-transport model.

It is uncertain if any of the alternatives described in this document would result in significant cumulative impacts to the human environment. A detailed evaluation would be needed to assess cumulative impacts on environmental and socioeconomic resources.

12 RISK AND UNCERTAINTY

Future bed and water-surface elevations may be higher or lower than those projected using the conditions listed in Table 8-1 due to model uncertainty and boundary condition uncertainty. These uncertainties were accounted for in order to provide a robust analysis of alternatives. This was accomplished using the principles of risk and uncertainty found in Engineer Manual 1110-2-1619 Risk-Based Analysis for Flood Damage Reduction adapted to the particulars of this study, but not with the standard risk and uncertainty framework used to assess flood damage. Appendix C – Future Without-Project Model Projections with Risk and Uncertainty discusses reasons why the standard risk and uncertainty framework for flood damage was impractical or inapplicable. Model uncertainty (which integrates uncertainty in all model parameters, roughness values, sediment functions, etc.) was quantified by how well the mobile-bed model reproduced observed bed and water-surface degradation from 1994 to 2014. Boundary condition uncertainty was quantified by separately varying the input parameters and re-running the 50-year simulation. Boundary conditions assessed included flow series, the flow-sediment relationship, floodplain deposition amount, and dredging locations. The range of model results for each sensitivity analyses were combined to create a composite standard deviation using adapted forms of equations found in EM 1110-2-1619 (see Appendix C).

Sensitivity analysis on the effect of channel mining indicates a strong relationship between the future volume of channel mining and future volume of degradation (R^2 = 0.99). A 50% decrease in channel mining reduces the maximum degradation at St. Joseph from 4.4 feet to 1.4 feet. A 50% increase in channel mining increases the maximum degradation at St. Joseph from 4.4 feet to 7.3 feet. Changes in channel mining quantities were evaluated in the project alternatives rather than included in the combined uncertainty analysis.

Model uncertainty and boundary condition uncertainties were combined to generate a standard deviation around bed and low-flow water surface projections. Combined uncertainties were added or subtracted to the base projection to generate a more-degradation and less-degradation scenario. For features dependent on bed elevations, an additional offset based on cross section analysis during the 2011 flood was included for temporary flood-related degradation in which the bed degrades during a flood but takes several months to recover. Appendix C – Future Without-Project with Risk and

Uncertainty describes these analyses. Figure 12-1 provides an example of the results of the three scenarios at RM 425.71. The base-case projection was used in all previous sections of this report. The economic impact of the less degradation and more degradation scenarios were analyzed separately and included in Tables 12-1 to 12-6.

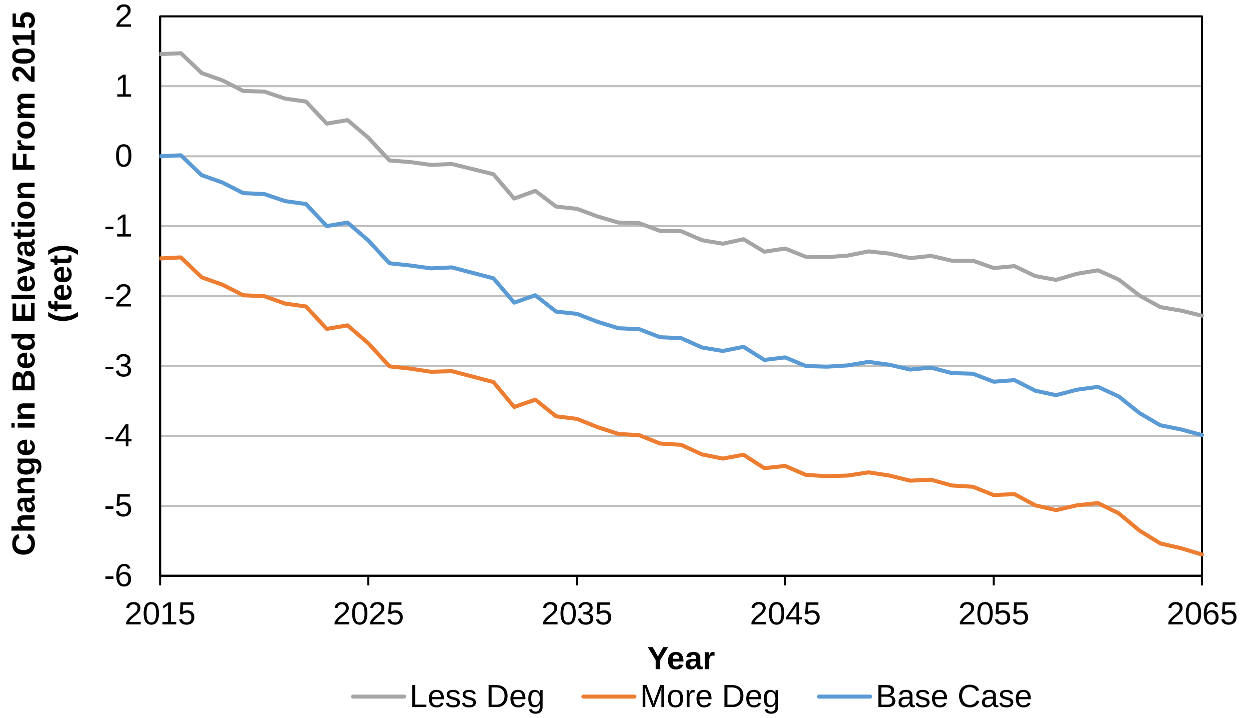

Figure 12-1: Low-flow water-surface elevation change at RM 425.71 under the base case, the less degradation, and the more degradation scenarios. See Appendix C for further information regarding the details for the base, less and more degradation scenarios.

Geotechnical and structural analyses were conducted to assess and quantify the impact of current and future levels of bed degradation on flood damage risk reduction structures such as levees and floodwalls, and on other structures such as bridges, water intakes and outlet pipes.

The geotechnical analysis considers failure during flood events, which could cause direct economic damages and possible loss of life, and failure during non-flood events which would require repair. Probabilistic analyses were performed on levees and floodwalls that are in relatively close proximity to the river to assess the impacts of channel bed changes on their performance during a flood event. The failure modes considered were loss of river bank initiating either an underseepage failure at the landside toe or a riverside slope failure, both leading to inundation of the leveed area.

Different probabilistic methods were used to assess the underseepage and slope stability failure modes. Underseepage analyses were performed using Taylor Series methods and underseepage analysis methods discussed in Engineering Technical Letter 1110-2-556 Risk-Based Analysis in Geotechnical Engineering for Support of Planning Studies and EM 1110-2-1913 Design and Construction of Levees, respectively. Slope stability analyses were performed using SLOPE/W in the Geo-Studio 2007 software package. This software uses the Monte Carlo technique, which generates repeated random samples of a given parameter from a given probability distribution function and the parameter statistical mean and standard deviation. Coefficients of variation used in both analyses were carefully selected from various reports and based on guidance presented in Engineering Technical Letter 1110-2-556. See Appendix I – Geotechnical Analysis of Flood-Risk Management Projects for further discussion.

The structural analysis utilizes specific methods which vary by type of structure. The general approach involves determining a critical elevation for each structure. This is the elevation of the river bed which, when reached, would prompt action and expenditure of funds to ensure the stability of the structure. These impacts and associated costs are then considered in the economic analysis. See Appendix J – Structural Analysis of Independent Structure for details.

Several meetings of the project delivery team and Agency Technical Review team were held to determine the most appropriate way to evaluate risk and uncertainty for the economic modeling. One approach used was to include triangular distributions around cost inputs using the @Risk add-in for Microsoft Office Excel. This approach produced anticipated results but did not sufficiently address risk and uncertainty concerning bed-degradation model inputs into the economic model.

Instead, the composite standard deviation of uncertainty developed from the sediment modeling, as explained in Appendix C – Future Without-Project Model Projections with Risk and Uncertainty, was used to create two scenarios. The more-degradation scenario equals the base-case projection minus the standard deviation of uncertainty, resulting in lower bed and water-surface elevations and more degradation damages. The less-degradation scenario equals the base case plus the standard deviation of uncertainty, resulting in higher bed and water-surface elevations and less degradation damages. The economic evaluation of the alternatives conducted for the base case was repeated for these two scenarios (see Tables 12-1 to 12-6), and a scenario that accounts for potential land-based costs associated with switching from in-river sand-and gravel mining operation to a pit-mine operation (Tables 12-7, 12-8, and 12-9).

As with the base-case future-bed-degradation scenario, there are no alternatives with positive net benefits at the permitted level of commercial sand and gravel mining for any of the risk and uncertainty scenarios. Again, the economic evaluation does not find a federal interest in any structural solution to the problem.

In the less degradation scenario, none of the structural alternatives (Alternatives 4A, 4B, 4C, 5A, 5B, 5C) provide positive net benefits. In the more-bed-degradation scenario, none of the BSNP structural alternatives (Alternatives 4A, 4B,and 4C) provide more net benefits than the corresponding non-structural alternative with reduced or eliminated commercial sand and gravel dredging (Alternatives 1B and 1C).

For the Install New Grade Control structural alternatives (5A, 5B, and 5C) under the more-bed-degradation scenario, none of the alternatives provide positive net benefits. Similarly, the land-based cost scenario under the base-case level of bed degradation does not provide any positive net benefits.

Table 12-1: The less-bed-degradation scenario for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%)..

Average Annual Economic Results	**Alternative 1A**	**Alternative 1B**	**Alternative 1C**
FWOP Damages	$3,100,000	$3,100,000	$3,100,000
Residual Damages	$3,100,000	$1,660,000	$1,660,000
Damages Avoided (Benefits)	$0	$1,450,000	$1,450,000
Alternative Implementation Cost	$0	$0	$0
Net Benefits	**N/A**	**$1,450,000**	**$1,450,000**

Table 12-2: The less-bed-degradation scenario for Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	**Alternative 4A**	**Alternative 4B**	**Alternative 4C**
FWOP Damages	$3,100,000	$3,100,000	$3,100,000
Residual Damages	$3,180,000*	$1,880,000	$1,880,000
Damages Avoided (Benefits)	($80,000)	$1,220,000	$1,220,000
Alternative Implementation Cost	$2,840,000	$2,840,000	$2,840,000
Benefit/Cost Ratio	0.0	0.4	0.4
Net Benefits	**($2,920,000)**	**($1,620,000)**	**($1,620,000)**

*Under Alternative 4A, the damages avoided (benefits) are negative because this alternative shifts the degradation toward reaches of the river where higher value impacts occur.

Table 12-3: The less-bed-degradation scenario for Alternative 5A – Install New Rock grade-control structures & Maintain Existing Commercial Sand and Gravel Mining, Alternative 5B – Install New Rock grade-control structures & Reduce Commercial Sand and Gravel Mining, and Alternative 5C – Install New Rock grade-control structures & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).Costs do not include O&M.

Average Annual Economic Results	**Alternative 5A**	**Alternative 5B**	**Alternative 5C**
FWOP Damages	$3,100,000	$3,100,000	$3,100,000
Residual Damages	$1,070,000	$410,000	$410,000
Damages Avoided (Benefits)	$2,040,000	$2,690,000	$2,690,000
Alternative Implementation Cost	$12,780,000	$11,750,000	$11,750,000
Benefit/Cost Ratio	0.2	0.2	0.2
Net Benefits	**($10,740,000)**	**($9,060,000)**	**($9,060,000)**

Table 12-4. The more-bed-degradation scenario for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	**Alternative 1A**	**Alternative 1B**	**Alternative 1C**
FWOP Damages	$7,750,000	$7,750,000	$7,750,000
Residual Damages*	$7,750,000	$2,920,000	$2,960,000
Damages Avoided (Benefits)*	$0	$4,840,000	$4,800,000
Alternative Implementation Cost	$0	$0	$0
Net Benefits	**N/A**	**$4,840,000**	**$4,800,000**

* The residual damages, damages avoided, and net benefits in Alternatives 1B and 1C are nominally equivalent. The difference is due to model noise.

Table 12-5: The more-bed-degradation scenario for Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	Alternative 4A	Alternative 4B	Alternative 4C
FWOP Damages	$7,750,000	$7,750,000	$7,750,000
Residual Damages	$9,350,000*	$3,370,000	$3,350,000
Damages Avoided (Benefits)	($1,600,000)	$4,830,000	$4,410,000
Alternative Implementation Cost	$2,840,000	$2,840,000	$2,840,000
Benefit/Cost Ratio	-0.6	1.5	1.6
Net Benefits	**($4,440,000)**	**$1,540,000**	**$1,570,000**

*Under Alternative 4A, the damages avoided (benefits) are negative because this alternative shifts the degradation toward reaches of the river where higher value impacts occur.

Table 12-6: The more-bed-degradation scenario for Alternative 5A – Install New Rock grade-control structures & Maintain Existing Commercial Sand and Gravel Mining, Alternative 5B – Install New Rock grade-control structures & Reduce Commercial Sand and Gravel Mining, and Alternative 5C – Install New Rock grade-control structures & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%). Costs do not include O&M.

Average Annual Economic Results	Alternative 5A	Alternative 5B	Alternative 5C
FWOP Damages	$7,750,000	$7,750,000	$7,750,000
Residual Damages	$6,090,000	$1,800,000	$1,790,000
Damages Avoided (Benefits)	$1,670,000	$5,950,000	$5,960,000
Alternative Implementation Cost	$12,780,000	$11,750,000	$11,750,000
Benefit/Cost Ratio	0.1	0.5	0.5
Net Benefits	**($11,110,000)**	**($5,800,000)**	**($5,790,000)**

12.1 Land-Based Costs Sensitivity Analysis

As a sensitivity analysis, an NED economic evaluation using the base-case level of degradation was conducted that includes assumptions concerning the costs of switching from a river dredging operation to a pit-mining operation (Tables 11-1, 11-2, and 11-3). While these start-up costs may be incurred, it is assumed that the industry would adjust in the long-term and there would not be an increase to overall price of commercially available sand and gravel aggregate. There could be short-term unquantified impacts that the study team did not evaluate. As shown below, even if the short term start-up cost to switch to a new operation is considered, the alternatives that provides the greatest economic net benefits are Alternatives 1B and 1C.

For Alternative 1B – Reduced Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, and Alternative 5B – Rock grade-control structures & Reduce Commercial Sand and Gravel Mining, it was assumed that 100 acres of land needs to be purchased for one floodplain pit mine in St. Joseph. Cost assumptions include:

- Land value is estimated at $15,000/acre;
- $3,000,000 will be needed for permitting (EIS document); and
- $500,000 for reclamation of the land.

For Alternative 1C – Eliminate Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining, and Alternative 5C – Rock grade-control structures & Eliminate Commercial Sand and Gravel Mining, it was assumed that 400 acres of land needs to be purchased for one floodplain pit mine in the St. Joseph area, two floodplain pit mines would open in the Kansas City area and one floodplain pit mine would open in the Waverly area. Cost assumptions include:

- Land value is estimated at $15,000/acre;
- $3,000,000 for permitting each site (EIS document); and
- $500,000 for reclamation of the land at each site.

Table 12-7: Pit-mine costs for Alternative 1A – No-Action/Future Without-Project Condition, Alternative 1B – Reduced Commercial Sand and Gravel Mining, and Alternative 1C – Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	**Alternative 1A**	**Alternative 1B**	**Alternative 1C**
FWOP Damages	$5,270,000	$5,270,000	$5,270,000
Residual Damages	$5,270,000	$2,200,000	$2,170,000
Damages Avoided (Benefits)	$0	$3,080,000	$3,100,000
Alternative Implementation Cost	$0	$190,000	$760,000
Net Benefits	**N/A**	**$2,890,000**	**$2,340,000**

Table 12-8: Pit-mine costs for Alternative 4A – Lower BSNP Sills and Dikes & Maintain Existing Commercial Sand and Gravel Mining, Alternative 4B – Lower BSNP Sills and Dikes & Reduce Commercial Sand and Gravel Mining, Alternative 4C – Lower BSNP Sills and Dikes & Eliminate Commercial Sand and Gravel Mining. All values are average

annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	**Alternative 4A**	**Alternative 4B**	**Alternative 4C**
FWOP Damages	$5,270,000	$5,270,000	$5,270,000
Residual Damages	$5,420,000*	$2,360,000	$2,310,000
Damages Avoided (Benefits)	($150,000)	$2,920,000	$2,960,000
Alternative Implementation Cost	$2,840,000	$3,030,000	$3,600,000
Benefit/Cost Ratio	-0.1	1.0	0.8
Net Benefits	**($2,990,000)**	**($110,000)**	**($640,000)**

*Under Alternative 4A, the damages avoided (benefits) are negative because this alternative shifts the degradation toward reaches of the river where higher value impacts occur.

Table 12-9: Pit-mine costs Alternative 5A – Rock grade-control structures & Maintain Existing Commercial Sand and Gravel Mining, Alternative 5B – Rock grade-control structures & Reduce Commercial Sand and Gravel Mining, and Alternative 5C – Rock Grande Control Structures & Eliminate Commercial Sand and Gravel Mining. All values are average annual values in FY17 dollars amortized over 50 years at the FY17-discount rate (2.875%).

Average Annual Economic Results	**Alternative 5A**	**Alternative 5B**	**Alternative 5C**
FWOP Damages	$5,270,000	$5,270,000	$5,270,000
Residual Damages	$2,140,000	$880,000	$840,000
Damages Avoided (Benefits)	$3,130,000	$4,400,000	$4,430,000
Alternative Implementation Cost	$12,780,000	$11,940,000	$12,510,000
Benefit/Cost Ratio	0.2	0.4	0.4
Net Benefits	**($9,650,000)**	**($7,540,000)**	**($8,080,000)**

12.2 Summary of Effects Not Quantified

This study quantified the effects of degradation on a sufficient number of infrastructure features for alternatives comparisons and planning decisions. The information developed was sufficient for a determination that there would not be a structural alternative that could be implemented pursuant to the Section 216 Study Authority, and the project was terminated. Further investigation would not be conducted. However, there were additional infrastructure or environmental impacts recognized but left unquantified. This section summarizes some of those impacts.

Impacts from bed recovery were not quantified. Bed recovery in areas that have recently degraded is assumed to have net positive benefits. The mobile-bed model quantifies the bed recovery (see Appendix C and N), but the economic effects of this recovery were not quantified.

For the purposes of the study the future without project condition assumed that the current permitted sand and gravel mining extraction limits would continue through the study period of analysis. Future changes to permit conditions are determined through the regulatory process under the adaptive management framework (USACE 2011). Changes are dependent upon measurements, location, timing and other factors. Given the uncertainty of these types of decisions the adaptive management measures were not analyzed.

A major benefit of bed recovery is less dependence for the water supply and power supply industry on supplemental winter releases from the mainstem dams. This water is then available for other uses, the value of which is difficult to quantify without detailed analysis.

In none of the alternatives do the bed elevations rise to pre-degradation levels by the end of 50 years, therefore no major costs are expected. Some costs could be incurred, however, such as the need to re-build BSNP dike and sill structures that had been previously lowered in response to bed degradation. The bed recovery in the Future Without-Project Condition is generally less than the two-foot threshold that triggers a BSNP-maintenance action.

The effects of bed elevation changes on flood damage were not quantified. See Section 11.2.1.2 for more discussion.

The O&M costs associated with the grade control structures (Alternatives 5A, 5B, and 5C) were not quantified or included. These costs would be substantial.

Wetland loss and impacts to alluvial aquifers from bed degradation is expected but was not quantified. See Section 11.2.1.4 for more discussion.

Impacts to tributaries were included, but may be underestimated as a highly detailed evaluation was not conducted. Rather than conducting a detailed evaluation of each tributary, grade control on tributaries was assumed when the Missouri River at the tributary confluence degraded two feet and again at four feet. This underestimates the degradation damages on tributaries because (1) the actual tributary damages likely exceed the cost of the grade control, and (2) the costs of additional grade control structures required when degradation exceeds six feet (in the FWOP base case) and when degradation exceeds eight feet (in the More-Degradation scenario) have not been included. See 7.2.1.1 and Appendix L for more discussion.

Impacts from RM 448 to 500 were included, but may be underestimated. This is in part because the degradation rate was assumed to linearly taper from the model value at

RM 448 (the upstream end of the modeled reach) to 0 ft. at RM 500 for the purposes of the evaluation. Actual degradation may migrate upstream and be more severe than this assumption.

Potential impacts upstream of RM 500 were not included. Degradation may migrate upstream and impact additional infrastructure (particularly BSNP structures) upstream of RM 500.

Direct impacts to the single entity that commercially mines sand and gravel from the Missouri River in the St. Joseph and Kansas City reaches, or direct impacts to the two entities that commercially mine sand and gravel from the Missouri River in the Waverly reach were not evaluated. Direct impacts to either the single entity or both entities may require further consideration under any future decision-making processes concerning commercial sand and gravel mining in the study reach of the Missouri River.

RED impacts that would include a boost to the local economy based on project implementation (construction of a new project) was not considered since there was not a structural plan recommended.

13 TECHNICAL FINDINGS

Key technical finds from this study are summarized in the following sections.

13.1 Bed Degradation

- Current bed elevations are highly degraded compared to conditions in 1987.
- This bed degradation has induced costly damage to infrastructure on the mainstem Missouri River and tributaries.
- The river from RM 367 to 391, which includes the Kansas City metropolitan area upstream of the confluence of the Kansas River, is in a slight recovery phase. At the currently permitted levels of channel mining, bed degradation from downstream of Kansas City will migrate upstream, causing a return to a degradation trend.
- The river downstream of the confluence with the Kansas River to the downstream end of the Kansas City metropolitan area (RM 367 to 350) is projected to be relatively stable in the near term. At the currently permitted levels of channel mining, bed degradation from downstream of Kansas City will migrate upstream, causing a return to a degradation trend.
- The river from RM 400 to 450, which includes the St. Joseph metropolitan area is expected to continue to degrade over time if commercial sand and gravel mining is continued at the currently permitted levels.
- Bed degradation has damaged and, if not addressed, will continue to damage BSNP revetments, cause the perching BSNP dikes and sills, and require retrofitting of control structures for Missouri River Recovery Program side-channel projects that benefit fish and wildlife.

13.2 Effects of Floods

- The bed of the Missouri River drops significantly during floods.
- Rebound of the bed typically lags behind the end of the flood by three to six months.
- Floods and other high flows cause bed degradation to migrate upstream.

13.3 Effect of Bed Degradation on Low and High Water Elevations

- The water-surface elevations during low-flow conditions decrease as a result of bed degradation and increase as a result of bed recovery.
- The water-surface elevations during high flows are much less sensitive to bed elevation changes and are somewhat mitigated by changes in channel width and vegetation.
- This report does not quantify changes in flood risk associated with changes in bed elevations or evaluate if alternatives may impact flood risk.

13.4 Missouri River Bank Stabilization and Navigation Project

- The perching of BSNP structures is a result of bed degradation and not a substantive cause of bed degradation.
- Perched structures within the study reach have been lowered historically in response to the lowering of the CRP due to bed degradation.
- Lowering dike and sill structures would not be effective in addressing future bed degradation.

13.5 Commercial Sand and Gravel Mining

- Segments of the Missouri River are interconnected. Commercial sand and gravel mining in one segment affects adjacent segments.
- Commercial sand and gravel mining was the dominant cause of the bed degradation observed in Kansas City since 1994.
- In the absence of channel mining, the river bed in Kansas City would have been in a recovery phase following the 1993 flood.
- Commercial sand and gravel mining is the dominant driver of projected bed degradation over the next 50 years.
- Restrictions to commercial sand and gravel mining may be an economically viable means to stop bed degradation.
- Conclusions on the effects of commercial sand and gravel mining restrictions are not transferable to portions of the Missouri River outside the focused study area (St. Joseph, Missouri to Waverly, Missouri) without additional analysis.

13.6 Grade Control

- Grade control is very effective at stopping bed degradation.
- Grade control shifts the bed degradation from upstream of the grade control to downstream of the grade control. Protecting St. Joseph with grade control shifts the bed degradation back towards Kansas City.
- Grade control represents a navigation impediment unless backwater from each structure extends to the toe of the next structure. This fundamentally alters the free-flowing nature of the river at less than navigation flows.
- Grade control is not economically viable.
- Additional navigation impacts from grade control were not quantified.

14 FUTURE MODEL APPLICATIONS

These results contribute significant, new information on the damages associated with continued bed degradation, the relative importance of channel mining vs. dike maintenance, and the range of future bed elevation levels under different scenarios. These results assume representative future conditions for the purpose of assessing the benefits of stopping or reversing bed degradation via the listed alternatives. Designers of infrastructure features that could be impacted by changes in bed elevations may want to choose a more conservative projection (see Appendix C – Future Without-Project Model Projections with Risk and Uncertainty). Additional projects could also utilize the modeling tools developed in this study with different boundary conditions to create a projection tailored to the specific objectives of individual projects.

The information from this study has provided new information to better understand future risks associated with bed degradation. The information is being incorporated in recent flood-risk management projects and continues to be considered in ongoing projects within the Kansas City District. Examples include:

- Harlem and National Starch relief-well projects which considered shortened seepage entrance conditions due to loss of foreshore.

- Jersey Creek Sheetpile Wall Reconstruction which considered future anticipated bed elevations.

- L-385 repairs to headcuts on Line Creek, Burlington Creek and the Quindaro Pump Station outfall to install grade control for protection against current and future tributary headcutting.

- Argentine levee unit, which is considering tributary headcutting potential on the Kansas River.

- St. Joseph levee project, currently under design, which is considering the effect of future predicted headcut on project features.

Future USACE planning and construction projects will consider the information generated from this study accordingly.

Future permitting actions (e.g. Section 408, Section 404) should also consider the information generated for this study accordingly.

15 CONCLUSION

Bed degradation between RM 457 near St. Joseph, Missouri to RM 329 near Waverly, Missouri was evaluated in detail. Bed degradation in this portion of the river is a significant problem that has caused considerable and costly damages to federal, state, and local infrastructure. Continued bed degradation has the potential to negatively impact navigation structures, levees and floodwalls, bridges, water-supply intakes, and a host of other features. Results from this study indicate that continued bed degradation could result in over $269 million (2017 dollars) in added expenses over the next 50 years if the problem is not addressed. The study also addressed uncertainty described in the *Missouri River Commercial Dredging Final EIS* (USACE 2011a) related to the effectiveness of potential modifications to the BSNP to reduce ongoing bed degradation.

This report documents the development of two models that were used to evaluate alternative plans: (1) A HEC-RAS sediment model to project future water-surface and bed elevations and (2) an economic model that assesses the economic damages of projected-bed degradation. These are new tools that were developed specifically for this study that were not available to previous studies that evaluated bed degradation within the study area. Note that these models may require modifications and re-approval prior to use in future evaluations.

The HEC-RAS sediment model was used to project future bed and water-surface elevations for a variety of alternative plans including the future condition if no actions were to be taken to address bed degradation. In total, 15 alternative plans were developed for the study. Following a screening process, nine of the plans were evaluated in detail.

HEC-RAS sediment modeling projects that under the Future Without-Project Condition, the reach of the river between St. Joseph and the Platte River confluence will continue to degrade. Projected degradation at St. Joseph, Missouri reaches 4.6 feet by the end of 50 years. The Kansas City area is projected to continue a recovery trend for the near term. However, at the currently permitted commercial sand and gravel mining quantities, degradation in the reach downstream of the Kansas City area will migrate upstream over time and induce a new degradation trend starting in about year 2043. Reaches between the downstream boundary of the Kansas City metropolitan area and Waverly, Missouri are projected to degrade up to an additional 4.2 feet.

The study documents that lowering BSNP dikes and sills would be largely ineffective in addressing the bed-degradation problem. It also determined that rock grade-control structures could address bed degradation in the vicinity of St. Joseph, Missouri but this would decrease bed recovery in the Kansas City area. The large number of grade-control structures needed to address bed degradation while maintaining navigability would not be economically viable and would likely result in significant environmental impacts. Reductions in commercial sand and gravel mining substantially reduce or eliminate bed degradation. Elimination of commercial sand and gravel mining induces bed recovery. None of the alternatives evaluated would result in bed elevations returning to elevations observed in 1987 before bed degradation became a problem.

The economic evaluation of alternatives was conducted using the Missouri River Economic Model to determine NED benefits as required for this type of study. The alternative that would provide the greatest net benefits is a non-structural: Alternative 1C – Eliminate Commercial Sand and Gravel Mining. Alternative 1B – Reduced Commercial Sand and Gravel Mining, also a non-structural alternative would provide a very similar amount of net benefits to Alternative 1C, in part because the economic evaluation did not quantify the impacts and/or benefits associated with bed recovery.

The BSNP modification alternative at the 2015 permitted dredging level (Alternative 4A) does not provide positive-net-benefits in the base-case analysis. Residual damages under Alternative 4A are greater than the without-project condition damages because this alternative shifts the degradation toward reaches of the river where higher value impacts occur. Alternatives 4B and 4C provide only nominal positive net benefits. (Table 10-3). Alternatives that include measures for grade-control structures (Alternatives 5A, 5B, and 5C) do not result in any positive-net-economic benefits (Table 10-4).

Alternatives that include measures for grade-control structures (Alternatives 5A, 5B, and 5C) would not result in positive-net-economic benefits under base-case assumptions nor under any of the sensitivity analyses conducted

Based on the economic analysis none of the structural alternatives would result in greater positive-net-benefits then the positive-net-benefits of Alternatives 1B and 1C, which indicates that there is no federal interest in a structural solution to the problem. The alternatives that would result in the greatest positive NED benefits are the reduction or elimination of commercial sand and gravel mining in the study reaches of the Missouri River. Modifications to the permitted quantity of sand and gravel are regulated under the purview of the USACE regulatory program and USACE Section 408 processes. As there is no federal interest in a structural solution at the permitted level of commercial sand and gravel mining, the economic evaluation does not support a recommendation that would require congressional authorization.

While the study conducted and documented in this Missouri River Bed Degradation Feasibility Technical Report did not find a federal interest in a structural solution to the problem or a project implementable pursuant to Section 216 authority, the evaluation and findings provide new and useful information that was not available during previous investigations concerning bed degradation within the study area. The study also addressed uncertainty described in the *Missouri River Bed Degradation Reconnaissance Study, Section 905(b) Analysis* (USACE, 2009) and the *Missouri River Commercial Dredging Final EIS* (USACE 2011a) related to the effectiveness of potential modifications to the BSNP to reduce ongoing bed degradation.

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Appendix A

Existing Condition of the Bank Stabilization and Navigation Project Structures, River Miles 330 and 400

Appendix B

Mobile-bed model Calibration Report

Appendix C

Future Without-Project Model Projections with Risk and Uncertainty

Appendix D

Missouri River Bed Degradation Public Scoping Report

Appendix E

Report Synopsis Following Planning Charrette

Appendix F

Mobile-Bed Model Review Documentation

Appendix G

Economic Model Documentation

Appendix H

Analysis of the Cost of Bed Degradation of the Bed of the Missouri River to the Missouri River Bank Stabilization and Navigation Project (BSNP)

Appendix I

Geotechnical Analysis of Flood-Risk Management Projects

Appendix J

Structural Analysis of Independent Structures

Appendix K

Analysis of the Cost of Degradation of the Bed of the Missouri River to the Missouri River Recovery Program Side Channel Chutes for Shallow Water Habitat

Appendix L

Cost Estimate to Construct Rock Grade-Control Structures on Tributaries to the Missouri River

Appendix M

Value Engineering Study

Appendix N

Future With Project Model Projections

Appendix O

Economic Analysis

Appendix P

U.S. Fish and Wildlife Service Planning Aid Letter

Appendix Q

Review