South Bismarck Sediment Management Study

Bismarck, North Dakota

Revised - January 2014
U.S. Army Corps of Engineers
Omaha District

Cover Photo: *March 2009 Missouri River ice jam near Bismarck, North Dakota, looking downstream, Prison Farm on left of photo. Photo courtesy of U.S Army Corps of Engineers, Omaha District.*

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1. Introduction

The Purpose of this report is to describe the methodology, data used, assumptions, and results of analysis of the flooding problem and channel stability along the Missouri River near Bismarck, North Dakota. Results of the analysis include description of the flood risk associated with open water and ice-affected flows on the Missouri River for both existing and future conditions, an examination of Missouri River channel stability and sedimentation within the study area, and an evaluation of sediment management alternatives to minimize flood potential.

1.1. Problem Definition

Flood risks in the study area are exacerbated by the effects of ice and sediment build-up along the Missouri River. During severe flood events, and in particular, ice-affected flood events along this reach of the Missouri River, residential homes, commercial businesses, and roads may be surrounded by flood waters. Ice located within and along the river can jam, causing additional increases in water elevations, with limited warning. A factor identified as having the ability to increase the occurrence of ice jams is the continued build-up of sediment in the Missouri River channel. Upstream of Lake Oahe, this free flowing reach of the river contains a high concentration of sandbars and sediment aggradation in the channel. In addition to high concentrations of sediment in this reach, ice can begin to accumulate in the river at the head of the sheet ice cover on Oahe Lake and progress upstream towards the City of Bismarck.

1.2. Scope of Study

The purpose of the study is to determine the technical feasibility of implementing sediment management measures aimed at reducing flood risk, particularly ice-affected flood risk. The study outcome will be used to determine whether there is justification to conduct a feasibility study in this area. The study area is shown in Plate 1, Project Vicinity Map.

1.3. Study Authorities

This study was conducted under the Title VII study authority at the request of the Title VII Task Force. The purposes of Title VII, *Missouri River Restoration, North Dakota*, and Title IX, *Missouri River Restoration, South Dakota*, of the Water Resources Development Act (WRDA) of 2000 are to reduce siltation of the Missouri River in the States of North Dakota and South Dakota, respectively; develop and implement a long-term strategy to improve conservation, protect recreation from sedimentation, improve water quality, improve erosion control, and protect historic and cultural sites along the Missouri River from erosion; and develop and finance new projects. Any project implemented under the Title VII authority must meet the stated purposes of Title VII and cannot result in environmental degradation. To date, no projects have been constructed under either of these authorities.

Sediment management in the study area is a complex issue that has been addressed by a number of different authorities since the construction of Garrison and Oahe Dams. Other relevant authorities to the study area are discussed in the following three sections.

1.3.1. Flood Control Acts of 1963 and 1968

Flood Control Acts of 1963 and 1968: Under this authority, more commonly known as the Garrison to Oahe Project, the U.S. Army Corps of Engineers (Corps) constructed six stream bank stabilization projects in the reach between Garrison Dam and Lake Oahe. This construction took place from 1965 to 1975 and stabilized approximately 28.5 miles of bank line. These projects were turned over to the local sponsor, the North Dakota State Water Commission (SWC), for operations and maintenance. In most cases the SWC signed subsequent agreements with local water boards.

1.3.2. Water Resources Development Act of 1974

Section 32 of WRDA 1974 authorized a national erosion control demonstration program aimed at promoting lower cost erosion control techniques. From 1978 through 1982 the Omaha District constructed 29 separate projects on the Missouri River from Garrison Dam to Ponca State Park. The total length of protection is approximately 51.5 miles of bank. The breakdown by state is as follows: North Dakota - 18 projects, 26.2 miles; South Dakota - five projects, 12.8 miles; and Nebraska - 6 projects, 15.5 miles. All of these projects were turned over to the local sponsors (SWC in North Dakota, counties in South Dakota, Natural Resource Districts in Nebraska) for O&M. The Omaha District also constructed two Section 32 projects on the lower Yellowstone River.

1.3.3. Section 33 of the Water Resources Development Act of 1988

Referred to as the Section 33 Program, this authority applies to the open water reaches of the Missouri River (non-reservoir) from Fort Peck Dam in Montana to Ponca State Park in Nebraska. The Section 33 authority allows the Corps to stabilize eroding Missouri River banks, or purchase a sloughing easement on affected property, whichever is least expensive. Section 33 also provides the authority for the Corps to maintain existing federally constructed stream bank stabilization projects within the project reach. The authority is limited to no more than $3 million per fiscal year and is subject to the availability of funds. To date the Corps has constructed three projects under this authority. Two projects were demonstrations of bio-stabilization techniques in McCone County, Montana and the other involved erosion control and river training structures to ensure adequate stabilization and flow depths for the Buford-Trenton Irrigation District intake in McKenzie County, North Dakota. Thirdly, under this authority, the Omaha District purchased one sloughing easement in Nebraska. Maintenance and demonstration activities were completed in the Garrison to Oahe reach in 1994 and 1995 and in the Fort Randall reach in 1996. Following the 2011 flood event, the Section 33 authority was used to conduct inspections of all the federally constructed stream bank stabilization projects to develop priorities and repair plans. However, the only project receiving construction funds was the repair at Hogue Island, located upstream of the study area in the Bismarck, ND, vicinity.

2. Background Information Used for Analysis

2.1. Study Area

The study vicinity focuses on the south Bismarck area of the open water reach of the Missouri River. The study area is roughly between River Miles 1280 and 1325 on the Missouri River. Although outside the study area, the Oahe and Garrison Dams affect relationships in the study vicinity. The Garrison Dam regulates flow into the reach and was completed in 1953; the Oahe dam was completed in 1959 creating the reservoir that forms the downstream boundary of the reach. Within the study locale, the Missouri River is used for flood control, hydropower, navigation, irrigation, water supply, recreation, and fish and wildlife including habitat for threatened and endangered species.

The primary area of concern for the study area is within south Bismarck, ND, along the Missouri River from approximately the West Main/Memorial Hwy bridge (1960 River Mile 1314.2) downstream a distance of 20 to 30 river miles where the Missouri River begins to enter the Lake Oahe pool region.

2.2. Flow Data

The main flood threats in the Bismarck-Mandan area are from the Missouri and Heart Rivers due to both open water and ice-affected flows. The Missouri River near Bismarck is highly regulated by Garrison Dam and other dams upstream, but is subject to long-duration, high flows during periods of heavy upstream basin runoff, such as occurred in 1997 and 2011.

2.2.1. Missouri River

The study reach is bounded by Garrison Dam near Riverdale, ND upstream of Bismarck and Oahe Dam near Pierre, SD downstream of Bismarck. The drainage area of the Missouri River is approximately 181,400 square miles above Garrison Dam and 243,490 square miles upstream of Oahe Dam. Flow-frequency and flow-duration relationships for Garrison releases were recently updated (USACE, 2012) and are presented in the tables below.

Table 1. Flow-frequency for Garrison Releases

% Chance Exceedance (Return Interval, Years)	Adopted Flows, cfs
50 (2-year)	39,000
20 (5-year)	42,000
10 (10-year)	48,000
4 (25-year)*	60,000
2 (50-year)	72,000
1 (100-year)	85,000
0.5 (200-year)*	102,000
0.2 (500-year)	150,000

* Values interpolated

Table 2. Flow-Duration Garrison Releases

% Time Exceeded	May-Aug, cfs	Annual, cfs
1	115,400	59,000
5	40,000	36,900
10	37,000	31,400
20	28,900	27,100
50	20,200	19,900
80	16,000	14,700
90	14,100	12,300
95	13,100	10,700
99	10,200	9,800
100	9,100	0

The USGS has maintained a gage near Bismarck, ND with daily flow records during the period October 1, 1927 through the present. The gage is located at River Mile 1314.5, on the left bank 40 feet upstream from the City of Bismarck's municipal intake. The peak discharge recorded at Bismarck was 500,000 cfs on April 6, 1952; this peak discharge was the result of a combination of rapid snowmelt and the release of an upstream ice jam. The largest peak discharge recorded at Bismarck following the closure of Garrison Dam in 1953 was 155,000 cfs on June 25, 2011. Due to the ability of Garrison Dam to regulate Missouri River flows in response to tributary inflows below Garrison Dam, it is assumed that the flow-frequency release relationship at Garrison Dam can be used to describe the flow-frequency relationship throughout the study reach for open water conditions. Since the impact of dam regulation on flows is so large, a typical hydrologic frequency analysis using the Bismarck gage data would not be applicable.

2.2.2. Tributaries

There are two significant tributaries to the Missouri River within the study vicinity: the Heart River and Apple Creek. The Heart River is a right bank tributary with its confluence near River Mile 1311, while the Apple Creek is a left bank tributary with its confluence near River Mile 1300. The Heart River is capable of producing sudden, significant increases in discharge, as well as delivering significant volumes of ice into the mainstem of the Missouri River, such as occurred in March 2009. The Apple Creek, in contrast, is usually much slower to increase in discharge, due to the gentle topography of the basin, and the peak flows are typically much smaller than Heart River peak flows. The largest flows on the Heart River have all been in response to snowmelt events, with some snowmelt events augmented by rainfall, and are relatively short in duration. The largest Apple Creek flows have also all been in response to snowmelt events, with some snowmelt events augmented by rainfall, but the durations of flow are typically longer due to a slower responding watershed. Due to the differences in basin response, Heart River flows are the only significant source of increased flows in the Missouri River flow-frequency relationship in the study reach below the Heart River.

The USGS has maintained a gage on the Heart River near Mandan with daily flow records during the period April 1, 1924 through present. The highest discharge recorded at the gage was 30,500 cfs on April 19, 1950. The highest discharge since the closure of Garrison Dam was 29,200 cfs on March 24, 2009. The highest discharge outside of the snowmelt period was 12,900 cfs on June 27, 1966.

The USGS has maintained a gage on the Apple Creek near Menoken, ND with daily flow records during the period March 1, 1905 through June 30, 1905 and October 1, 1945 through present. The highest discharge recorded at the gage was 6,750 cfs on April 18, 1950. The highest discharge since the closure of Garrison Dam was 5,980 cfs on April 19, 1979. The highest discharge outside of the snowmelt period was 1,290 cfs on July 16, 1993.

2.3.Stage Data

Stage data is necessary to help evaluate how high historic flows have been at a particular location and trends in stage for a particular discharge over time in areas such as the Bismarck area where significant aggradation has occurred downstream of the community. Hourly and daily gage data is also useful for evaluating when ice formation or ice jams may have occurred at a particular river location. The two Missouri River gages utilized in this analysis are described below.

2.3.1. Missouri River at Schmidt

The USGS has maintained a gage at Schmidt for the period October 1, 1966 through the present, with a record of daily average gage height. The gage is located on the right bank at River Mile 1298, approximately 2 miles downstream from the abandoned town site of Schmidt. Stages at Schmidt can be influenced by Oahe pools. The record stage at the Schmidt gage occurred on July 10, 2011.

2.3.2. Missouri River at Bismarck

As mentioned in Section 2.2.1 above, the USGS has maintained a continuous gage record at Bismarck since October 1927. Annual peak stages are available for 1881 and 1929 through the present, while daily stage records are available for the period October 1, 2000 through the present. The highest stage ever recorded at Bismarck occurred on March 31, 1881 and was the result of an ice jam on the Missouri River. The highest subsequent stage occurred on April 6, 1952 in conjunction with the highest discharge recorded at Bismarck. Since closure of Garrison Dam in 1953, the highest annual peak stage typically occurs during the winter months as the river freezes in, although a few instances of peak stage have occurred with ice breakup and about 10% of the annual peak stages have been associated with open water releases.

2.3.3. Other

Several high water marks were collected in the Bismarck area following the 2011 flood. These high water marks were utilized in open water model calibration. The location and elevation of these high water marks are shown in Figure 1 below.

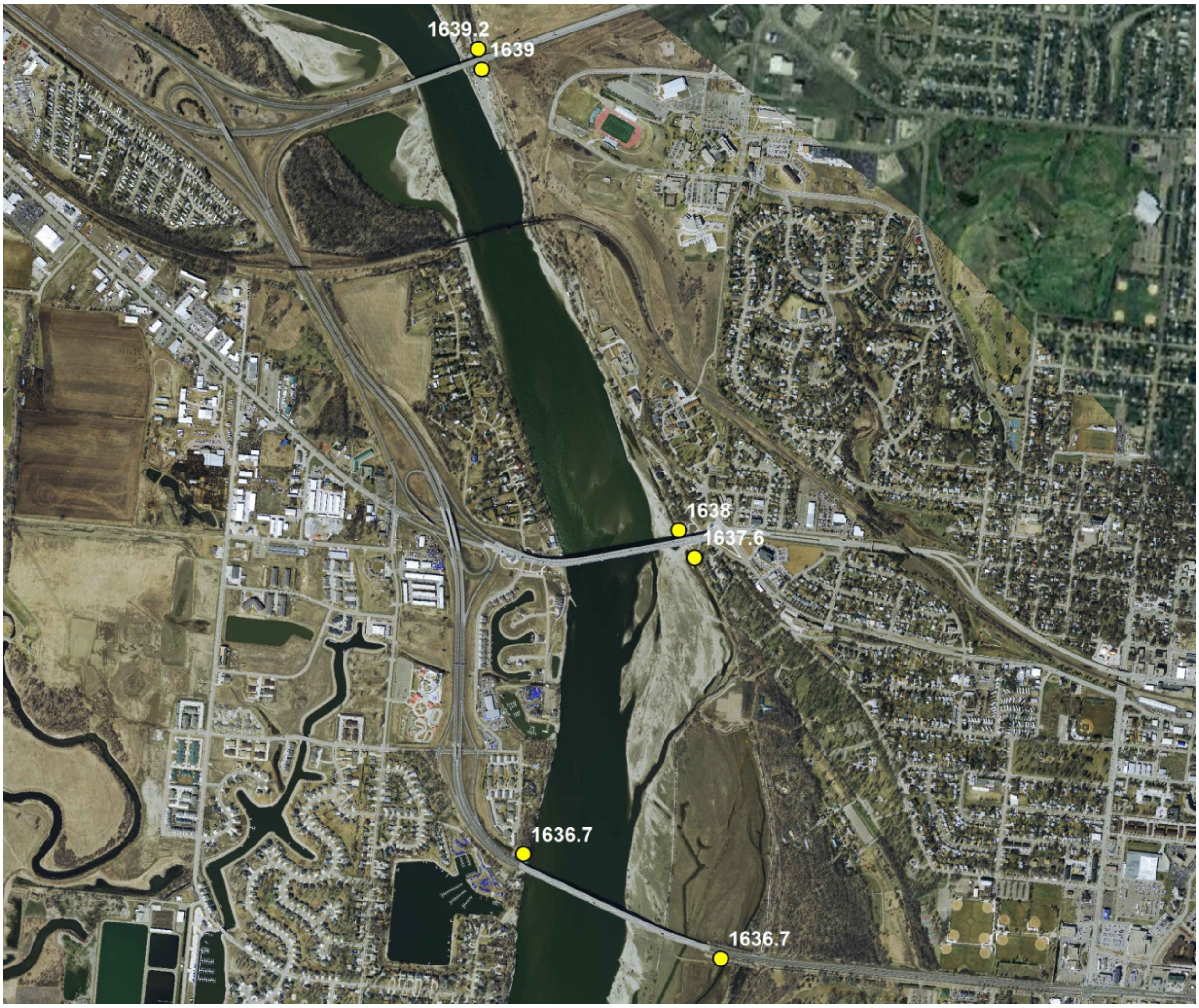

Figure 1. Location of 2011 High Water Marks and Elevations (NAVD88)

2.4. Climate

The National Weather Service operates a number of gages that collect meteorological data. Records for stations near the Bismarck area included daily minimum and maximum air temperature, as well as snowfall and precipitation. These data were used to compute average daily air temperature (ADAT), freezing degree-days (FDD), and accumulated freezing degree-days (AFDD) for the winter season. The average daily air temperature is simply the average of the daily minimum (T_{min}) and maximum (T_{max}) air temperatures:

$$ADAT = \frac{T_{max} + T_{min}}{2}$$

Freezing degree-days (FDD) are calculated from the ADAT using the equation:

$$FDD = 32 - ADAT$$

When FDD is positive, it means that the average daily air temperature is lower than 32°F, while a negative value indicates the average daily air temperature is above 32°F. The accumulated freezing degree-days are the sum of the freezing degree-days (positive or negative) during the winter, beginning October 1 of the season in question. Since air temperatures in central North Dakota are still relatively high in October, the AFDDs are summed until a minimum value is reached; on this date the AFDD is reset to zero and begins accumulating again until a maximum value is reached (termed $AFDD_{max}$). An examination of the relationship between ice formation in the Bismarck reach, AFDD and discharge is presented in Appendix A.

2.5. Sediment Range Data

During the mainstem dam construction era, the interruption of Missouri River sediment transport by the dams was identified as a major concern with degradation and aggradation zones established for each segment of the Missouri River between the constructed dams. Within these zones, sediment ranges were established as cross sections to aid with tracking channel changes and reservoir aggradation.

Established in the 1950's, the sedimentation range locations are based on 1941 river miles. Recent data provided for this study, as well as referenced reports, primarily use 1960 river miles. For purposes of this study, 1960 river miles were used for referencing project features while the sediment ranges continue to use the 1941 river mile stationing for consistency. The location of sediment ranges within the study area is illustrated on Plate 1.

Sediment ranges have been surveyed multiple times since initial installation in the 1950's. These surveys provide a method for tracking changes with time since dam construction. The most recent survey in the Bismarck study area was completed in 2012. Sediment ranges 1358.3 and 1362.8 were not included in any of the sediment range evaluation because of the lack of historical data. Plots of the sediment range data illustrate significant change in cross section shape since 1956. Cross section plots of the multiple surveys at each sediment range are illustrated in Appendix B.

2.6. Bank Stabilization Status Overview

Since Garrison Dam closure, numerous bank stabilization projects were constructed within the project reach during the period from the 1960's through the early 1990's. Historic bank stabilization projects constructed under Section 32 authority are shown in Plate 1.

Within the past twenty years, the U.S. Environmental Protection Agency, U.S. Fish and Wildlife Service (FWS), North Dakota Department of Health (NDDH), and North Dakota Game and Fish Department have sent correspondence to Omaha District indicating concern with cumulative effects from bank stabilization on the Missouri River, Garrison Reach and potential impacts of bank stabilization to the habitat-forming processes for the least tern, piping plover, and pallid sturgeon. The FWS has recommended a moratorium on bank stabilization.

The NDDH has not issued Section 401 Water Quality Certification for bank stabilization proposals greater than 200 feet on the Missouri River, Garrison Reach since approximately 1997. Prior to this, bank stabilization permits were issued annually for about 12-15 new projects and 17-20 maintenance actions. The NDDH has stated that Section 401 certification will be held in abeyance until the Corps completes a cumulative impacts assessment on the Missouri River, Garrison Reach. The only exceptions to the NDDH position have been for maintenance and emergency work.

The Omaha District initiated a Cumulative Environmental Impact Statement (CEIS) for ongoing bank stabilization within the Missouri River from Fort Peck Dam to Ponca, NE. Multiple agencies were requested by letter to be Cooperating Agencies for the National Environmental Policy Act (NEPA) process in March 2006. Through the history of the CEIS, progress was impacted by many issues such as insufficient funding, schedule delays, lengthy reviews, and multiple document rewriting. The technical report evaluated the amount of bank stabilization between two time periods and the potential relationship between increased bank stabilization and sandbar habitat formation in the Missouri River at a “reach” level. However, the relationship between bank stabilization and sandbar formation, based on this comparison, was inconclusive. As a result, the Corps was unable to determine a geomorphological basis on which to recommend altering the rate or amount of bank stabilization permits currently being permitted in the Missouri River. The Omaha District recognized that even though the technical analysis was inconclusive, the lack of a demonstrated correlation could be attributed to the relatively recent completion of major bank stabilization projects and an insufficient time interval to accurately measure the river adjustment to those changes. In 2009, the Omaha District developed a study scope for evaluation in the Garrison reach of cumulative effects from bank stabilization. This study was not funded. At this time, no further evaluation is currently underway or planned to address the cumulative impacts of bank stabilization in the Garrison to Oahe reach of the Missouri River.

With respect to this study, an alternative was considered that included bank stabilization. Prior to proceeding further with any such alternative, the issues with sandbar habitat and the construction of bank stabilization would need to be addressed.

2.7. Study Area Sandbar Habitat and River Processes

Sandbars are present on the Missouri River within the study area. Sandbars have both endangered species habitat value and implications for any sediment management strategy.

2.7.1. Habitat for Endangered Species

The Omaha District has an ongoing program to create and/or reclaim a sufficient amount of Emergent Sandbar Habitat (ESH) critical habitat to stabilize interior least tern and piping plover populations with the eventual goal to support a self-sustaining population along the Missouri River. These measures are recommended by the 2003 Biological Opinion Amendment (USFWS, 2003) and the 2000 Biological Opinion (USFWS, 2000). In accordance with the Endangered Species Act (ESA) and in consultation with the U.S. Fish and Wildlife Service (USFWS), the Corps must ensure that any action carried out is not likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of critical habitat.

Prior to construction of the Main Stem dams on the Upper Missouri River, periods of high and low flows along the River would result in the creation of the sandbars suitable for nesting for the Least Tern and Piping Plover. Since closure of the dams, extreme peak flows and the occurrence of downstream flooding has been reduced greatly, and base flows have been increased. The upstream dams have also significantly altered sediment concentrations with channel degradation observed in the reach downstream of the dams. As a result, suitable sandbar habitat acreage has declined. Many of the existing sandbars are not high enough for the Least Tern and Piping Plover to nest on. Moreover, those that are high enough become covered with vegetation over the years without the presence of overtopping flows.

Within the last ten to twenty years, resource agencies and other focused groups have strongly opposed stream bank stabilization projects within the Garrison to Oahe open channel reach due to: (1) the presence of least terns and piping plovers, (2) the extensive stabilization that already exists, and (3) the fact that stabilization usually is followed by development. As a result, implementation of measures that include stream bank stabilization or other measures that would impact the amount of sediment in the system, thus resulting in the possible reduction of sandbar habitat, would likely encounter opposition from a number of groups. However, the purpose of this study is to evaluate the engineering design aspects of sediment management alternatives. Technically feasible alternatives will require a full evaluation of environmental implications in future studies and likely require methods to mitigate impacts.

2.7.2. Sandbar Processes Overview

Sandbar evolution has been studied in both flumes and natural rivers extensively by numerous investigators. Sandbar vertical and lateral growth results in flow separation and deflection and can be associated with subsequent erosion of sandbar side channel banks and the growth of new bars downstream in the flow expansion zone from side channels. In natural rivers with fluctuating discharges and variable sediment supply, the bar-forming processes are more complex. The net erosion of the upstream bar area and deposition along the downstream perimeter causes the bars to both move downstream and grow. Sandbars do not occur in isolation and bar migration is part of an overall natural channel process. Variable flow rates also influence this process as high flows inundate the entire channel while lower flows dissect moving sandbars and expose areas of bare sand.

The processes of bar formation, partial erosion, exposure, and re-formation are intimately connected with habitat issues in the Missouri River. The piping plover and interior least tern use both the submerged and aerial portions of the active sandbars. Productive habitat is dependent on the regular inundation of the entire channel to keep the sandbars mobile and vegetation free while lower flows are necessary for exposure of the sandbars during nesting season. Sandbar zones are shown in Plate 2.

2.8. HEC-RAS Model

The HEC-RAS 4.1 (USACE, 2010) software was utilized to determine water surface profiles in the vicinity of Bismarck. HEC-RAS computes one-dimensional hydraulic calculations for a full network of natural and constructed channels. The HEC-RAS software is capable of computing steady flow with gradually varied flow, unsteady flow for gradually or rapidly varied flow, sediment transport and movable boundary calculations, and riverine water quality analysis. For purposes of this study, steady flow computations were used in HEC-RAS, although the model geometry can be readily adapted for unsteady flow computations if desired.

2.8.1. Data Sources and Model Development

The hydraulic model utilized for this study was developed based on previous hydraulic models of the Missouri and Heart Rivers. The Missouri River portion of the model was originally developed as an HEC-2 model developed for assessing aggradation in the Oahe delta in the mid-1980s (USACE, 1985). This HEC-2 model was updated in the early 1990s for purposes of evaluating a range of Garrison Dam releases with varying Lake Oahe pools. The updated HEC-2 model was converted to a georeferenced HEC-RAS model in 2009 in conjunction with the USACE Critical Infrastructure Protection and Resilience program. The 2009 HEC-RAS model was then updated with channel bathymetry collected by North Dakota State Water Commission in 2012 between River Miles 1305.6 and 1324.6 and sediment range surveys conducted in 2012 from Garrison Dam downstream to River Mile 1228.1. Overbank geometry was updated based on LiDAR data collected in 2012 between Garrison Dam and Oahe Dam. For purposes of this study, the overbank geometry was only updated between River Miles 1292.69 and 1325.53. For sediment ranges that did not extend across overbanks sufficient distance to fully contain the modeled flows, overbank elevations were extracted from LiDAR data and 10-meter DEM data (USGS), depending on the cross-section location.

The Heart River portion of the model was originally developed as an HEC-2 model for the Lower Heart River Section 205 report (USACE, 1986) and later converted to an HEC-RAS model for the Heart River Section 205 report (WEST Consultants, 2002). The cross-sections were georeferenced and new cross-sections cut using the 2012 LiDAR data. Previous channel geometry was then merged into the newly cut sections. The Heart River geometry was then merged into the Missouri River geometry for a combined geometry.

For this study, all data was converted to a common horizontal projection and vertical datum. The vertical datum used was NAVD88, and the horizontal projection was Albers Equal Area, with Central Median 96° W, Standard Parallel 1 of 29.5° N, Standard Parallel 2 of 45.5° N, and Latitude of Origin 23° N. Contraction and expansion coefficients were set to 0.1 and 0.3, respectively. The HEC-RAS geometry did not include any bridge geometry on the Missouri or Heart Rivers as the main area of concern for the study does not contain any bridges. Reach lengths, channel roughness values, encroachments and bank stations from the previous models were imported as-is for this study, although some channel roughness values were adjusted during model calibration. Bank stations were adjusted in those areas where the stream bank has eroded. Aerial imagery data utilized in this study were collected in 2012 (following the flood of 2011).

2.8.2. Model Calibration

In order to calculate accurate water surface profiles in HEC-RAS, the model must be calibrated against observed data (i.e. flow and stage data) at various locations within a study reach. Previous hydraulic studies within the study reach had produced calibrated hydraulic models; however, with the change in model geometry, it was necessary to re-calibrate the hydraulic model. For purposes of this study, stage and flow data over the past 12 years at the Bismarck gage and stage data at the Schmidt gage, along with several high water marks from 2011, were used to calibrate the HEC-RAS model over the full range of flows that might be expected in the Bismarck vicinity under both open water and ice-affected flows, as described in the paragraphs below. As can be seen in Figure 2 below, the open water and ice-affected flow regimes can be quite different.

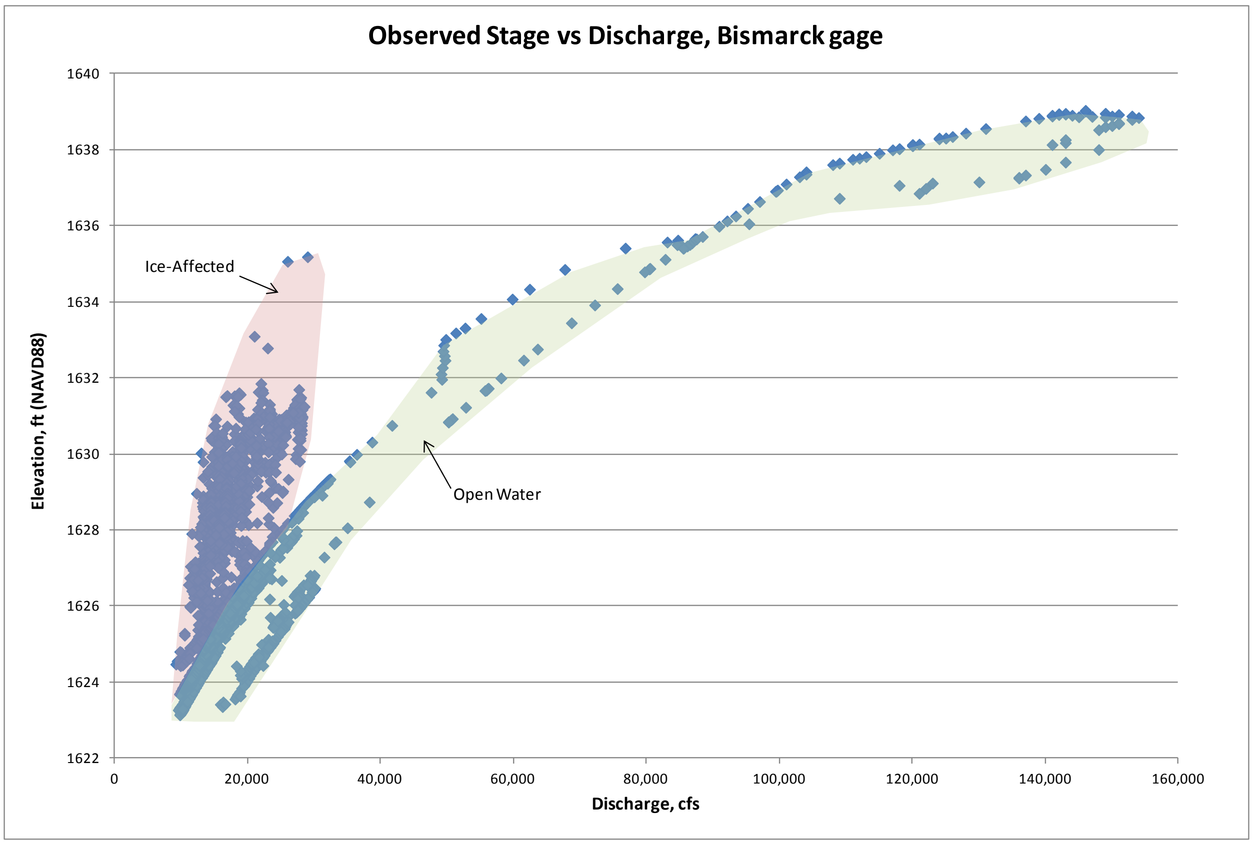

Figure 2. Stage-Discharge Flow Regimes for Open Water and Ice-Affected Flows, Bismarck, ND

2.8.2.1. Open Water

Initial Manning's n-values selected were guided by previous modeling efforts, and then the n-values were adjusted to better match the gage data at Schmidt and Bismarck. The resulting calibration resulted in Manning's n-values varying by river reach, as shown in Table 3 below.

Table 3. Manning's n-values selected, Missouri River

River Reach (by River Miles)	Channel "n"	Overbank "n"
1228.10 - 1274.56	0.018	0.1
1274.56 - 1298.55	0.024	0.06-0.1
1298.55 - 1314.63	0.023	0.05-0.12
1314.63 - 1326.69	0.022	0.1
1326.69 - 1388.19	0.024	0.1

However, the n-values above did not result in matching the Schmidt and Bismarck rating curves throughout the range of discharges modeled. Recognizing that n-values can vary in the vertical direction, flow roughness factors were used in HEC-RAS to better match the observed data at the two gages. Flow roughness factors were used from River Mile 1280.31 to 1314.63 as shown in the table below.

Table 4. Flow roughness factors, Missouri River

Flow (cfs)	Roughness Factor
5,000	1
10,000	0.85
20,000	0.9
30,000	0.9
40,000	0.95
50,000	1
60,000	1
80,000	1.1
90,000	1.1
100,000	1.1
120,000	1.05
160,000	1

Manning's n-values for the Heart River were left as previously calibrated at 0.026 for the channel and 0.075 for the overbanks between levees.

2.8.2.2. Ice-Affected

The ice-affected flow regime, in theory, is composed of three possible ice conditions: freezeup conditions, intact ice cover, and breakup conditions – in addition to open water conditions in the absence of ice. In reality, these conditions may overlap in the stage-discharge relationships, or may exist simultaneously in adjacent stretches of river. For purposes of model calibration, however, these three ice conditions are assumed to be independent of one another. The gage record was examined to best determine the relationship between these ice regimes, and the resulting demarcations are shown in Figure 3 below.

For purposes of calibration, the intact ice cover condition was modeled with a constant thickness of ice and Manning's n-value for the ice, with the Manning's n adjusted until it matched the upper range of the 'Intact Ice' zone, as shown in Figure 3. The final ice thickness values selected were 2.5 feet thick in the Oahe pool region, and 2 feet thick in the river above the pool. Ice roughness in the pool was set at 0.1 and at 0.02 in the river above the pool. The river reach was assumed to have thinner ice due to the shorter period of time with an ice cover and due to the warming effects of water releases from Garrison Dam, while the river reach ice is assumed slightly rougher due to the pushing and shoving of ice that occurs during the freezeup period, which does not "smooth" as completely as the thermally grown ice in the Oahe pool.

The HEC-RAS ice jam routines were utilized for the freezeup and breakup conditions, with the model set to automatically select ice thickness values, since these are the two conditions under which ice jams may form. As the model selects the appropriate ice thickness, the Manning's n-value for the ice cover was adjusted, based on recommended values from EM 1110-2-1612 (USACE, 2012). This process was performed iteratively until ice thickness values stabilized at all cross-sections for freezeup conditions. It was noted that freezeup jams tend to form in the same locations regardless of discharge.

For breakup conditions, ice jam locations varied slightly with discharge, so the most likely jam locations were manually selected, and an average ice thickness based on the iterative process described above was determined at each cross-section with the appropriate ice roughness value. Ice jam locations were manually set for the breakup condition to prevent the computed profiles from crossing. The cumulative volume of ice under breakup conditions was compared against the intact ice cover condition, and ice cover was removed from sections between ice jam locations such that ice was not being "generated" under breakup conditions; in other words, the volume of ice in an ice jam was not allowed to exceed the volume of ice that was available from the river upstream of each jam location. Ice jams were not allowed to occur above the Heart River in the Bismarck reach for breakup conditions, due to the lack of sufficient inflow to lift and break ice in the study reach. In 2009, outflows from the Knife River and other upstream tributaries contributed to an ice jam forming in the Double Ditch area; however, this jam was outside the study reach and was therefore not modeled.

For both the freezeup and breakup conditions, the ice roughness were manually adjusted at no more than 6 cross-sections to better match the upper range of each ice regime, while under breakup conditions, ice thickness was also manually adjusted at no more than 6 cross-sections. The resulting calibrations are shown in Figure 3. It should be noted that, although Figure 3 does not indicate it, flows as low as 8,000 cfs were used in calibrating ice-affected flows to the three ice regimes. Data contained in Appendix A was used to guide the selection of ice-affected regimes.

Ice thickness utilized in the freezeup condition were 1-foot thick in the Oahe pool, with an ice roughness value of 0.012, while the ice thickness ranged from 0.75-feet to 8-feet in the river reach above the pool, with ice roughness values ranging from 0.03 to 0.072. Ice thickness utilized in the breakup condition were 2.5-feet thick in the Oahe pool, with an ice roughness value of 0.01, while the ice thickness ranged from 2-feet to 9-feet in the river reach above the pool, with ice roughness values ranging from 0.02 to 0.10. Ice thicknesses during ice jam conditions typically reach several times the initial ice sheet thickness as the ice shoves downstream as the river breaks up and turns ice sheets on end, repeating the process as the jam continues to thicken to an equilibrium point where the upstream forces are counteracted by the resistance of downstream ice (and possibly debris).

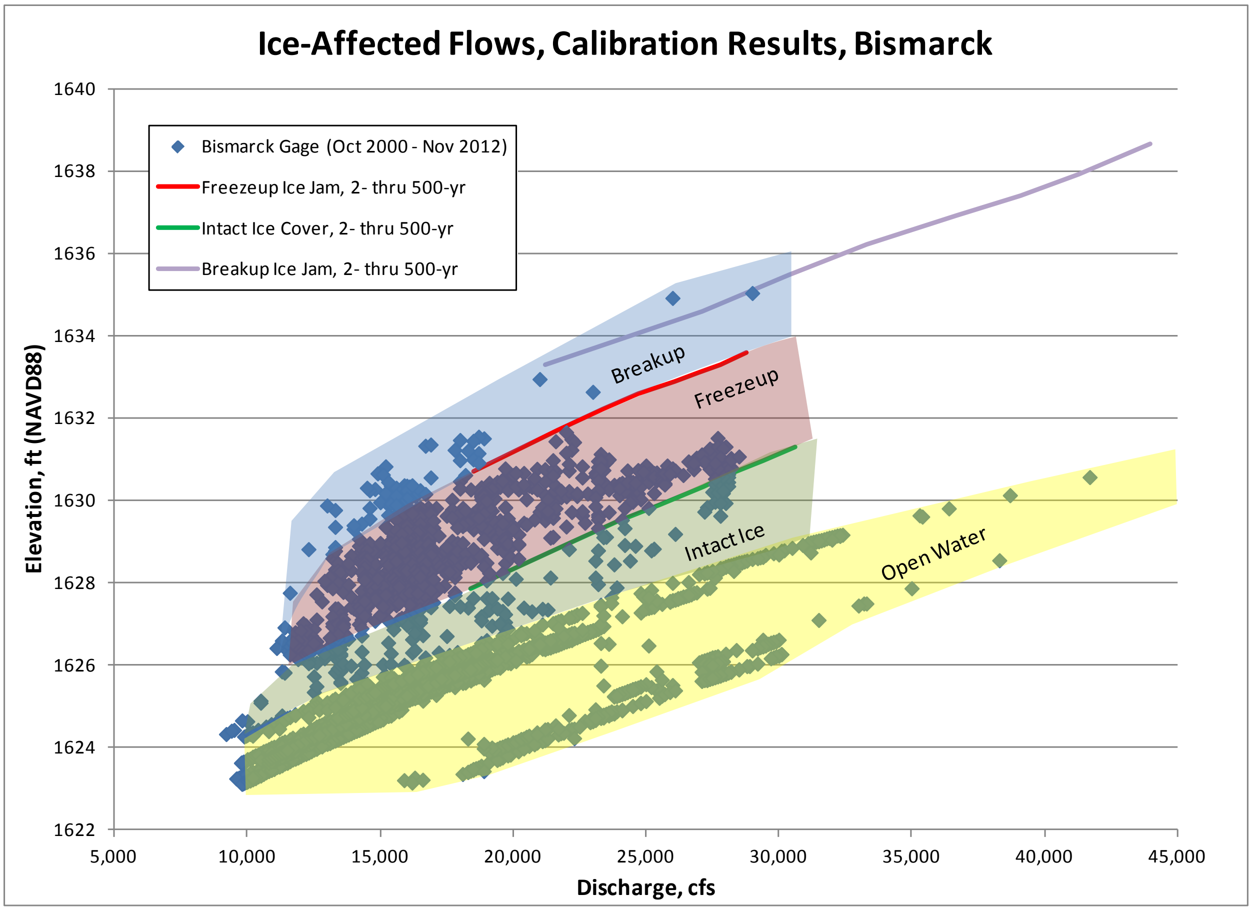

Figure 3. Ice-Affected Flow Regimes Used in HEC-RAS Calibration

2.8.3. Boundary Conditions

Downstream boundary conditions on the Missouri River for open water flows were set to Oahe pool levels corresponding to the same frequency of flow modeled on the Missouri River. These pool levels were obtained from updated flow statistics (USACE, 2012) and adjusted to the proper vertical datum; the values used are shown in Table 5. The downstream boundary condition for ice-affected flows was set to pool level of 1607.0 (NAVD88), as this is typically the highest pool experienced during periods of ice-affected flows.

Table 5. Starting Water Surface for Open Water Flows (NAVD88)

50% ACE[1]	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.5% ACE	0.2% ACE
1614.2	1618.2	1619.3	1619.9	1620.7	1621.2	1621.6	1622.2

[1] ACE = annual chance exceedance event

2.8.4. Model Flows

Flows between the 50% (2-year flood) annual chance exceedance event (ACE) to the 0.2% ACE (500-year flood) were determined for open water, ice freezeup, intact ice, and ice breakup conditions, with values differing upstream and downstream of the Heart River, as shown in the following paragraphs.

2.8.4.1. Open Water

Missouri River flows at Bismarck (above Heart River) were assumed to be the same as Garrison releases for the same probability event. Heart River flows were assumed to be 50 cfs (representative of mean daily flows), and the Missouri River flows below the Heart River was 50 cfs greater than the Missouri River flows above Heart River. The reasoning behind selecting the Garrison release probability relationships is that Garrison Dam can be operated to maintain relatively constant flows at Bismarck, regardless of tributary flow. The experience of the Flood of 2011 demonstrates that tributary inflows can be quite small, even for an extended period of time, during periods of high releases from Garrison Dam. The flows used for the open water modeling are shown in Table 6 below.

Table 6. Flows Used for Open Water HEC-RAS Modeling

River	50% ACE	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.5% ACE	0.2% ACE
Missouri River above Heart	39,000	42,000	48,000	60,000	72,000	85,000	102,000	150,000
Heart River	50	50	50	50	50	50	50	50
Missouri River below Heart	39,050	42,050	48,050	60,050	72,050	85,050	102,050	150,050

2.8.4.2. Ice-Affected

Flows at Bismarck under ice-affected flow conditions are usually limited by Garrison regulation so as to not exceed a certain stage at the Bismarck gage during the freezeup period. However, as the downstream channel has aggraded, the discharge required to reach that stage has gradually decreased for all ice flow regimes. The average annual decrease in discharge for all flow regimes was approximately 400 cfs, as shown in Figure 4. The annual maximum discharge in December and January of each water year was selected as the maximum discharge at freezeup, since freezeup typically occurs in those months, and flows do not usually increase significantly in these months, as the ice cover is still smoothing out. Several years of December data had to be censored, as the maximum discharge was from an open water release prior to downstream navigation flows being decreased and not representative of the maximum flow experienced at freezeup. Intact ice cover covered the same period, plus February, while the breakup period was assumed to cover late February through early April. Daily Heart River at Mandan and Missouri River at Bismarck flows were added together to determine the flow for the reach downstream of Heart River for each of these three time periods.

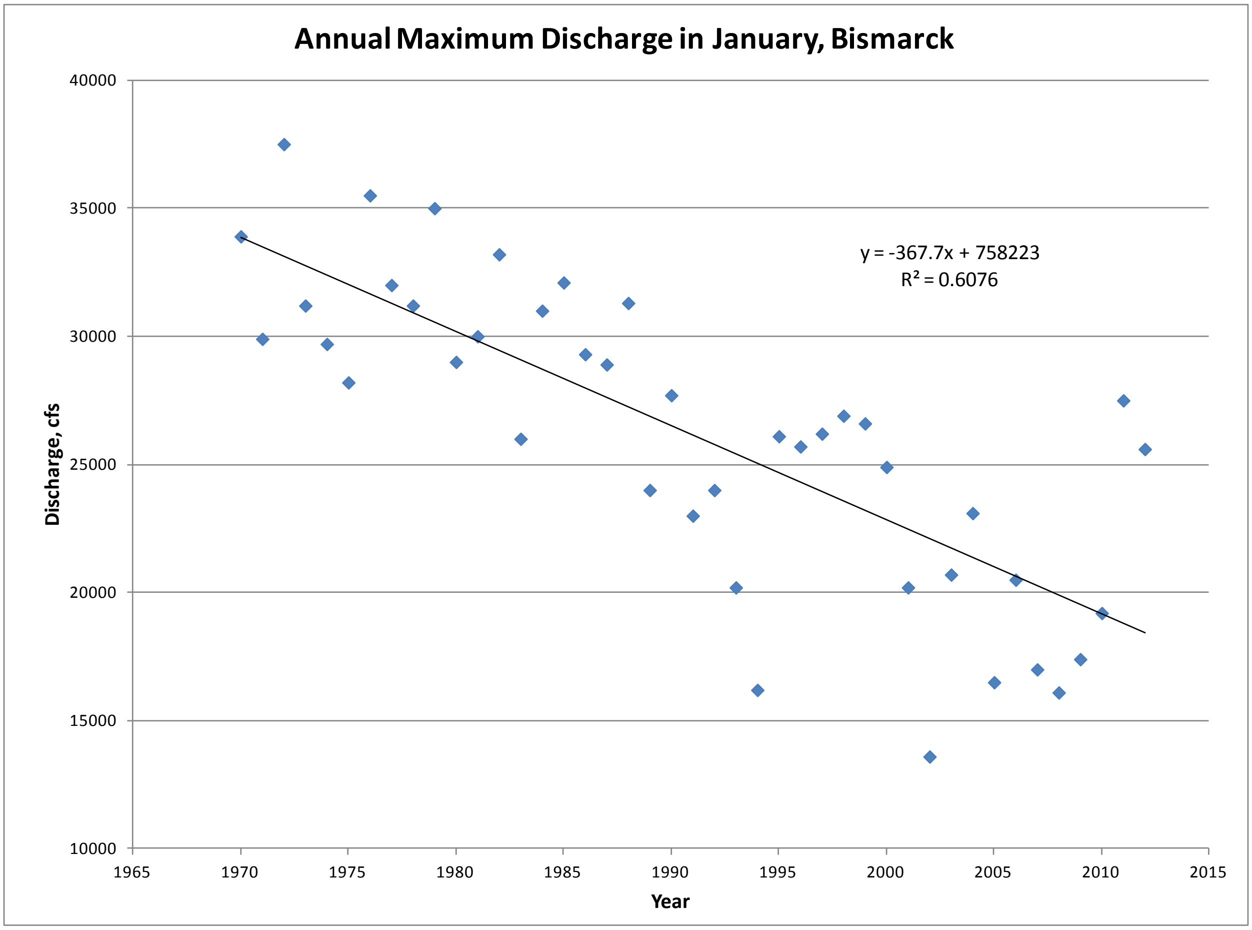

Figure 4. Annual Maximum Discharge Decreases ~400 cfs per Year

The maximum annual discharge for each of the three flow periods was determined for both upstream and downstream of the Heart River. These flows were then adjusted to current conditions by subtracting 400 cfs per year prior to 2012 (e.g., flows for 1982 were decreased by 30 years * 400 cfs, or 12,000 cfs) to reduce non-stationarity in the data. The program HEC-SSP was then used to tabulate the adjusted annual peak flows and perform a flow-frequency analysis utilizing Bulletin 17B methodology. It should be noted that Bulletin 17B methods are not generally recommended for flow-frequency analysis where flows are heavily regulated; since winter releases are much less variable than summer releases at Bismarck, the Bulletin 17B methodology serves as a reasonable proxy for more detailed methods for only the winter flow-frequency. The difference between upstream and downstream of Heart River was then assumed to be the flow in the Heart River for that ice flow regime. The flows used in the HEC-

RAS modeling for each of the three ice flow regimes are shown in the three tables (Table 7, Table 8, and Table 9) below.

Table 7. Flows Used for HEC-RAS Modeling of Freezeup Flows

River	50% ACE (2-yr)	20% ACE (5-yr)	10% ACE (10-yr)	4% ACE (25-yr)	2% ACE (50-yr)	1% ACE (100-yr)	0.5% ACE (200-yr)	0.2% ACE (500-yr)
Missouri River above Heart	18,500	21,700	23,400	24,700	26,100	27,000	27,800	28,800
Heart River	1	200	400	700	1000	1300	1600	1900
Missouri River below Heart	18,501	21,900	23,800	25,400	27,100	28,300	29,400	30,700

Table 8. Flows Used for HEC-RAS Modeling of Intact Ice Sheet

River	50% ACE	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.5% ACE	0.2% ACE
Missouri River above Heart	18,400	22,000	23,900	25,500	27,200	28,300	29,400	30,600
Heart River	300	800	1,400	1,900	2,700	3,400	4,000	4,900
Missouri River below Heart	18,700	22,800	25,300	27,400	29,900	31,700	33,400	35,500

Table 9. Flows Used for HEC-RAS Modeling of Breakup Flows

River	50% ACE	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.5% ACE	0.2% ACE
Missouri River above Heart	21,200	27,100	30,400	33,300	36,700	39,100	41,300	44,000
Heart River	1,900	5,100	8,100	11,400	16,500	20,700	25,400	32,300
Missouri River below Heart	23,100	32,200	38,500	44,700	53,200	59,800	66,700	76,300

It should be acknowledged that the above analysis is not detailed, in that the determination of the discharge just prior to and during freezeup is complicated by a lack of site-specific data as to when ice begins to form and freezeup actually occurred through the study reach, discharge measurements are much less reliable once ice begins to form on the river, formation of an ice cover does not always progress from a downstream to upstream direction as assumed, there are some years where an ice cover formed part way through the study reach and may not have formed through the study reach for a considerable time following initial ice cover formation, and there are some years when an initial ice cover deteriorated and re-formed. It should also be noted that the annual decrease in discharge used in the above analysis is not indicative of operational experience gained in trying to minimize impacts in the Bismarck reach.

3. Results of Analysis

3.1. Existing Conditions

The existing conditions flood profiles were computed by using the HEC-RAS model referenced in Section 2.8 above. The following sections briefly describe results from these analyses.

3.1.1. Open Water

Water surface profiles were computed for the existing conditions with HEC-RAS for the 50% ACE to the 0.2% ACE flows, utilizing discharges in Table 6. The projected water surface elevations near the Schmidt and Bismarck gages are tabulated in Table 10 below, while the computed water surface profiles are shown in Figure 5. Plots of the inundated areas are shown on Plates 3 through 11 for the 50% through 0.2% ACE flood events. Figure 6 shows the location covered by each plate.

Table 10. Existing Condition, Open Water Flood Profiles at Schmidt and Bismarck Gages

Flood Profile	Water Surface Elevation (ft, NAVD88) at River Mile 1298.55	Water Surface Elevation (ft, NAVD88) at River Mile 1314.63
50% ACE	1620.29	1628.33
20% ACE	1621.66	1628.95
10% ACE	1622.73	1630.03
4% ACE	1623.89	1631.65
2% ACE	1625.05	1633.44
1% ACE	1626.15	1635.00
0.5% ACE	1627.12	1636.20
0.2% ACE	1628.85	1638.76

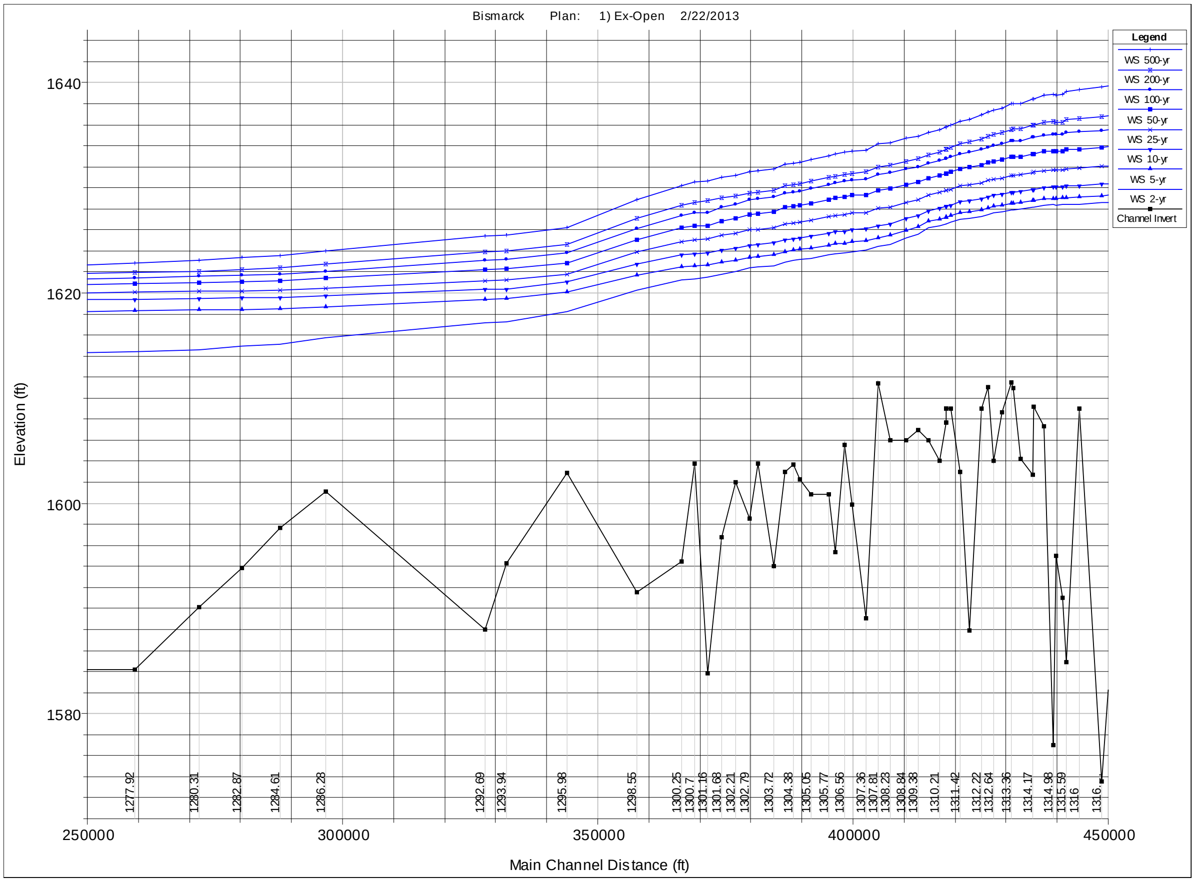

Figure 5. Existing Open Water Flow Profiles, Missouri River

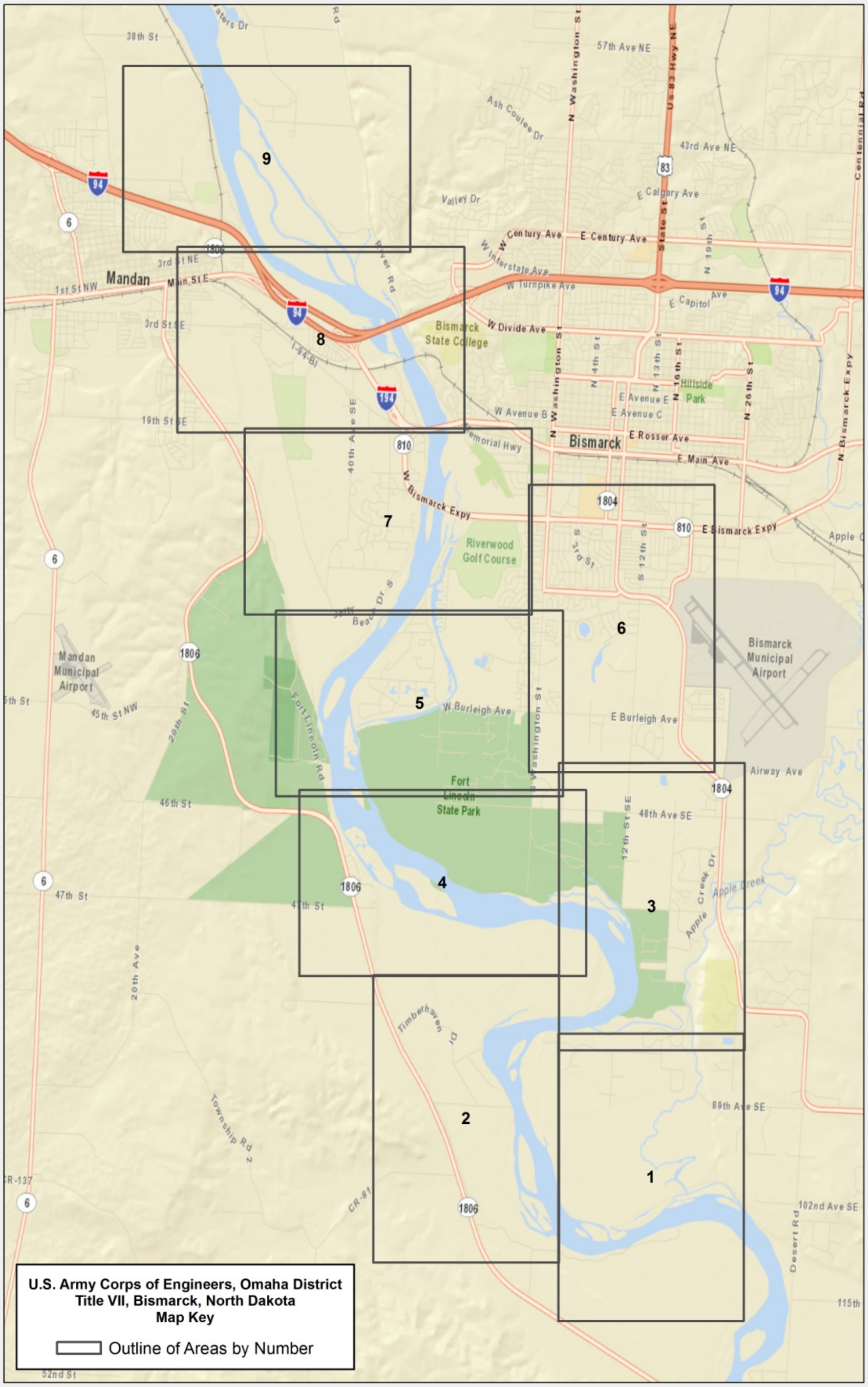

Figure 6. Map Key for Existing Conditions Inundation Maps

3.1.2. Ice-Affected

Water surface profiles were computed for the existing conditions with HEC-RAS for the 50% ACE through 0.2% ACE flows for each of the three ice regimes, utilizing the appropriate discharge from Table 7, Table 8 and Table 9. The projected water surface elevations near the Schmidt and Bismarck gages are tabulated in Table 11 through Table 13 below, while the computed water surface profiles are shown in Figure 7 through Figure 9, and a comparison of open water and ice-affected 1% ACE water surface profiles is shown in Figure 10. Plots of the inundated areas under ice-affected flow conditions are not shown, since the open water inundation maps cover the range in elevations affected by ice-affected flows; additionally, the freezeup and breakup profiles would need to be combined manually at every cross-section to produce an actual ice-affected profile, weighted by the percentage of years each resulted in the higher peak stage, which was beyond the scope of the study.

Table 11. Existing Condition, Ice-Affected Freezeup Flood Profiles at Schmidt and Bismarck Gages

Flood Profile	Water Surface Elevation (ft, NAVD88) at River Mile 1298.55	Water Surface Elevation (ft, NAVD88) at River Mile 1314.63
50% ACE	1621.21	1630.70
20% ACE	1622.43	1631.69
10% ACE	1623.01	1632.22
4% ACE	1623.47	1632.60
2% ACE	1623.90	1632.89
1% ACE	1624.19	1633.10
0.5% ACE	1624.45	1633.30
0.2% ACE	1624.76	1633.57

Table 12. Existing Condition, Ice-Affected Intact Ice Cover Flood Profiles, Schmidt and Bismarck Gages

Flood Profile	Water Surface Elevation (ft, NAVD88) at River Mile 1298.55	Water Surface Elevation (ft, NAVD88) at River Mile 1314.63
50% ACE	1618.13	1627.84
20% ACE	1619.26	1628.95
10% ACE	1619.85	1629.49
4% ACE	1620.30	1629.89
2% ACE	1620.82	1630.33
1% ACE	1621.21	1630.66
0.5% ACE	1621.56	1630.95
0.2% ACE	1621.97	1631.30

Table 13. Existing Condition, Ice-Affected Breakup Flood Profiles at Schmidt and Bismarck Gages

Flood Profile	Water Surface Elevation (ft, NAVD88) at River Mile 1298.55	Water Surface Elevation (ft, NAVD88) at River Mile 1314.63
50% ACE	1623.09	1633.29
20% ACE	1624.71	1634.60
10% ACE	1625.17	1635.46
4% ACE	1625.67	1636.20
2% ACE	1626.36	1636.91
1% ACE	1626.83	1637.40
0.5% ACE	1627.39	1637.93
0.2% ACE	1628.05	1638.65

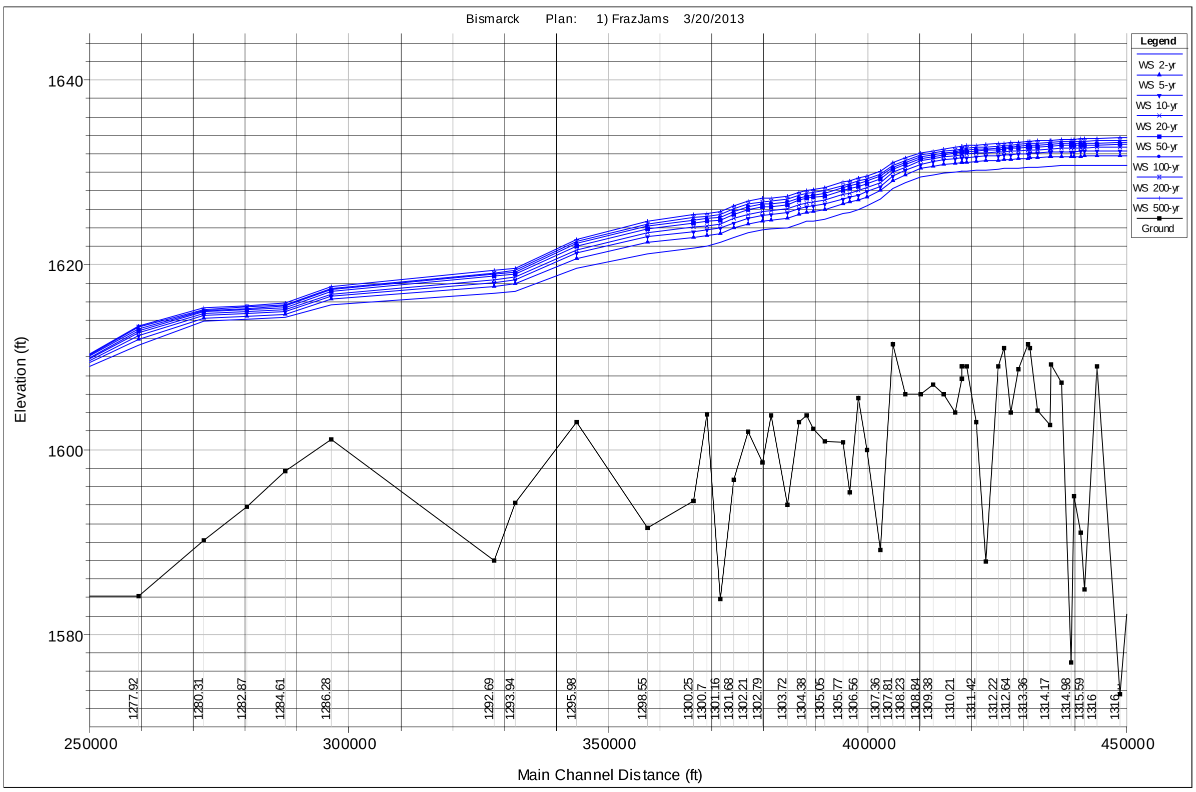

Figure 7. Existing Ice-Affected Freezeup Flow Profiles, Missouri River

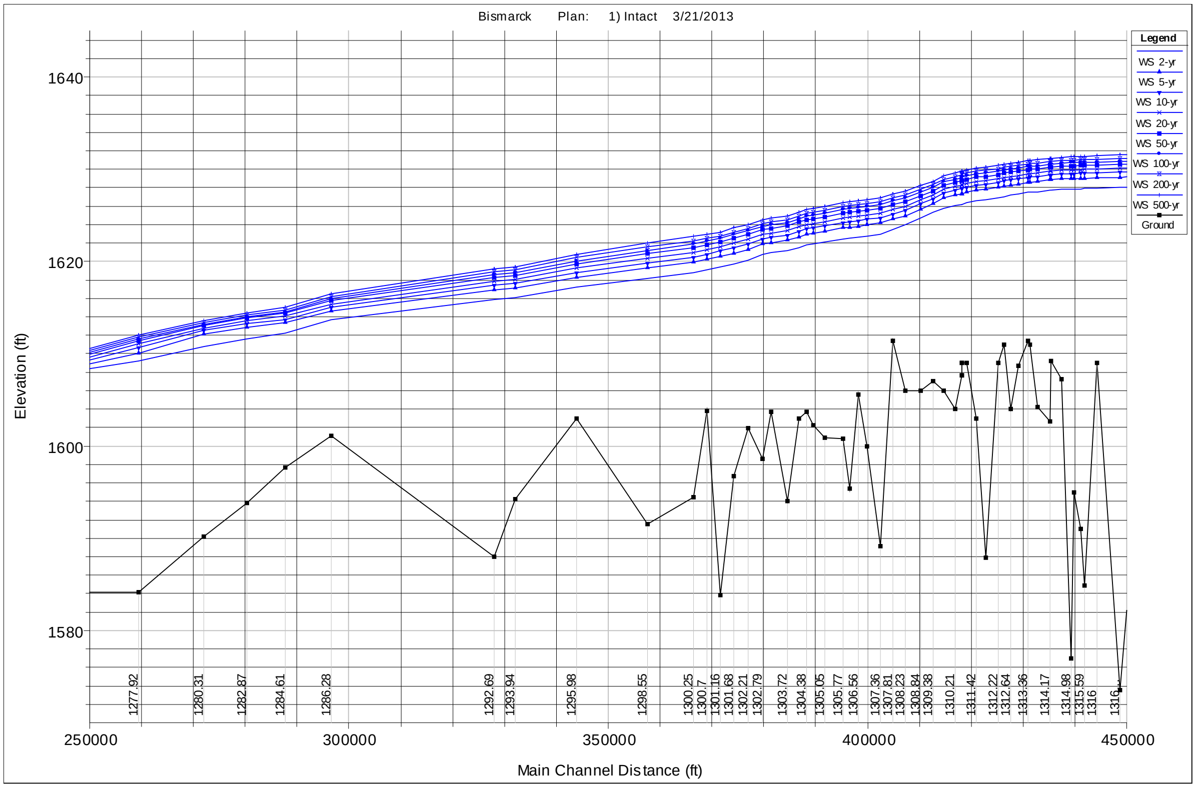

Figure 8. Ice-Affected Intact Ice Cover Profiles, Missouri River

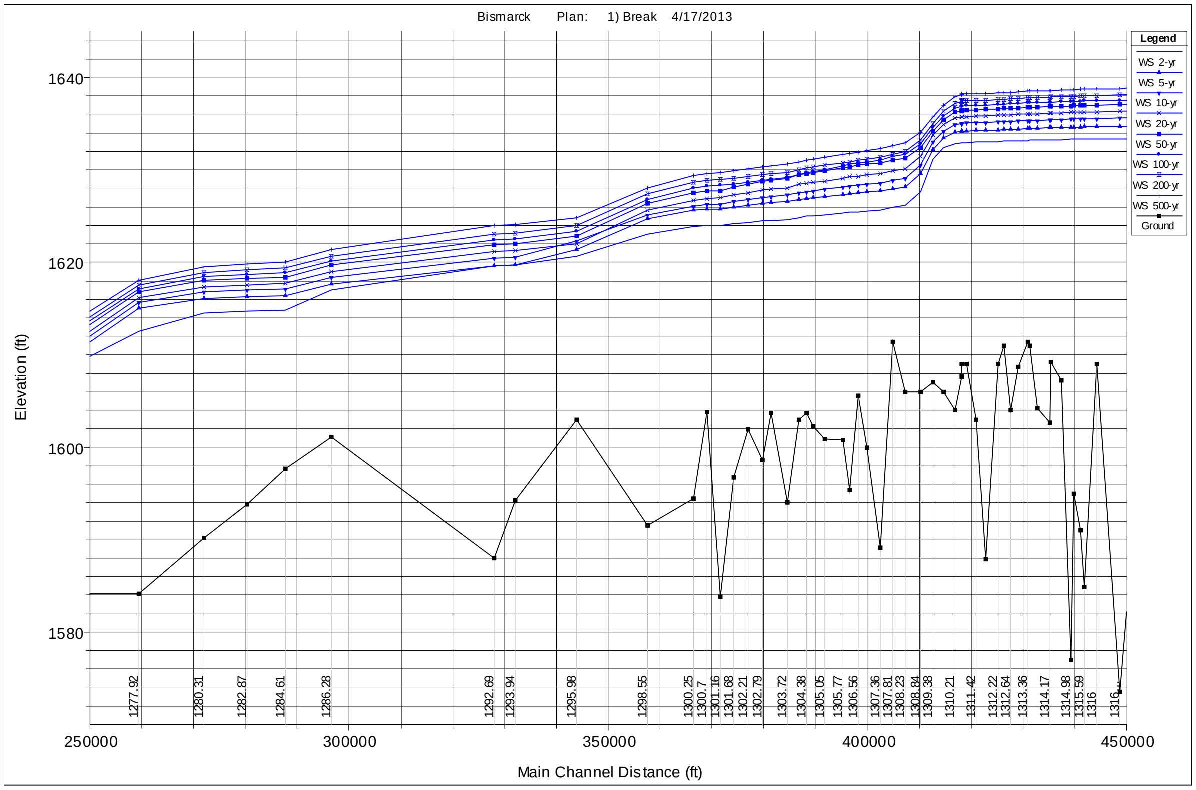

Figure 9. Ice-Affected Breakup Flow Profiles, Missouri River

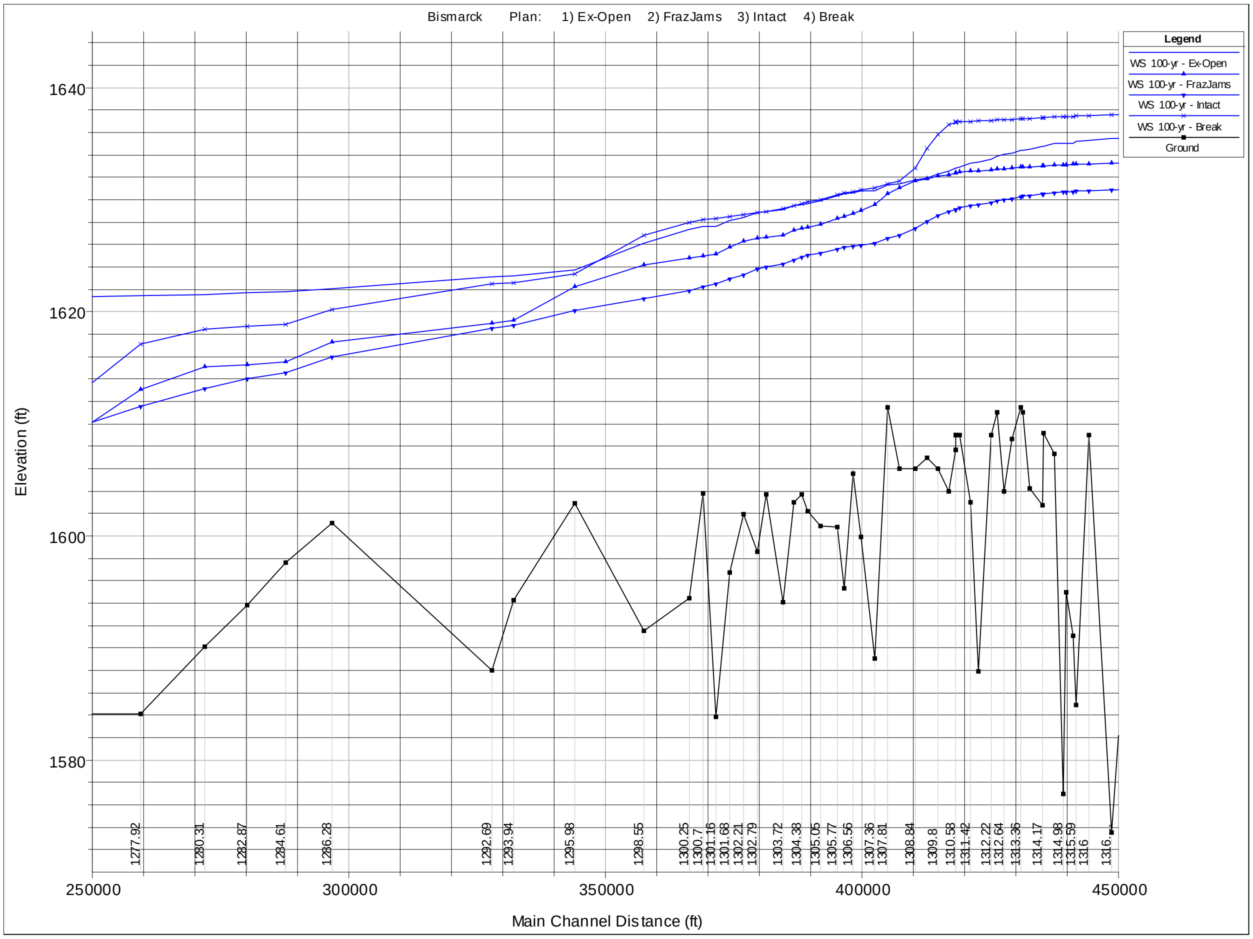

Figure 10. Comparison of 1% ACE water surface profiles for open water and ice-affected profiles

3.2. Existing Condition Stability Evaluation

An investigation was conducted of the existing condition to identify channel stability. The evaluation focused on using available data from historic surveys, gage stage trends, and data analysis to evaluate sediment deposition or erosion trends within the project area.

Within the Bismarck area, the channel is generally confined and has a narrower top width than the channel upstream or downstream. Downstream of the Bismarck area, the Missouri River transitions into the delta region entering the headwaters of Lake Oahe. Within the delta, the river tends to aggrade due to the reduction of the sediment transport capacity in the reservoir compared to the open river. Delta aggradation is a concern for flood stages upstream.

3.2.1. Sediment Range Evaluation

An analysis was performed to evaluate how the cross section changes may have affected Missouri River conveyance and flow levels within the study area. The sediment range data was evaluated to track changes in section conveyance and provide an indication of stability over time. Three primary hydraulic element indicators were evaluated consisting of top width, average bed elevation, and flow area. The changes with time at each section are graphically illustrated in Appendix B.

To simplify understanding of the evaluation, combined data plots were prepared for the study area. All parameter values were computed from the sediment range surveys referenced to the existing condition HEC-RAS computed water surface elevation. Range 1357.8 (RM 1292.7) was not included in the computation because of the lack of data from the 1950's.

3.2.1.1. Top Width Change

Top width refers to the water surface width at a specified flow elevation computed at each sediment range cross section. As used in this analysis, computed top width change is the difference from surveys collected in 1956 which is the earliest available survey and represents the pre-dam construction river geometry. A top width decrease represents deposition and an increase represents bank erosion compared to 1956. Comparison was performed using the computed top width at an elevation selected to approximate the 10% and 1% (10-year and 100-year, respectively) annual chance exceedance event (ACE) determined with the existing condition HEC-RAS model. Top width change is shown in Figure 11 and Figure 12.

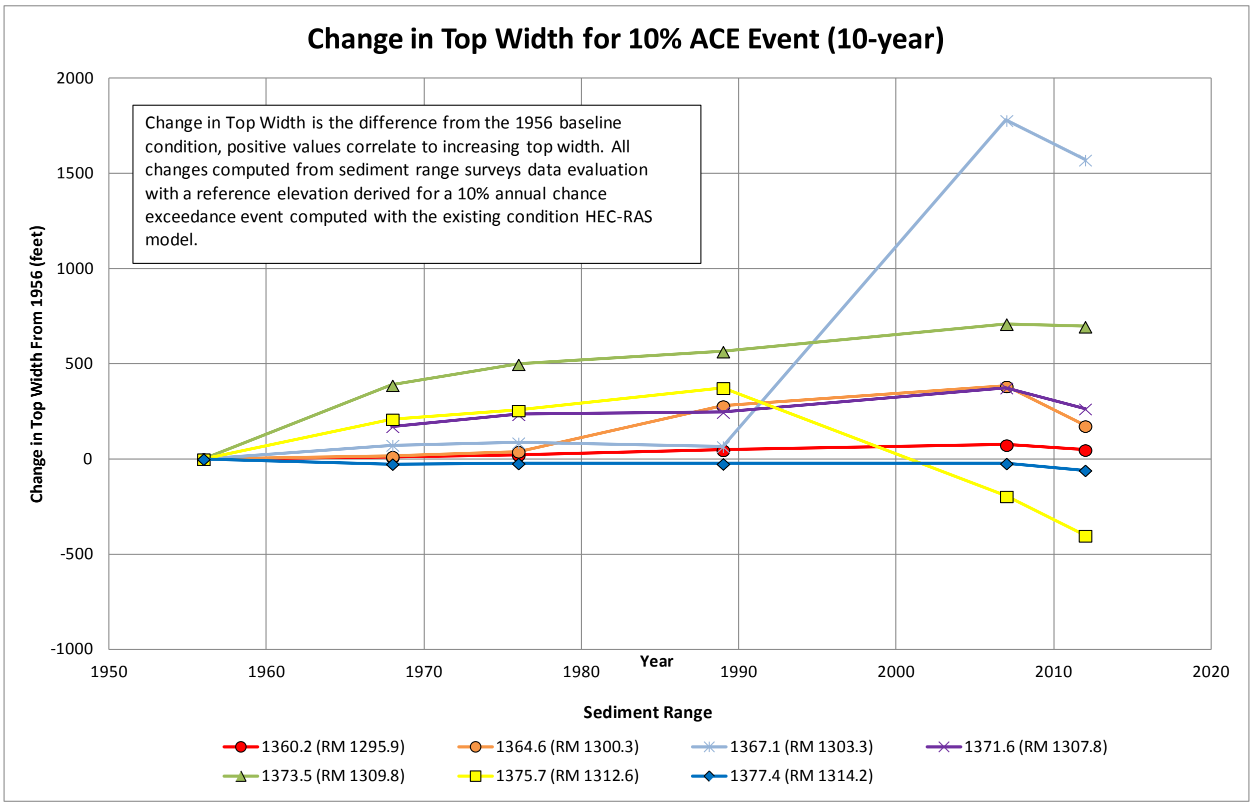

Figure 11. Change in Top Width for 10% ACE Event

The top width has increased along most of the study extents except in the reach from River Mile 1312.6 to 1314.2. The largest top width decrease is about 500 feet at River Mile 1312.6

located midway in the Fox Island region. This reversed a slight increase in top width that occurred through 1990. Top width decrease did not occur at this location until 2007 and persisted in 2012. The reason for the large decrease in top width at this location is not known, but is likely due to bank line accretion associated with the stream bank stabilization works within the area. The large increase in top width at River Mile 1303.3 is shown by examining the sediment range plots in Appendix B. At this location, the bank has retreated substantially while the average bed depth has decreased. The aerial photo indicates the existence of a large sandbar at this location.

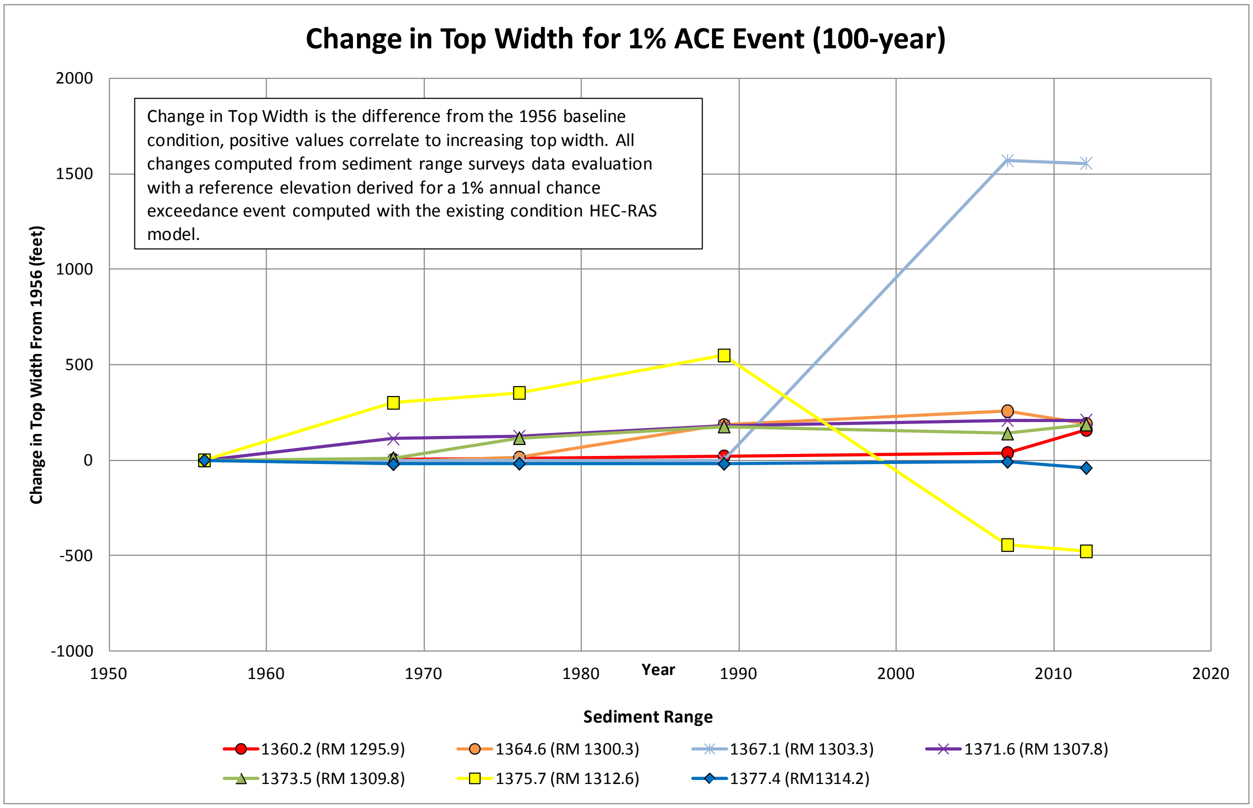

Figure 12. Change in Top Width for 1% ACE Event

The largest top width increase is at River Mile 1303.3 with an increase of over 1500 feet for both the 10% and 1% ACE events. This area is in the middle of a one-mile straight segment of river between large river bends at River Mile 1302 and 1304. Aerial photos of this area illustrate retreating banks with the formation of bank attached bars. The relatively large increase in top width at river mile 1303.3 is due to retreat of the right bank. Other locations showed much smaller changes in the range of 100 to 200 feet.

At the remaining locations, the slightly increasing trend from 1956 to 2012 for the top width change computed for the 10% and 1% ACE events is similar. The 10% ACE top width change is larger than the 1% ACE event by a few hundred feet at many locations. This may indicate a higher rate of bank retreat for the more frequent flow events. In general, the overall increasing top width trend is a possible indicator of channel instability. However, it should be noted that other factors must also be considered when evaluating overall stability.

3.2.1.2. Average Bed Depth

Missouri River thalweg elevation, the minimum channel elevation, is often variable and not indicative of channel change. Average bed depth is computed from the flow area and top width and reflects the average bed elevation within the channel section. Average bed depth is often used as an indicator of channel aggradation or degradation instead of thalweg. Average bed depths were computed using the 10% ACE event profile from the 2012 existing condition HEC-RAS model. Average bed depth change for the 1% event is not as relevant since this would more reflect a combination of several factors rather than actual bed elevation change. The average bed depth change is shown in Figure 13.

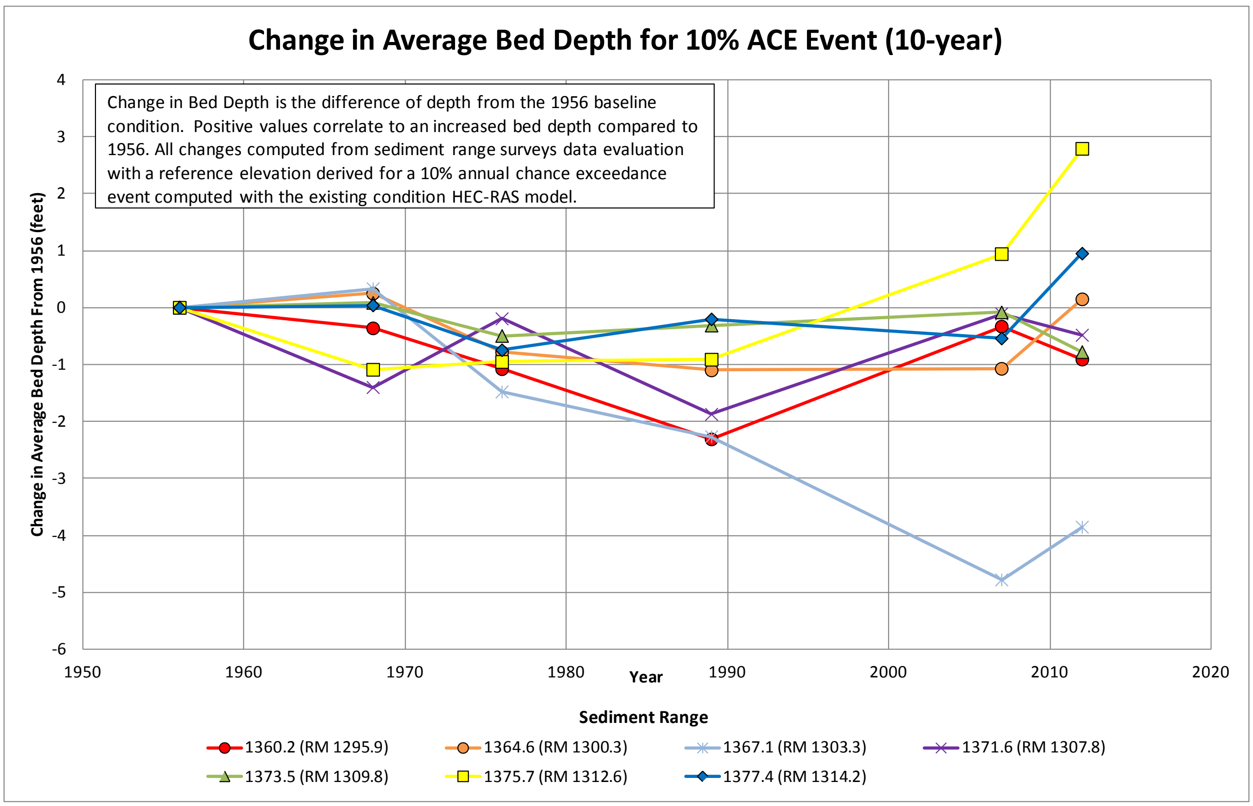

Figure 13. Change in Bed Depth for 10% ACE Event

The 1956-1989 and 1989-2012 differences in bed depth at each elevation interval were averaged to attain average bed change values for the two time intervals. Most sections showed a decrease in average bed depth or aggradation in the period from 1956 to 1989 followed by a degradation trend in the 1989 to 2012 period. The largest change occurred at river mile 1303.3 with an average bed depth decrease of 4 feet. This also correlates to increased top width and bank erosion. Examining the section plot in Appendix B, it appears that the average bed depth was actually high for the lower elevations at this location and then decreased in the upper elevations when the sandbar area is overtopped. The largest increase in average bed depth occurred at river mile 1312.6 with an increase of 1 foot in 2007 and 3 feet in 2012. At this location, the top width decreased which would confine flow with a correspond reduction in flow area. Higher velocities would generally be expected to result in degradation. However, while degradation occurs at lower elevations, that is not the case at the 10-year ACE. These two large change locations illustrate how average bed elevations are often due to local affects. All other locations were within 1 foot of the 1956 value in both 2007 and 2012. With the exception of the two noted locations, the relatively small change in average bed depth is indicative of relative normal channel stability.

3.2.1.3. Flow Area

Flow area refers to the cross sectional area at a specified flow elevation. Since all surveys are referenced to the existing condition water surface elevation, a flow area decrease represents deposition and a flow area increase represents erosion compared to the 1956 flow area. Comparison was performed using the computed flow area at an elevation selected to approximate the 10% and 1% annual chance exceedance event (10-year and 100-year, respectively) determined with the existing condition HEC-RAS model. Flow area change is shown in Figure 14 and Figure 15.

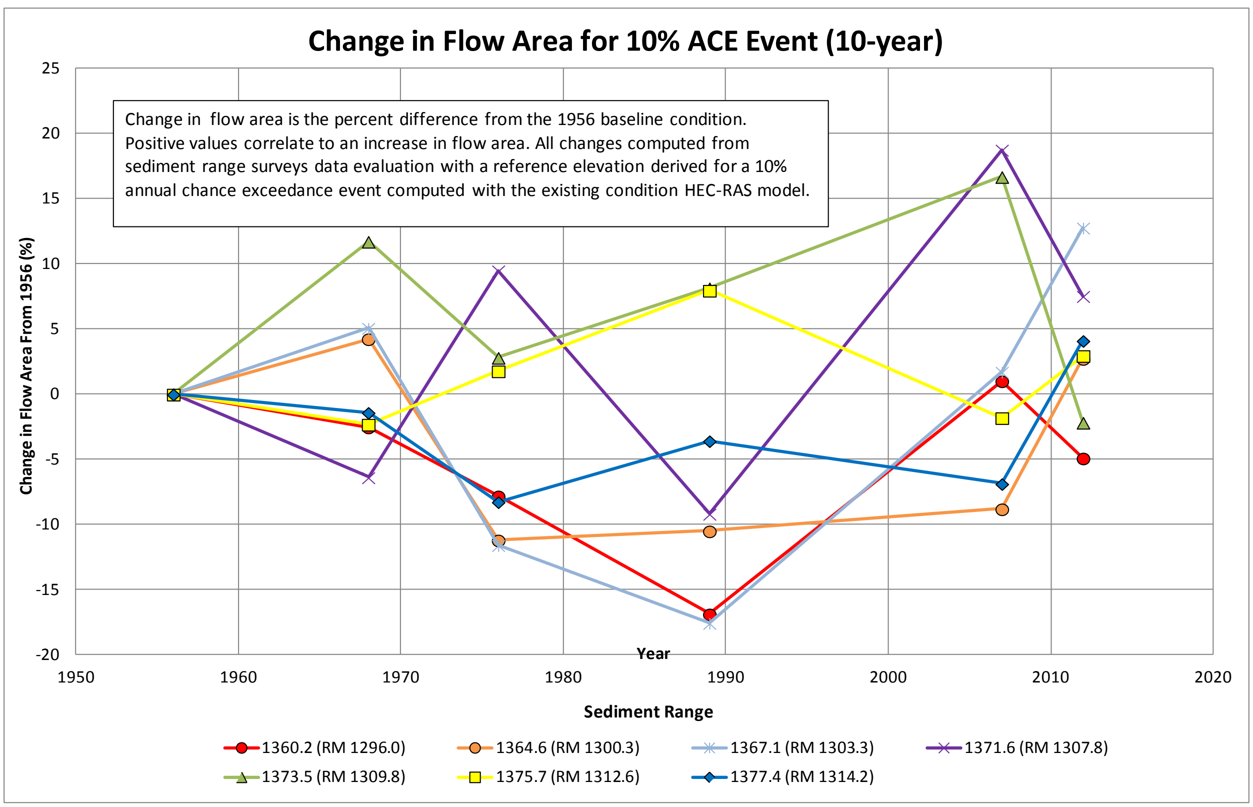

Figure 14. Change in Flow Area for 10% ACE Event

The flow area change figures are inconclusive and do not provide a significant trend. A spatial distribution change from downstream to upstream is not apparent. The largest visible change is the flow area increase at river mile 1303.3 in both the 2007 and 2012 surveys. This location also had a large top width increase although the average bed depth had a large decrease. The 10% ACE flow area change is positive in 2007 and 2012 at most locations. Increased flow area is a noticeable trend from 1989 to current at most areas. Overall, the total flow area change at the 1% ACE change is minor with a slight upward trend that is most noticeable in both 2007 and 2012.

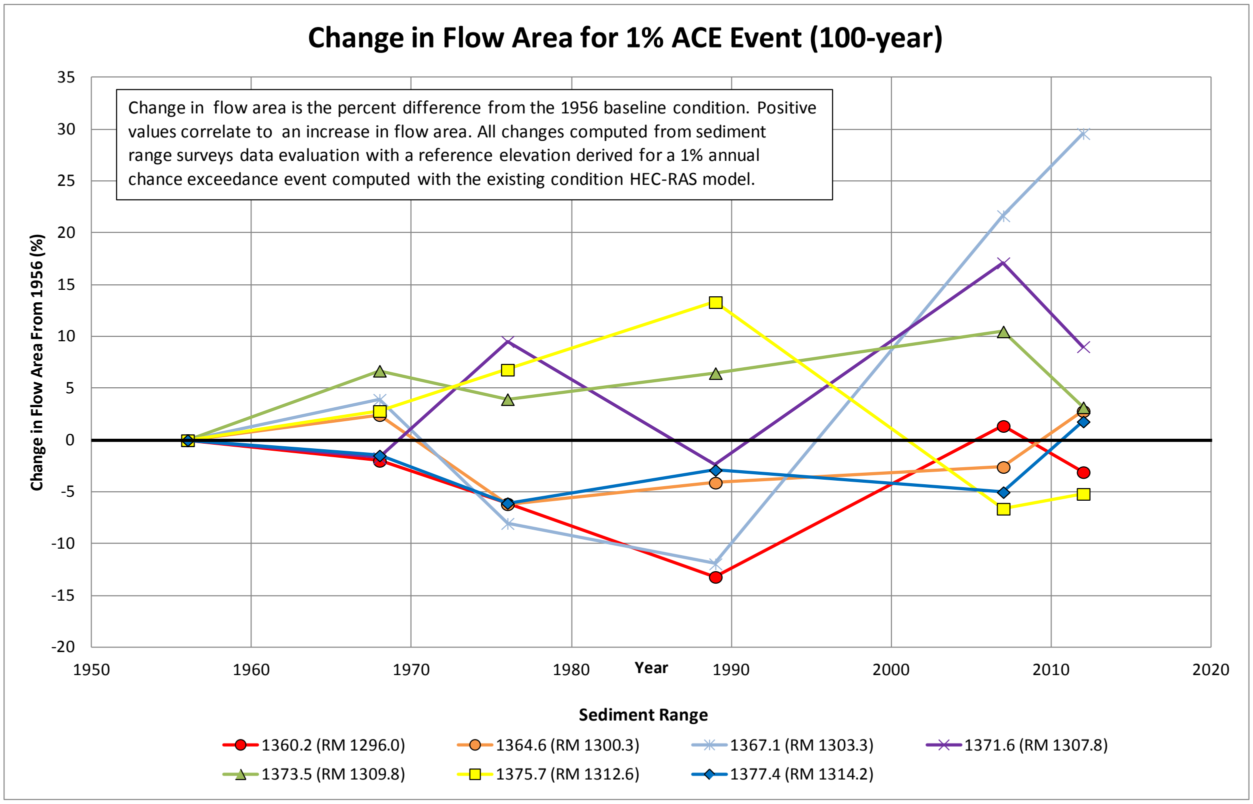

Figure 15. Change in Flow Area for 1% ACE Event

3.2.1.4. Average Change Values

Individual sediment range changes are informative and indicate rate of change spatially and allows for comparison to adjacent locations. Average change values were also computed for the entire area to indicate overall trends with results shown in Table 14. Results show an increasing top width, decreasing average bed depth, and a recent increase in flow area. These variables are all correlated and indicate that channel conditions are changing. However, a conclusive relationship suitable for predicting future trends cannot be determined from the results. Considering all these factors together, a reasonable interpretation is that the reach experiences a slight aggradational trend for normal to minor flood events that is altered by high flow events.

Table 14. Summary of Average Change With Time for All Sediment Ranges

	Average Change From 1956*				
Year	**1968**	**1976**	**1989**	**2007**	**2012**
Top Width - 10% ACE (feet)	119.6	158.6	221.6	443.0	327.5
Top Width - 1% ACE (feet)	57.3	85.8	155.9	251.7	255.0
Average Bed Depth - 10% ACE (feet)	-0.3	-0.8	-1.3	-0.9	-0.3
Flow Area - 10% ACE (%)	1.2	-3.5	-5.9	3.0	3.3
Flow Area - 1% ACE (%)	1.5	-0.9	-2.1	5.2	5.4

* Computed as the average at all seven sediment range cross sections using the listed ACE event water surface elevation as a reference plane.

3.2.2. Sediment Range Volume Change

Storage volume change within the study area, or the change in the total water volume beneath a reference water surface, was also evaluated. Computed storage volume change combines together all channel changes including the average bed depth, top width, and flow area to indicate an overall trend. For example, a decrease in storage volume for the study area would indicate overall deposition within the study area as the net result of all observed channel changes. However, storage volume computations are for a level water surface elevation for all segments. This computation ignores river slope. Instead, the storage volume represents the condition of an Oahe pool at the reference elevation with no flow input from the Missouri River or any tributaries.

When the sediment ranges were installed, the pre-dam era contours were used to develop an estimated elevation – volume relationship by segment for the entire Oahe pool. The storage volume computation using the sediment range data is performed on a broad scale over the extensive pool length. Computational output within the Oahe reservoir storage zone is available on a segment basis that allows tracking the storage volume change over time within the south Bismarck study area. The sediment range cross sections used to calculate the Lake Oahe storage volume span the entire Missouri River valley and are much larger than the sediment range section top width used for this study. In addition, the sediment volume is only available by segment which includes multiple sediment ranges. Sediment range volume is also computed at a constant elevation to reflect Oahe storage volume instead of a sloping water surface plane.

Storage volume was available for three segments in the area from river mile 1292.7 to 1314.2 from the Lake Oahe computational output data for the 1956, 1989, and 2012 sediment range data. The volume rate of change was previously determined for two pool elevations, 1620 and 1630, for the available time periods. For comparison, the 10% ACE event water surface varies from about elevation 1620 to 1630 through the storage volume computation area while the 1% ACE event elevation varies from about 1625 to 1635. As previously stated, the storage volume computation does not include the river water surface slope which complicates results comparison.

A summary of segment storage volume change is provided in Table 15.

Table 15. Sediment Range Segment Volume Change

Time Period / Elevation	Segment Volume Change by Period and Elevation (acre feet)				
	1292.7-1300.4	1300.4-1309.8	1309.8-1314.3	Segment Avg.	# Years
1989 - 1956, Elev 1620	-4,500	-1,837	-164	-2,167	33
2012 - 1989, Elev 1620	2,775	516	117	1,136	23
2012 - 1956, Elev 1620	-1,725	-1,321	-47	-1,031	56
1989 - 1956, Elev 1630	373	1,781	1,210	1,121	33
2012 - 1989, Elev 1630	922	1,154	245	774	23
2012 - 1956, Elev 1630	1,294	2,936	1,455	1,895	56

1 Segment 1292.7 - 1300.4 used 1964 survey data since 1956 data was not available
2 Change computed as difference from new period to old (positive represents increase in storage)

The segment volume change data was evaluated to review for patterns spatially for the different time periods. Results of the evaluation are graphically illustrated in Figure 16 and Figure 17.

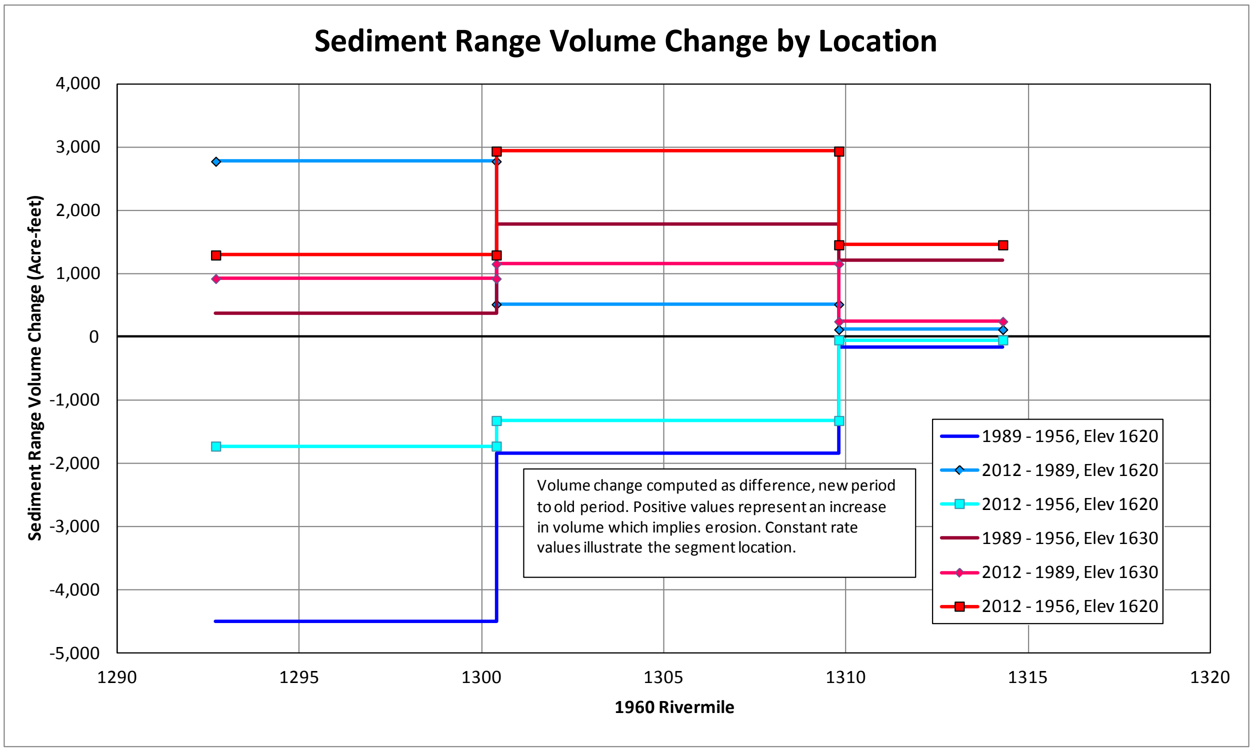

Figure 16. Sediment Range Volume Change by Location

Figure 16 illustrates a significant difference between the 1620 and 1630 elevation pool data and also between time periods. The smallest volume changes occur in the upstream segment with very little change at elevation 1620. The volume change is quite variable for the downstream lower two segments at elevation 1620. At elevation 1630, while the value varies, the volume change is positive for all periods, indicating a continued increase or erosion. This would indicate a continued increase in volume over time, indicating erosion, at the 1630 elevation level pool.

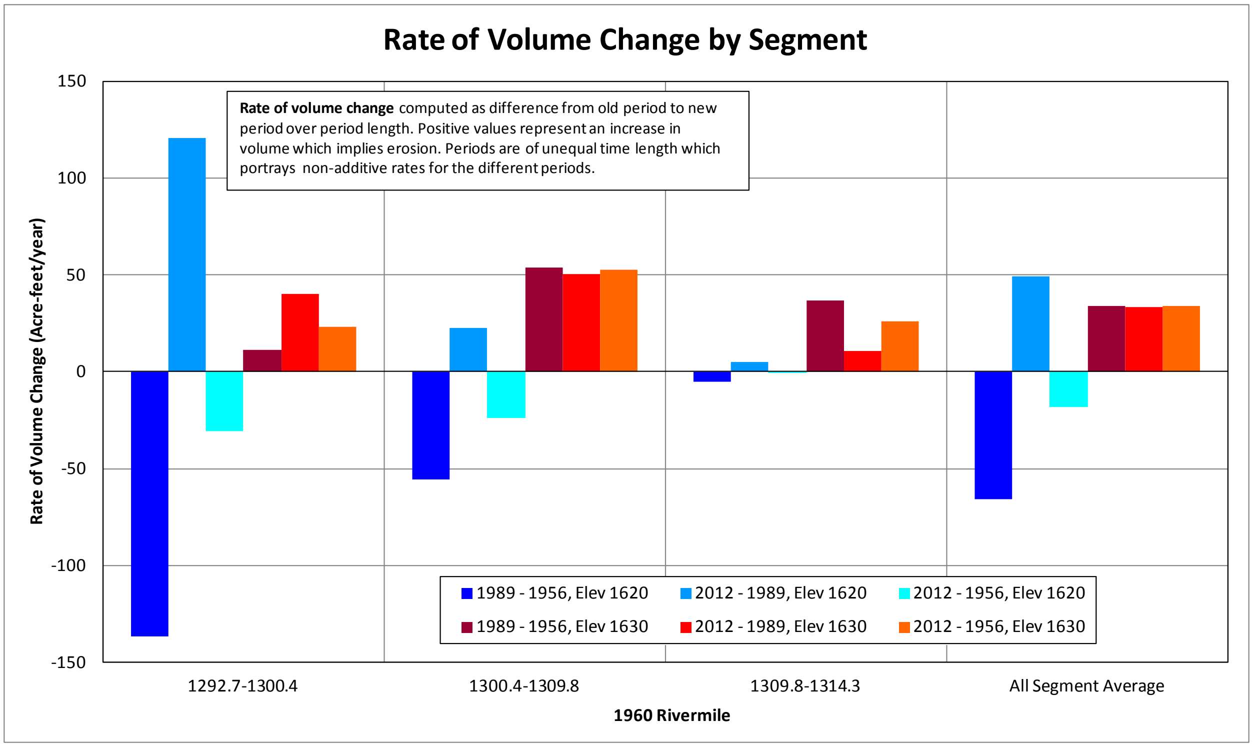

Figure 17. Rate of Volume Change by Segment

Figure 17 provides the rate of volume change by segment and for different time periods. The rate is computed using the volume change shown in Table 15 and Figure 16 over the number of years between surveys. The computed rate reflects the variable time between surveys and provides trend information for each segment.

The sediment rate volume change evaluation shows a variation between the 1620 and 1630 computation planes. The positive rate of volume change at elevation 1630 indicates a fairly constant erosion rate. This correlates with the 1% ACE top width and flow area trends shown in Figure 12 and Figure 15. At elevation 1620, results show decreasing volume (deposition) for the change from 1956 to 1989 followed by an increasing volume from 1989 to 2012. While the 1989 to 2012 volume change rate is consistent with the 1630 rate, the 1956 to 1989 deposition process with a decreasing volume change rate does not correlate with either the 1630 rate or the top width and flow area changes previously shown.

For an assessment of sediment volume magnitude, the average bed elevation change over the entire study area is about 0.26 feet for each 1000 acre feet change of storage volume. Therefore, the -1031 acre feet of volume lost at the 1620 elevation analysis for the 2012 – 1956 time period would equate to an average channel elevation rise through the study area of about 0.26 feet.

The sediment range hydraulic element changes previously presented were generally consistent with the computed sediment rate volume changes. Direct comparison of results is difficult due to differences in methodology. However, results appear to be supportive.

3.2.3. Sandbar Processes and Sediment Management

The presence of sandbars in a channel may have an effect on channel capacity through processes such as a reduction in flow area, ice jam formation, and woody debris accumulation. Within the study area, active sandbar processes and formation may reduce the effectiveness of any sediment management alternative intended to add channel capacity and mitigate flood risk.

Previous studies have conducted evaluations regarding channel conditions associated with the presence of sandbars and the sandbar material size. Local channel geometry and, in particular, channel width, is one of the dominant factors that affects bar and island morphology.

Biedenharn et al. (December 2001) analyzed the relationship between channel width and the presence of islands and sandbars for two different periods, the mid-1980s and the late 1990s. Performed for various reaches between Fort Peck Dam and Ponca State Park, NE, the study included the reach from Garrison Dam to the Bismarck vicinity. Through the use of aerial photography, the channel width was measured every 0.5 mile along each study reach. In addition, the aerial photographs were examined for the presence of islands and sandbars at each 0.5-mile increment. Islands were considered to be features having considerable vegetative cover, while sandbars were any feature devoid of visible vegetation. Each increment was classified as one of the following: 1) no sandbars or islands were present; 2) the presence of sandbars was visible; or 3) the presence of islands was visible. Cumulative distribution curves were generated based on the classification versus the channel width.

The results of a previous geomorphic evaluation (Biedenharn et al 2001) revealed that there is a strong relationship between channel width and the presence or absence of bars and islands. Using the absence of bars relationship, the upper bound channel width value for the Garrison reach at which 90% of the selected sites did not contain bars was 630 meters. Using the presence of bars relationship, the lower bound channel width value for which only 10% of the sites contained a bar was 370 meters (Biedenharn et al. 2001, Figure 5.11). Therefore, the 370 meters and 630 meters provide a channel width bounding range indicative of sandbar presence/absence. These values were used to examine the channel within the study reach for bar presence. Using a range of channel width values was determined to be necessary based on the wide range shown in the previous geomorphic study results.

For the purposes of this study, the channel width – sandbar relationship was used as an indicator for alternative design and stability evaluation. The upper and lower bound channel widths of 370 and 630 meters provide a reasonable design range for alternative analysis. For instance, if the stabilization measures physically reduce the channel width such as with transverse dike structures, then an impact to sandbars may occur. Another situation that could be significant with respect to the future formation of sandbars would be if both banks of the river were stabilized or if the bank opposite the proposed stabilization measures was composed of a naturally erosion resistant material and channel width was locked. The data provides only a guide for estimating the presence of bars based on channel width.

While many factors must be considered when evaluating sandbar processes, the sandbars shown in aerial photos within the study area showed good correlation with the selected upper and lower bound channel widths. Although the selected values should not be regarded as absolute, the current location of sandbars supports the derived bounding values. A conceptual view of the upper and lower bound channel width as an indicator for the presence of sandbars, 630 meters and 370 meters respectively, is shown in Plate 2. Sediment management alternatives should consider the impacts of project features on the presence / absence of sandbars in both the current and future condition, and implications regarding the longevity of benefits.

3.2.4. Specific Gage Analysis

A tool that has often been used to study river stability is a specific gage analysis. The analysis generates a plot of stage over time for constant discharge using gaging station data. A channel is considered to be in equilibrium if the specific gage record shows no consistent increasing or decreasing trend over time. An increasing or decreasing trend is indicative of aggradation or degradation, respectively. A specific gage analysis requires a sufficient record length to develop a meaningful relationship.

The specific gage analysis performed for the Bismarck USGS gage is shown in Figure 18.

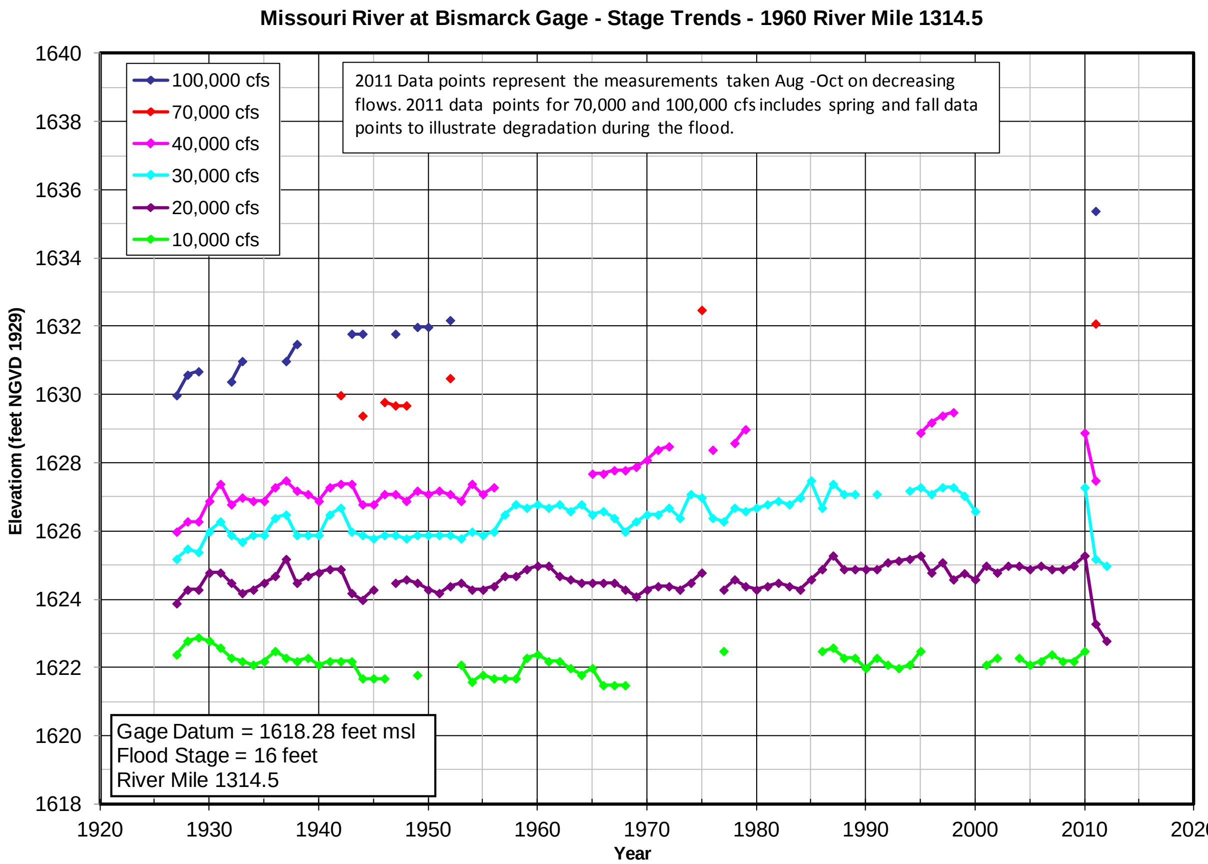

Figure 18. Missouri River at Bismarck Specific Gage Analysis

Examination of the Bismarck specific gage record shows that stages for flows in the 20,000 to the 30,000 cfs range, which corresponds to normal Garrison releases, were fairly constant from the period of 1930 to 1985. A slight upward trend with a small rise of 0.5 feet or more occurred from 1985 to 2010. At 40,000 cfs, a greater rise is shown with an increase of over 2 feet from the 1950's to 2000. The extreme event increase is even larger with an increase of about 2 feet at 70,000 cfs and over 3 feet at 100,000 cfs from 1950 to 2011 cfs.

The 2011 extreme event resulted in degradation of nearly 2 feet at 30,000 cfs and about 1 foot at 40,000 cfs with flow levels now lower than any other time in the post Oahe / Garrison Dam construction era at this flow range. No recovery in gage elevation was observed in the 2012 gage data.

Comparing specific gage results to the reach average changes for average bed depth, top width, and area is misleading since the largest impact to the gage elevations occurs within the first few miles downstream of the gage. Sediment range data from river mile 1312.6 and 1314.2 would be most representative of conditions in this reach. At these locations, average bed depth is stable or rising, top width is stable or decreasing, and flow area is inconsistent since 1989. While generally supportive and definitely not contradictory, the results indicate that these two locations may not be wholly representative of changes occuring in the downstream gage reach.

The Schmidt gage located at River Mile 1298 is not a discharge rated gage and records stage only. For the purposes of this analysis, flow at the site was estimated as the combination of Missouri River flow at Bismarck and the gage data flow from the Heart River. Examination of the data illustrates that the Oahe pool can have a large impact on flow elevations as illustrated in Figure 19.

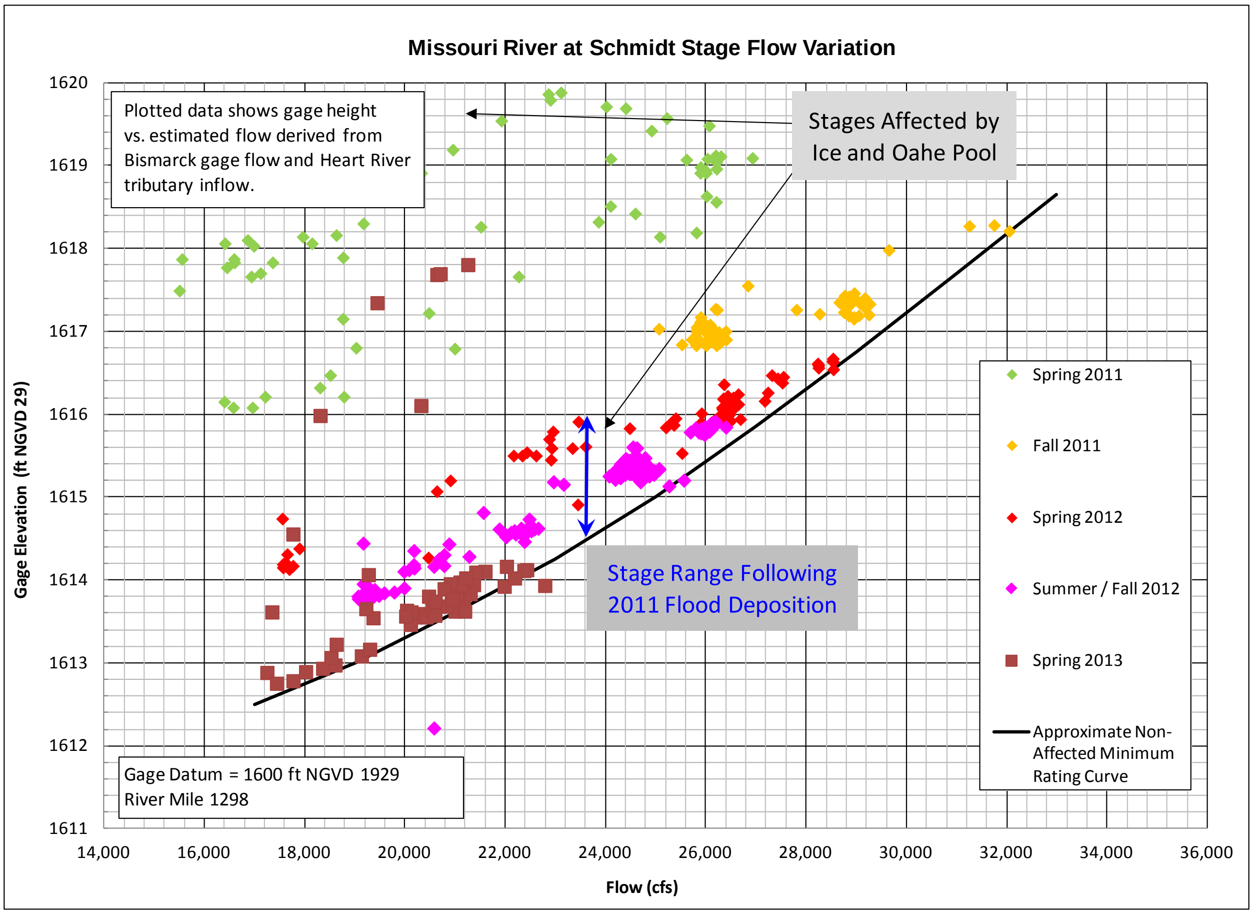

Figure 19. Missouri River at Schmidt Stage Flow Variation

Figure 19 illustrates the significant impact that Oahe pool levels have on river flow levels at the Schmidt location. Bismarck gage data, located about 16 river miles upstream, does not illustrate this impact. High Oahe pool levels raise stage and consequently reduce flow velocities. Data from the estimated flow and the recorded stage information from the gage at Schmidt were also used to perform a specific gage analysis that is shown in Figure 20.

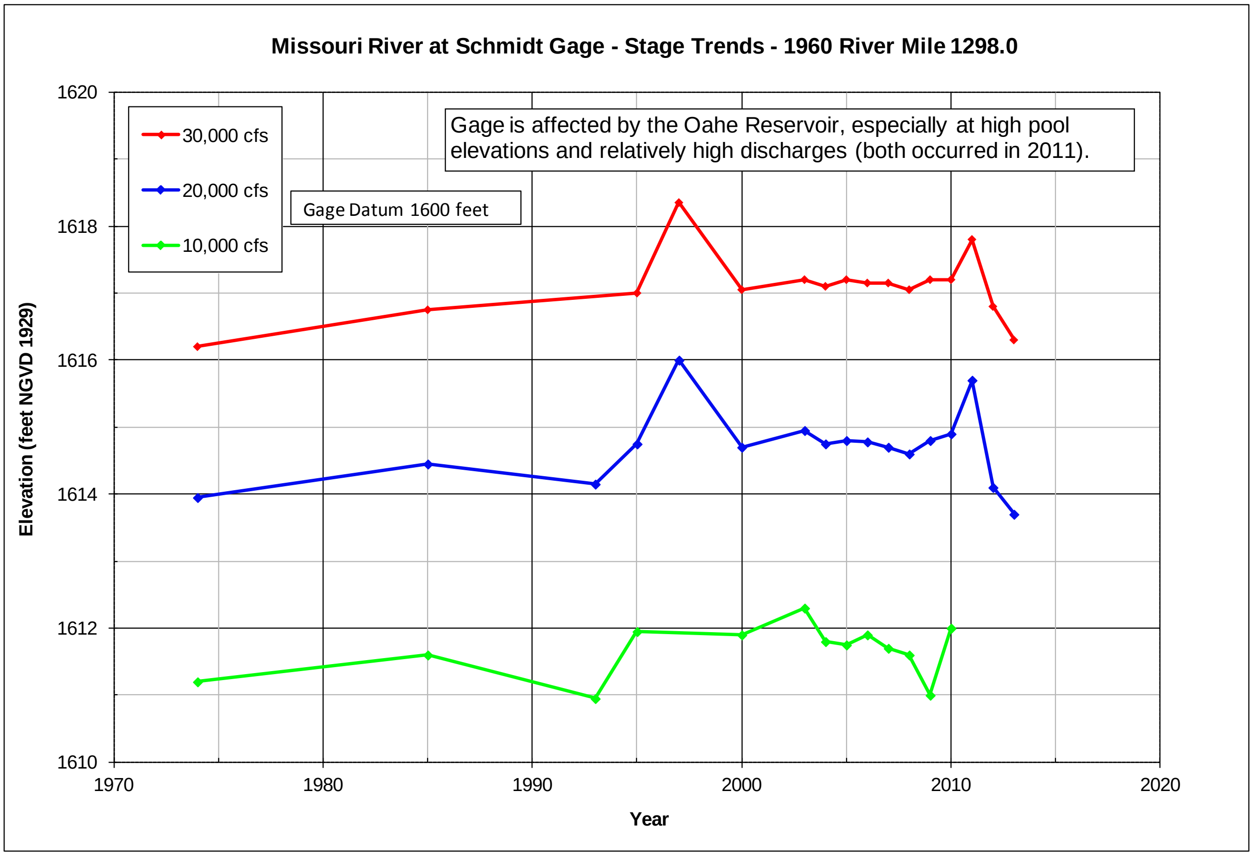

Figure 20. Missouri River at Schmidt Specific Gage Analysis

Examination of the Schmidt specific gage record shows that stages for flows in the 20,000 to 30,000 cfs range of normal Garrison dam releases have a slight upward trend from 1974 to current. Both the 1997 and 2011 extreme events resulted in significant aggradation of nearly 1 foot at 20,000 cfs. This is similar to the large aggradation that occurred in 1997. Both aggradation events are correlated with high Oahe pool elevations. The 1997 event was followed by a lowering of stages. Since 1974, the total stage rise is just about 1.3 feet at a 30,000 cfs flow if the 2011 extreme event is included. This was followed by a large degradation in 2012 and 2013 that returned stages to about 1974 levels at 20,000 and 30,000 cfs flows. A similar cycle of stage deposition followed by degradation also occurred in the 1997 event that had a high Oahe pool. The gage stage recovery is a factor of both the Oahe pool and the Missouri River incoming sediment load.

The cycle of high pool events with flood deposition followed by degradation may not occur in the future as Oahe pool deposition continues. In the future, as the Missouri River sediment deposition delta continues to advance into the Oahe pool, some continued rise within the upstream delta zone is likely. This process has been observed to occur within reservoirs. Detailed hydraulic modeling with sediment would be required to evaluate future conditions.

3.2.5. Existing Condition Stability Evaluation Summary

Several different methodologies were evaluated for indications of existing condition stability. These included evaluation of changes in sediment range cross section hydraulic elements from 1956 to 2012, changes in sediment range volume from 1956 to 2012, the prediction for the presence of sandbars correlated with channel width, and specific gage analysis at Bismarck and Schmidt. Results indicate that areas of significant change are occurring within the study area. However, a strong correlation between the methods indicating definite trends was not observed. The specific gage analysis at Bismarck and Schmidt is particularly critical and does not demonstrate a consistent gage trend.

It should be stressed that the stability evaluation is not meant to be a predictor of the future condition. In fact, the high degree of influence of the Oahe pool on Schmidt gage levels, 2011 flow observations at Schmidt, and the known continued growth of the Oahe delta strongly support the conclusion that flow stages in the study area will rise in the future. However, stability results for the existing condition do not illustrate that this trend has initiated at this time.

Significant observations from the stability analysis are as follows:

- Sediment range analysis was performed to evaluate changes in top width, flow area, average bed depth, and storage volume with time. Results show increasing top width, decreasing average bed depth, and a recent increase in flow area. These variables are all correlated and indicate that channel conditions are changing. However, a conclusive relationship suitable for predicting future trends cannot be determined from the results.
- Sediment rate volume change evaluation shows a variation from deposition at the 1620 and 1630 computation planes. The positive rate of volume change at elevation 1630 indicates a fairly constant erosion rate. At elevation 1620, the 1989 to 2012 rate is consistent with computed erosion while the 1956 to 1989 rate is reversed and does not correlate with the 1630 rate. Overall, results are generally consistent with the results from the top width and flow area change evaluation. Direct comparison of results is difficult due to differences in methodology.
- Previous studies had identified channel width as a reliable indicator for the presence of sandbars. While many factors must be considered when evaluating sandbar processes, channel width was further evaluated within the study area to compare with the estimated upper and lower bound widths. The evaluation showed good correlation with the upper and lower bound channel width and the presence of sandbars in those areas currently shown in aerial photos.
- The specific gage analysis at Bismarck and Schmidt gage station locations indicate that impacts from the 2011 flood were significant. The Schmidt gage record shows the impact of high Oahe pools with raised water levels and deposition during the 2011 event.

3.3. Future Conditions

3.3.1. Sediment Management Alternatives

Alternatives consisted of three ranges of channel excavation and a combination alternative of channel excavation and stabilization. Computation results were reviewed with respect to project objectives for flood risk reduction and sustainable sediment management. The existing condition HEC-RAS model available from the hydraulic modeling tasks was used to evaluate the sediment management alternatives. It should be noted that all HEC-RAS modeling was performed with fixed channel geometry. No predictive sediment movement modeling was performed. Modeling did not develop predicted geometry or an evaluation of long term performance.

Alternative evaluation was performed for a range of steady flows and Oahe pool levels for both duration and annual exceedance. Flow and pool levels were obtained from updated flow statistics (USACE, 2012). Duration statistics are determined from an analysis of all the daily values for the period of record and are typically expressed as percent of time equaled or exceeded. For example, the 10-percent duration flow of 37,000 cfs represents a high flow that has been exceeded only 10-percent of all days of the flow record. Conversely, the 90-percent duration flow of 14,100 cfs characterizes a low-flow because 90 percent of all daily mean flows in the record are greater than that amount.

The annual chance exceedance (ACE) flows are derived from a statistical analysis of the annual maximum flows and express the percent chance of an event being equaled or exceeded in any year. For example, the 10% ACE event of 48,000 cfs refers to the chance in any given year that a flow of 48,000 cfs will be equaled or exceeded.

A duration curve is not a probability curve. It should not be interpreted on an annual event basis because it provides only the fraction of time that a given event was exceeded and not the annual probability of an event occurring. Therefore, the 10% ACE event is not the same as the 10% duration event. Events modeled with alternatives are shown in Table 16.

Table 16. Flow and Oahe Pool Events Modeled with Alternatives

Duration Event Flows (cfs) and Oahe Pool Elevations (NGVD 29) Modeled								
10% Flow/Pool	10%Flow 50% Pool	10% Flow 90% Pool	50% Flow 10%Pool	**50% Flow/Pool**	50% Flow 90% Pool	90% Flow 10% Pool	90% Flow 50% Pool	**90% Flow/Pool**
37,000	37,000	37,000	20,200	**20,200**	20,200	14,100	14,100	**14,100**
1616.9	1608.5	1585.2	1616.9	**1608.5**	1585.2	1616.9	1608.5	**1585.2**

Annual Chance Exceedance Event (ACE) Flows (cfs) and Oahe Pool Elevations (NGVD 29) Modeled			
10% ACE (10-Year)	2% ACE (50-Year)	1% ACE (100-Year)	0.2% ACE (500-Year)
48,000	72,000	85,000	150,000
1619.3	1620.7	1621.2	1622.2

Note: Tabulated pool elevations in the referenced report (USACE, 2012) were in 1929 NGVD and are listed as such in Table 16 for consistency. All HEC-RAS computations and study results are reported in 1988 NAVD. In the Bismarck area, an elevation referenced to 1988 NAVD is approximately 1.36 feet higher than 1929 NGVD.

3.3.1.1. Alternative Description

A range of channel excavation alternatives were developed to evaluate possible reduction of water surface elevation within the study area. The alternatives presented in this study provide a reasonable comparison of water surface reduction for material volume removed. However, channel excavation can be performed in a wide variety of ways with multiple configurations. In addition, the alternatives were evaluated using a relatively coarse cross sectional geometry within the HEC-RAS model. Further evaluation of any excavation alternative is required prior to implementation.

Channel excavation was performed within the HEC-RAS model by adding flow area to the cross section by setting a bottom width and invert elevation for the excavation. Excavation within a range of sections is performed by setting the starting downstream excavation invert and an upstream slope to link the removal area between adjacent cross sections.

The location of the bed material excavation within the existing channel section affects both total volume and the impact on computed flow elevation. The excavation cut was located within the active channel on a bench adjacent to the main channel. Excavation along the thalweg was avoided due to concerns with deposition and reduced project life. Excavation into the bank was avoided to reduce real estate and also due to concerns with an over widened channel. A view of a typical cross section showing the original geometry and the excavation cut is shown in Figure 21.

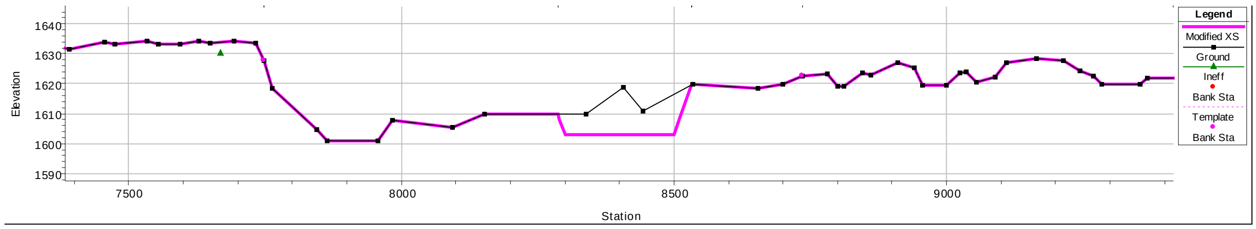

Figure 21. Typical View of Channel Excavation

Channel excavation was performed through a range of sections. The starting location for excavation was determined through a trial process with the objective to achieve approximately a 1 foot water surface elevation reduction at the 1% ACE event in the vicinity of RM 1311 near the Heart River and the downstream end of Fox Island. This process resulted in defining the excavation extent for alternative 1. Alternative 2 increased the bottom width to provide additional excavation over the same extent. Alternative 3 extended alternative 2 further downstream. A final combination alternative was developed to include both channel excavation and top width reduction. As described in the existing condition section, top width is highly correlated with sandbar presence. Reducing channel top width may be an effective way to reduce the amount of future deposition following channel bed excavation and provide longer project benefits from water surface elevation reduction. The selected value for this study of 1500 feet was based on the sandbar presence data previously stated. Detailed analysis in further design would be required to determine the optimum width that will be a balance of sustaining sediment transport without inducing increased energy loss due to channel confinement and reduced flow area. Alternative features are summarized as:

- Alternative 1 – Excavation from near RM 1298.5 to upstream of West Main Ave.
- Alternative 2 – Increase bottom width of alternative 1.
- Alternative 3 – Increase downstream limit of alternative 2 another 10 river miles
- Combination – Add encroachment reducing channel width to 1500 feet to alternative 3 from West Main Ave to RM 1300 to represent structures.

The channel excavation alternatives provide a reasonable indication of beneficial water surface reduction for material volume removed. However, channel excavation can be performed with multiple configurations and alternatives were evaluated using a relatively coarse cross sectional geometry. Further evaluation of any excavation alternative is required prior to implementation.

Additional permutations of the combination alternative could be evaluated. For example, if only channel encroachment were considered with limited or no excavation, the reduced channel width would initially cause a water surface elevation increase due to the smaller flow area. However, reducing channel width may mobilize sandbars and create a higher flow area main channel. Analysis of the performance of this type of project would require detailed sediment transport modeling beyond the scope of this study.

A summary of the alternatives is provided in Table 17.

Table 17. Channel Excavation Summary

Alternative No.	Downstream Excav. Start (River Mile 1960)	Upstream Excavation Stop (River Miles 1960)	Average Bottom Width[1] (feet)	Downstream Invert Elev (NGVD 29)	Upstream Slope (ft/ft)	Total Volume Material Removed (cu yds)
1	1298.55	1311	100	1598	0.00015	5,033,000
	1311	1314.6	100	1610.3	0.00015	
2	1298.55	1311	200	1598	0.00015	8,630,000
	1311	1314.6	200	1610.3	0.00015	
3	1286.3	1298.55	300	1588.9	0.00015	15,480,000
	1298.55	1311	200	1598	0.00015	
	1311	1314.6	200	1610.3	0.00015	
Combination	Same excavation configuration and material volume as Alternative 3 Add channel encroachment to reduce effective flow top width to about 1500 feet (structure quantities for top width reduction not estimated, would require detailed evaluation for proper structure location)					

[1] Excavation bottom width varies. Tabulated value is for relative comparison between alternatives.

The amount of material removed at each cross section varies significantly through the reach as the Missouri River cross section also varies. The distribution of excavated material for each alternative is provided in Figure 22.

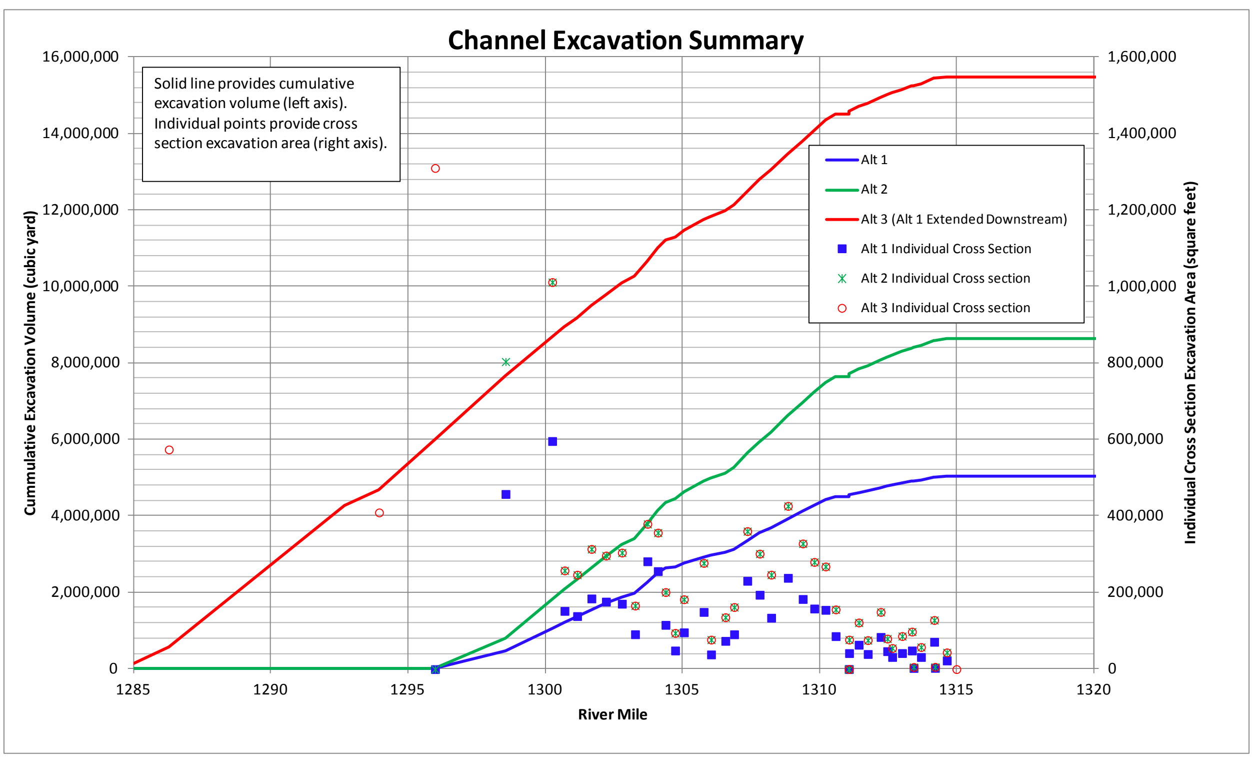

Figure 22. Channel Excavation Summary

3.3.1.2. Alternative Evaluation Results

Alternative results were evaluated to compare the change in computed water surface elevations for the range of flow and pool conditions tabulated in Table 16. Comparison of the average water surface elevation change for Alternative 1 within the primary Bismarck, ND, area from the West Main Bridge downstream to the Heart River is shown in Figure 23 for all modeled events. Comparison between alternatives was performed for selected events to simplify from the array of events evaluated as shown in Figure 24. Profile plots for the existing condition and the various alternatives using the selected comparison events are shown in Plates 12 - 21.

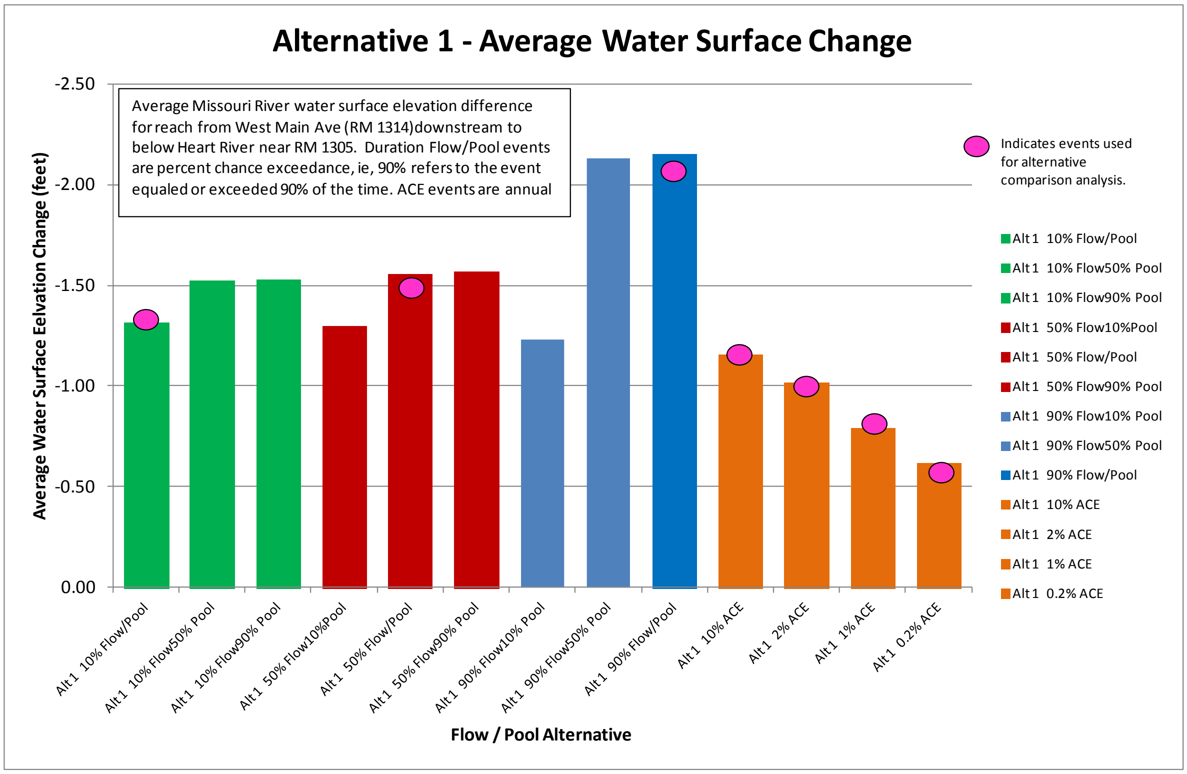

Figure 23. Alternative 1 Average Water Surface Change.

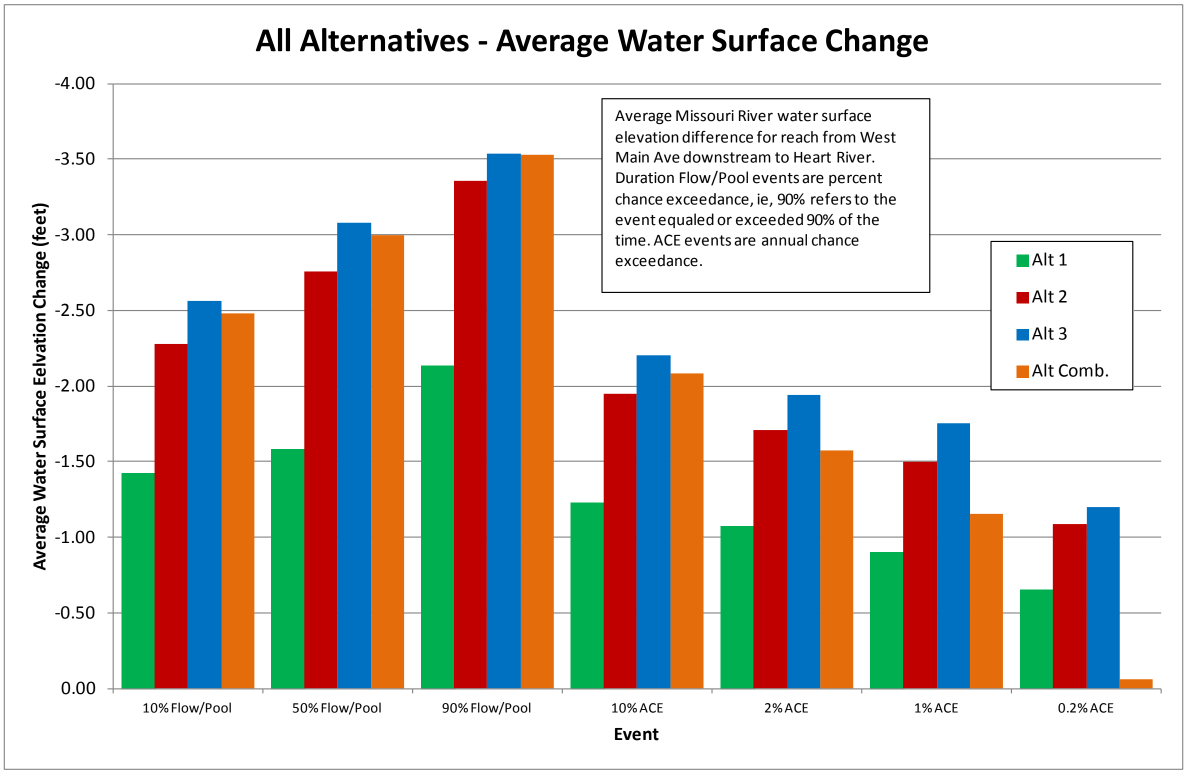

Figure 24. All Alternatives Water Surface Change.

The evaluation results illustrate that water surface elevation reduction is possible for both extreme annual events and more moderate duration events.

For the ACE events that were analyzed, results show decreasing water surface reduction as the events become larger. This relationship occurs for all events and is due to both increasing flow and rising Oahe pool levels. Alternative 2, an increase in the alternative 1 bottom width, shows a continued benefit. Alternative 3, an extension of alternative 2 further downstream, shows only marginal benefit. The combination alternative, which includes the excavation of alternative 3 combined with the channel width reduction, shows the impact of reducing channel flow area for some of the larger ACE events with reducing average water surface elevation change from about 2 feet at the 10% ACE event to near zero at the 0.2% ACE event.

The combination alternative 4, which includes channel width reduction, results in slightly less water surface reduction. The reduced benefit is due to the slightly higher energy loss as a result of channel confinement. However, the alternative does provide a significant reduction from the existing condition.

Results show that Oahe pool levels are a factor in the computed study area water surface elevation. Figure 23 shows a slightly reduced benefit for the 10% Oahe pool level when compared to the 50% and 90% pool elevations. Figure 25, which compares the existing condition to alternative 3 results for various Oahe pool elevations, also shows Oahe pool effects. At the 10% duration pool level, the alternative 3 water surface elevation reduction from the existing condition doesn't start until further upstream than for the 50% and 90% duration pool levels. In addition, the alternative 3 benefit is reduced for the 10% pool when compared to the benefit for the other pool levels. The higher water surface elevation correlates with lower flow velocities and likely a further upstream sediment deposition zone.

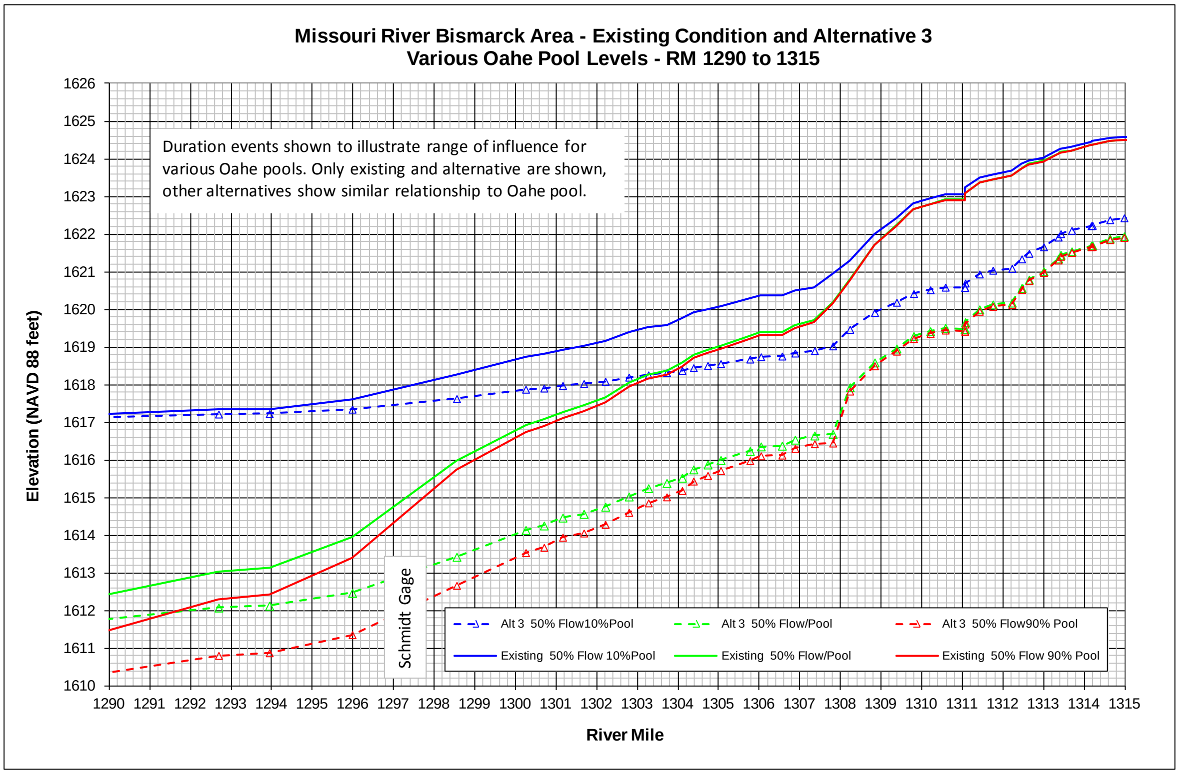

Figure 25. Oahe Pool Impact for Alternative 3

3.3.1.3. Alternative Implementation Considerations

The channel excavation alternatives include the removal of a significant amount of material. The combination alternative includes material removal combined with channel width reduction. Material removal would likely impact the amount and quality of sandbar habitat within the study area. Channel width reduction techniques would likely include the placement of bank stabilization structures. Both of these actions are likely to encounter obstacles to implementation due to the habitat impacts and current position of resources agencies as previously discussed in the study area background section of this report.

3.3.1.4. Evaluation of Alternative Sustainability

Several different methods were examined to provide an indication of how the alternatives may affect sediment transport through the project reach.

According to a 2000 study (USGS, 2000), the average annual sediment load entering Lake Oahe from the Missouri River below the Heart River and Apple Creek is 3.77 million tons/year. Using a unit weight of 85 lb/cu ft, this would equate to about 3.3 million cubic yards or about 65% of the material removal volume for alternative 1. Assuming a trap efficiency of 20 to 80%, the alternative 1 longevity may be in the range of 2 to 7 years.

Examining the shear stress or stream power change from existing to alternative condition using values determined by HEC-RAS was not effective. Further analysis using the sediment transport capacity routine within HEC-RAS Stable Channel Design Functions was performed. This function has the capability of predicting transport capacity for non-cohesive sediment at one or more stream sections based on hydraulic parameters and sediment properties. Results can be used to develop sediment transport capacity for the study area to understand and predict the fluvial processes for the existing and alternative condition.

Computations were performed using the Laursen (Copeland) transport function within HEC-RAS at each cross section. Due to the limitations of this approach, computation results should not be regarded as an absolute value. Meaningful conclusions can be determined by evaluating the computed change from the existing condition for each alternative. Comparison computations were performed using 50% duration Missouri River flow and the 50% duration Oahe pool level. Results were evaluated using the percent change in sediment transport capacity (tons/day). Results are shown in Figure 26.

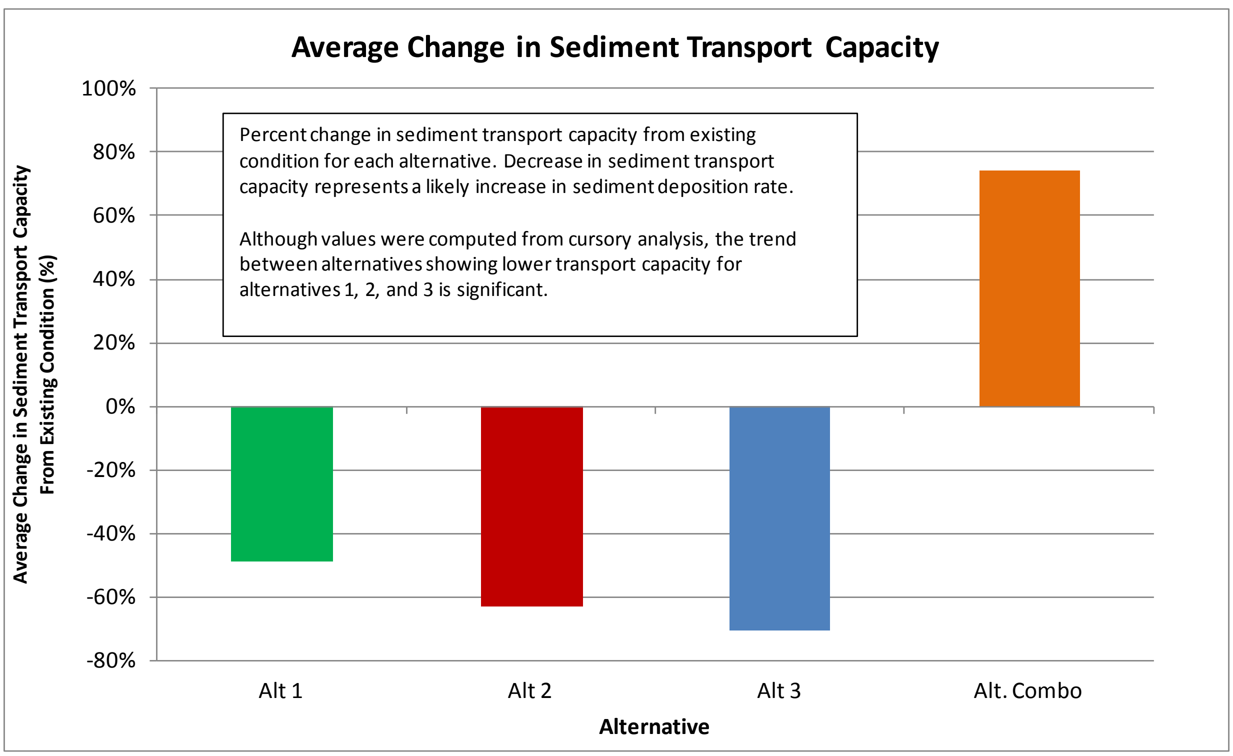

Figure 26. Average Change in Sediment Transport Capacity

Results demonstrate that each of the excavation only alternatives significantly lowers the transport capacity. Based on this analysis, it is likely that the increased channel area created by excavation is not stable and will experience an increased deposition rate within the excavation zone. The combination alternative that includes channel width reduction provides an increased sediment transport capacity. This would imply that the combination alternative would be stable and may even induce some channel degradation.

3.3.2. Ice-Affected

Water surface profiles were computed for the future condition of alternative 3 (channel excavation) with HEC-RAS for the 2- through 500-year floods for the ice breakup regime only. Since the breakup profiles are significantly higher than the other two regimes, it was felt that the breakup regime afforded the greatest opportunity for stage reduction of the three ice regimes. Alternative 3 was the only future condition alternative modeled with ice, since Alternative 3 has the greatest potential for altering the ice regime and flow conveyance in general.

Ice jam locations with the excavated condition were modeled with the HEC-RAS ice jam option, and it was determined that potential ice jam locations did not significantly change, so ice parameters were set the same as for existing conditions to ensure an equal comparison between the existing and future alternative. The projected flood elevations near the Schmidt and Bismarck gages are tabulated in Table 18 below, while the computed water surface profiles are shown in Figure 27. A comparison of existing and alternative 3 results is shown in Figure 28 for the 10% and 1% ACE events.

Table 18. Alt. 3 Conditions, Ice-Affected Breakup Flood Profiles near Schmidt and Bismarck Gages

Flood Profile	Water Surface Elevation (ft, NAVD88) at River Mile 1298.55	Water Surface Elevation (ft, NAVD88) at River Mile 1314.63
2-Year	1620.97	1630.04
5-Year	1622.77	1632.46
10-Year	1623.96	1633.75
25-Year	1624.63	1634.51
50-Year	1625.20	1635.47
100-Year	1625.83	1636.00
200-Year	1626.27	1636.58
500-Year	1626.95	1637.20

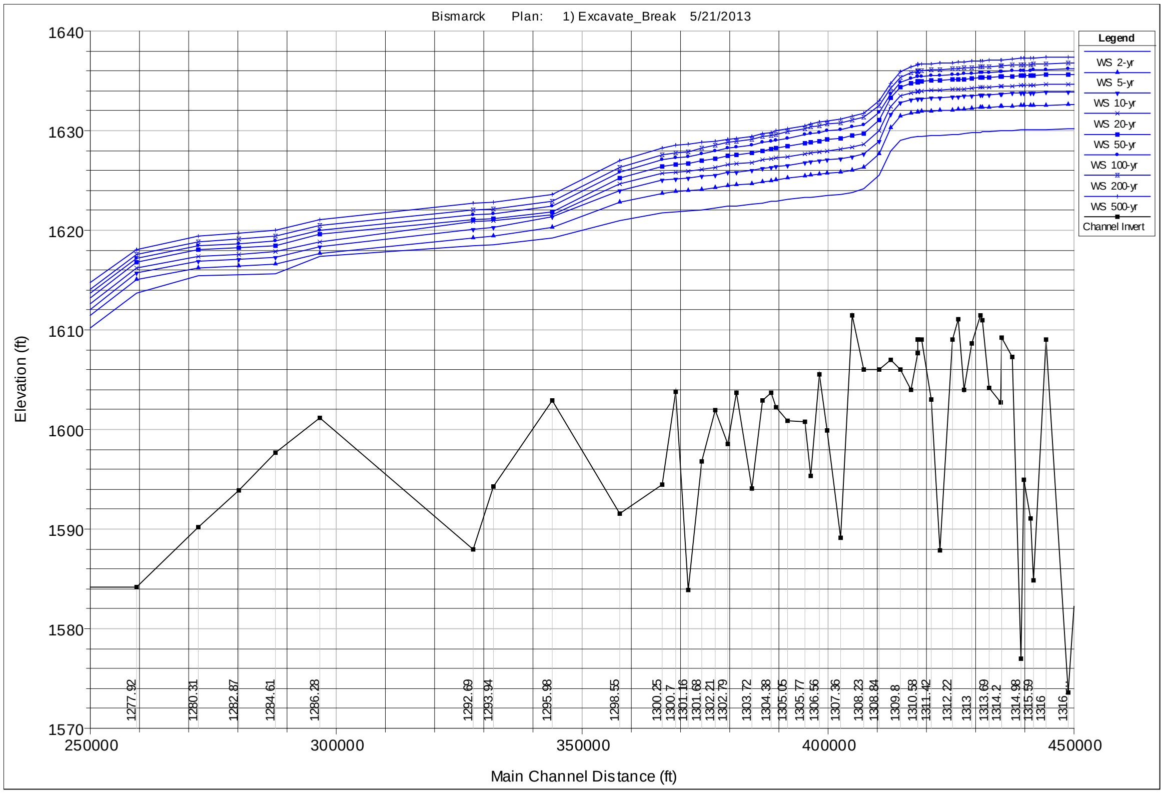

Figure 27. Alternative 3 Ice-Affected Breakup Flow Profiles, Missouri River

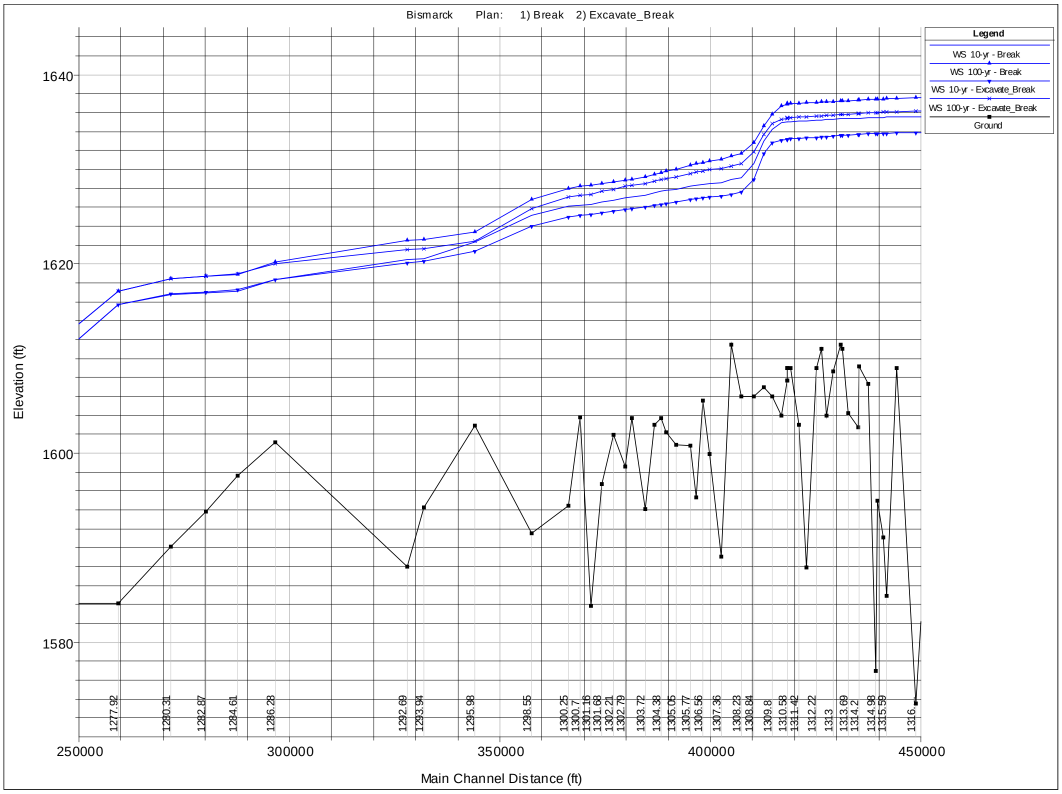

Figure 28. Existing and Alternative 3 Ice Jam Breakup profiles for 10% and 1% ACE events.

A comparison of existing conditions and future with alternative 3 conditions under ice breakup conditions shows a general reduction in stage throughout the study reach, although the stage reduction differs by flood event and river mile, as shown in Figure 29. For the reach between Apple Creek and Heart River, the average stage reduction is 2 feet for the 50% and 20% ACE (2-year and 5-year) events. For flood events equal to and greater than the 10% ACE, the average stage reduction is about 1 foot, varying between 0.5 and 1.5 feet. Upstream of Heart River, the stage reductions increase by varying amounts. The 50% (2-year) ACE event has a stage reduction of 3 to 3.5 feet, the 20% (5-year) ACE event has stage reduction of about 2.25 feet, and all other flood events show a stage reduction between 1.3 and 1.8 feet. Deposition within the excavated area could occur fairly quickly and will reduce the benefit of stage reduction.

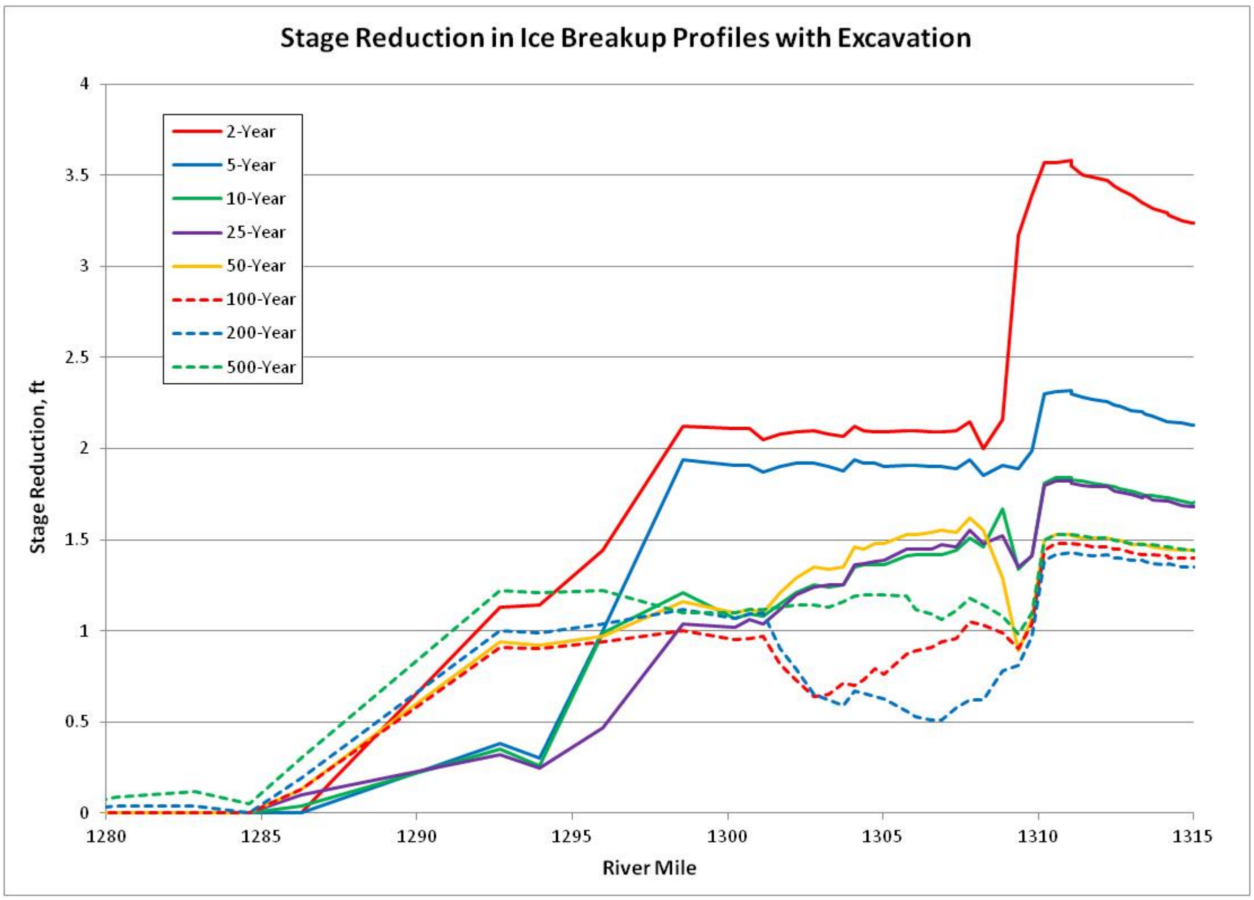

Figure 29. Stage Reduction for Ice Breakup with Channel Excavation Alternative 3

4. Conclusions

This study was conducted under the Title VII study authority at the request of the Title VII Task Force. The study vicinity focuses on the south Bismarck area of the open water reach of the Missouri River. The study area is between River Miles 1280 and 1325 on the Missouri River. Computations were performed for both open water and ice affected conditions. Alternatives were developed for potential flood risk reduction. Stability analysis was also performed to evaluate future conditions and likely channel response to the evaluated alternatives. Analysis was performed for both duration and annual chance exceedance (ACE) events. Significant conclusions are as follows:

Existing Condition HEC-RAS Model

Existing HEC-RAS models were utilized to create a new HEC-RAS model of the study area, representing 2012 channel and overbank conditions. Hydraulic modeling of the study reach was performed, evaluating water surface profiles for 50%, 20%, 10%, 4%, 2%, 1%, 0.5%, and 0.2% ACE events for both open water and ice-affected flows. Model calibration was deemed to be good to very good throughout the study reach for both open water and ice-affected conditions, and model calibration covered the full range of flows used for the various ACE events. Model results indicate the following:

- Ice-affected profiles are higher than open water profiles for more frequent events. However, open water profiles are higher at the less frequent events.
- Hydraulic modeling indicates that ice jams should tend to occur at 4 locations under both freezeup and breakup conditions: near River Mile 1278, River Mile 1286, River Mile 1298, and River Mile 1309. The latter can be verified as a potential ice jam location based on the March 2009 flood event. The other locations appear to be in general locations noted as being susceptible to freezeup ice jams, but could form breakup jams as well.
- Several residential and commercial areas are threatened by flooding at the 1% ACE event (or less frequent).

Stability Analysis

Several different methodologies were evaluated for indications of existing condition stability. These included evaluation of changes in sediment range cross section hydraulic elements from 1956 to 2012, changes in sediment range volume from 1956 to 2012, the prediction for the presence of sandbars correlated with channel width, and specific gage analysis at Bismarck and Schmidt. Significant observations from the stability analysis are as follows:

- Sediment range cross section data analysis was performed to evaluate changes in top width, flow area, average bed depth, and storage volume with time. Results show increasing top width, decreasing average bed depth, and a recent increase in flow area. These variables are all correlated and indicate that channel conditions are changing. However, a conclusive relationship suitable for predicting future trends cannot be determined from the results.
- Sediment rate volume change evaluation shows a variation from deposition at the elevation 1620 and 1630 computation planes. The positive rate of volume change at elevation 1630 indicates a fairly constant erosion rate. At elevation 1620, the rate is reversed for the initial period from 1956 to 1989.
- Overall, sediment rate volume changes results are generally consistent with the results from the top width and flow area change evaluation. Direct comparison of results is difficult due to differences in methodology.

- Previous studies had identified channel width as a reliable indicator for the presence of sandbars. While many factors must be considered when evaluating sandbar processes, channel width was further evaluated within the study area to compare with the estimated upper and lower bound widths. The evaluation showed good correlation with the upper and lower bound channel width and the presence of sandbars in those areas currently shown in aerial photos.
- Specific gage trends at the Bismarck gage, RM 1314.5, show a slight upward trend with a slight rise of 0.5 feet or more occurred from 1985 to 2010. The 2011 extreme event resulted in degradation of nearly 2 feet at 30,000 cfs with 30,000 cfs flows lower in 2012 than any previous post Garrison dam construction. No recovery in gage elevation was observed in the 2012 gage data.
- Schmidt specific gage record, RM 1298, showed aggradation in 2011 followed by degradation in 2012. Including the period through 2012, the Schmidt gage shows very little change in stage at the 20,000 and 30,000 cfs flows since 1974. The Schmidt gage record shows the impact of high Oahe pools with raised water levels and likely sediment deposition.
- Results indicate that areas of significant change are occurring within the study area. However, a strong correlation between the methods indicating definite trends was not determined. The specific gage analysis at Bismarck and Schmidt is particularly critical to understanding changes and does not demonstrate a consistent gage trend with little overall change over the past several decades.
- It should be stressed that the existing condition is not meant to be a predictor of the future condition. In fact, the high degree of influence of the Oahe pool on Schmidt gage levels, 2011 flow observations at Schmidt, and the known continued growth of the Oahe delta strongly support the conclusion that flow stages in the study area will rise in the future. However, existing condition data does not illustrate that this trend has initiated at this time.
- Future sediment deposition is expected and will alter stability analysis conclusions in the Bismarck and downstream area.

Alternative Evaluation

Three channel excavation alternatives were evaluated plus a combination excavation and channel confinement alternative. Results are summarized as follows:

- All results are based on a reconnaissance level analysis. Detailed further analysis is required to optimize any of the alternatives.
- Channel excavation can provide flow elevation reduction within the Bismarck area. The three excavation alternatives provide a water surface reduction of about 1 to nearly 2 feet.
- Material removal volume is extreme. Alternative 1, which provides an average water surface reduction of slightly less than 1 foot through the study area at the 1% ACE event, requires the removal of over 5 million cubic yards.
- Alternative 3 demonstrated that extending the excavation further downstream has limited additional water surface reduction benefit while the increase in excavation volume is significant.

- Alternative 4 demonstrated that combining channel excavation with channel width reduction may be effective and sustainable from a flood risk reduction point of view.
- Results show decreasing water surface reduction as the events become larger. This relationship occurs for all events and is due to both increasing flow and also rising Oahe pool levels.
- Oahe pool levels are a factor in the computed alternative water surface reduction as shown by comparing both the difference for various Oahe pool levels and the Schmidt specific gage record. At higher pool levels, the benefit for each alternative initiates further upstream and is also of lesser magnitude when compared to lower pool levels. The higher water surface elevation correlates with lower flow velocities and likely a further upstream sediment deposition zone. These results suggest that solutions to address flood risk and alter sediment deposition patterns within the study area may need to include the examination of Missouri River system operations. However, flood risk within the study area is a function of several different factors. Only implementing system management options is likely incapable of providing significant flood relief to the Bismarck study area for either existing or future conditions.
- Alternatives include the removal of a significant amount of material. Material removal would likely impact the amount and quality of sandbar habitat within the study area.
- The combination alternative includes material removal combined with channel width reduction. Channel width reduction techniques would likely include the placement of bank stabilization structures. Both of these actions are likely to encounter obstacles to implementation due to the habitat impacts and stated resource agency concerns.
- This study only considered a limited number of sediment management options. A thorough flood damage reduction study would consider additional sediment management options, nonstructural alternatives, and possible flood mitigation structures such as levees.

Alternative Sustainability

The sustainability of the alternatives was evaluated using the sediment transport capacity routine within HEC-RAS Stable Channel Design Functions. Results are summarized as:

- Results demonstrate that each of the excavation only alternatives significantly lowers the Missouri River transport capacity. It is likely that the increased channel area created by excavation is not stable and will experience an increased deposition rate within the excavation zone. Therefore, channel excavation will not provide a permanent water surface elevation reduction benefit.
- Assuming a trap efficiency of 20 to 80% of the Missouri River average annual sediment load passing through the study reach, the alternative 1 longevity may be in the range of 2 to 7 years. Longevity for alternatives 2, 3, and 4 would be greater due to the larger sediment volume and the lower trap efficiency for alternative 4.
- The combination alternative that includes channel width reduction provides an increased sediment transport capacity. This would imply that the combination alternative would be stable and may even induce some channel degradation.

5. Recommendations

This study performed a technical evaluation of open water and ice affected conditions to evaluate sediment management alternatives. Based on study results, the following recommendations for future actions are provided:

- A practical sediment excavation option for implementation was not found. Alternative 1 achieves only moderate water surface elevation reduction with a sediment removal volume of over 5 million cubic yards. Results indicate that sediment transport would be reduced with increased aggradation within the excavation zone such that the benefit longevity is limited. Further evaluation of mechanical sediment removal is not recommended.
- Existing stability evaluation was performed using an array of methods and data. The conclusions of this evaluation indicate that the stage-flow relationship has not changed significantly in the Bismarck, ND, area over the last 50+ years since Garrison and Oahe Dam construction. However, evidence strongly supports the concern that aggradation is occurring and will likely cause sedimentation issues in the future. Examination of the current monitoring program is recommended. Additional studies to develop future trend predictions may be warranted.
- Schmidt gage analysis and study area results support the general perception that Oahe pool levels and Garrison Dam releases interact and significantly affect water levels and sediment deposition patterns for some combinations of flow and pool levels in the Bismarck area. Future studies that would more thoroughly evaluate these relationships, correlation with other flood risk factors, likely future sediment deposition zones, and possible options to mitigate or reduce further detrimental impacts to flood risk in the Bismarck area may be warranted.

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