Missouri River at Florence Bend Bedrock Excavation

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Abstract

On the Missouri River near Omaha, NE a bedrock outcrop, known as the Florence rock shelf or reef, was blasted during the original navigation channel construction to create the authorized navigation channel depth. Removal included a minimal provision for future degradation and was limited to the 300 foot navigation channel width. The bedrock surface of the Florence Reef is rough and irregular, with elevation differences of several feet occurring along its length.

Downstream of the I-680 bridge, the Missouri River navigation channel contacts the bedrock outcrop. Missouri River degradation, accelerated by several extreme floods over the last 12 years, has resulted in insufficient navigation channel dimensions at several locations within the area between river mile (RM) 626.4 to 625.3. Material removal was deemed necessary to restore the minimum navigation channel dimensions and remove hazards to river navigation. Maintenance crews from the Omaha District performed partial removal of pinnacles in the fall of 2021, but the scope of the project required development of a contract to address the issue fully.

The project is novel in that dredging in the main channel is an atypical activity for the Omaha District and it is rare that bedrock is encountered in the predominately sand bed. Design activities associated with the project included geological study, multi-beam hydrologic surveys, bedload sediment sampling, and hydraulic modeling. Construction plans and specifications were developed in consultation with other USACE districts to appropriately address the unique construction project of mechanical excavation of bedrock from floating plant (i.e. river barge).

The project was awarded in April 2022, with construction completed in the Fall of 2022.

Introduction

Downstream of the I-680 bridge, near Omaha, NE, the Missouri River navigation channel contacts a bedrock outcrop commonly referred to as the Florence Reef. Missouri River degradation has resulted in insufficient navigation channel dimensions at several locations within the area between river mile (RM) 626.4 to 625.3. Material removal is necessary to restore the minimum navigation channel dimensions.

The project excavation consists of a base and 2 options. The base is for the minimum flow service navigation channel (200 ft width by 8 ft depth) and option 1 is to expand the navigation channel width to 300 ft at the same elevation. Option 2 is for lowering that same 300 ft width to accommodate future degradation.

The base project was accelerated to provide the minimum service flow channel (8 ft depth x 200 ft width) as soon as possible. The Contractor was required to provide a minimum removal rate of 750 cu yds/day, which translates to a time period of 24 days for the base volume removal. Typical excavation depths vary from 2 to 4 feet below the existing bed.

Material is generally a soft limestone or shale. Isolated pinnacle removal within the Florence Reef was performed by the Missouri River Project Office in 2021 using mechanical excavation.
The most likely Contractor methods for material removal consist of mechanical excavation with use of hydraulic hammer, within isolated hard rock areas, to facilitate material fracture and excavation.

Material disposal will be dependent on Contractor methods and will most likely be placed on existing navigation structures within 15 river miles of the project site. The project plans also allow the Contractor use an approved off-site disposal area at the Contractor expense.
Equipment will include floating plant for typical river operation.

The scope of this effort will be limited to excavation of bedrock material. Removal of other bed material in areas that are not hindered by or primarily composed of bedrock will not be included. However, there is an expectation that other material (sand) may be encountered. Examples include naturally moving bed material that may migrate into the area during construction or isolated deposits that may have occurred recently.

Existing Conditions

Bedrock Outcrop

A bedrock outcrop, known as the Florence rock shelf or reef, was blasted during the original navigation channel construction to create the authorized navigation channel depth. Removal included a minimal provision for future degradation and was limited to the 300 foot navigation channel width. (Figure 2) provides the approximate location of the Florence Reef. The Florence Reef elevation does not remain constant but fluctuates up and down along its length. It impacts the navigation functionality of the channel most noticeably just downstream of Mormon Bridge, RM 626.4 to 626.1, and again in the vicinity of RM 625.8 to 625.3. The Missouri River has an approximate depth of 9 to 11 feet at full service navigation flows through the reef area. (Figure 3) shows a portion of visible bedrock outcrop at low flow in 2012.

Figure 1 - Project Location Map

Figure 2. Bedrock Outcrop (Florence Reef) Vicinity


Figure 3. Looking Upstream at Bedrock Outcrop - Low Flow Fall 2012, approximate RM 625.5

Channel Degradation

The Missouri River Bank Stabilization and Navigation Project (BSNP) was authorized in a series of congressional actions with the latest specified in the Rivers and Harbors Act of 1945. Congressional authorization provided for a 9 foot deep and not less than 300 foot wide navigation channel from Sioux City, IA (RM 735.0) to St. Louis, MO (RM 0.0) with bank stabilization necessary to maintain a reliable navigation channel. The Missouri River BSNP is an open river waterway without locks or dams with high density river structures that confine and control the channel. Flow velocities provide a reliable self-scouring navigation channel without the need of regular dredging.

Degradation has been occurring on the Missouri River for a prolonged period as the result of multiple factors. Degradation occurs downstream of Gavins Point Dam, constructed in 1957 and located at RM 811.1, in response to the nearly sediment free water being released. The lack of sediment creates a transport deficiency that results in material erosion from the river bed and banks. (BSNP) channel construction included numerous channel cutoffs and a general deepening of the main Missouri River that also contributes to degradation. Prior to the 2011 extreme event with sustained high flows, degradation was mostly within the reach from Gavins Point Dam downstream to the Desoto Bend cutoff at about RM 642.0, 15 miles upstream of the project site. The Desoto Bend cutoff reduced the navigation channel length by about 7 river miles.

Prolonged duration high flows have occurred several times in the past decade. The 2011 and 2019 events are the top two annual volume events since 1898, which was the start of gage record keeping on the Missouri River. The sustained duration of high flows resulted in significant channel degradation from 2011 through 2019. Annual peak flows near the site are shown below in (Figure 4).

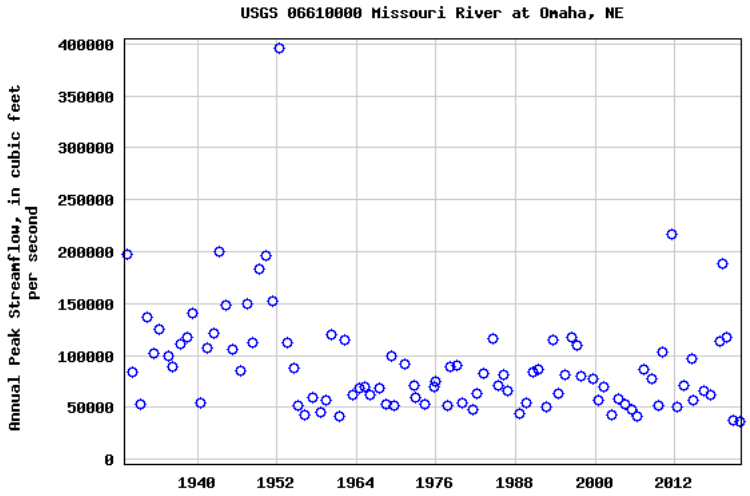

Figure 4. Annual Peak flow near Florence Bend

Figure 5. Missouri River at Omaha Hydrograph

Stage trend evaluation was performed using data from the stream gage USGS 06610000 Missouri River at Omaha, which is located about 10 river miles downstream of the Florence Reef. The evaluation relied on the most recent stage trend report (USACE 2017) and recent USGS flow measurements. The Omaha gage stage trends can be seen in (Figure 6).

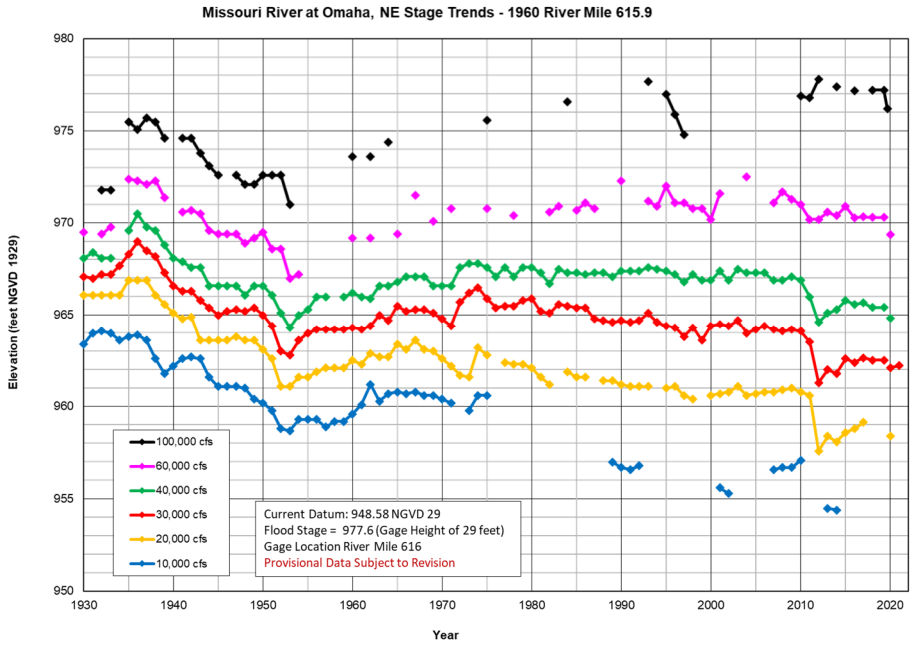

Figure 6 - Missouri River at Omaha, NE Gage Stage Trends

Notable from observation of the plot, Omaha river levels were relatively static from 1970-2010 at normal flows, large declines in river levels occurred following the 1952 and 2011 flood events, both events were followed by a rebound in river levels over the next few years, over 3 feet of degradation occurred in 2011 followed by rebound with a net stage decline of about 1.5 to 2 feet at CRP flows, further decreases occurred at Florence Bend in 2018 and 2019 with an additional decline of about 0.5 to 0.7 feet. As of November 2021, Omaha gage rebound has not occurred from this decline.

The degradation process results in a downward shift of the river stage-flow relationship. As a result, the river level is at a lower stage for the same river flow rate.

Degradation has been ongoing within the BSNP since the closure of Gavins Point Dam in the 1950's. Degradation factors include sediment depletion due to construction of the reservoir system and navigation channel efficiency. Prior to the 2011 event, the degradation reach progressed from Gavins Point Dam downstream to about the Desoto Bend cutoff at RM 642.0. Under the current conditions, about 12-15 feet of degradation has occurred at Gavins Point Dam (RM 811.1) that reduces downstream to near equilibrium at the Platte River confluence (RM 595). General degradation does not result in greater navigation channel depths. Recent high flows in 2011 and 2019 resulted in significant degradation with a total decline of about 3 feet at the Omaha gage at CRP flow. The Florence Bend bedrock outcrop is a static channel bed elevation that does not degrade. As a result of degradation downstream of Florence Bend, the navigation channel within Florence Bend has decreased depth and increased velocity.

Channel Depths

An analysis of flow depths within the Florence Reef was conducted utilizing hydrographic surveys and Omaha gage data.

On 8 April 2021, the motor vessel Far West filed an Area of Concern report with bottom bumping within a portion of the Florence Reef (RM 625.8 to 626.4). At that time, the river level at the Omaha gage was 14.7 feet and flow was 32,800 cfs. In response, the Omaha District conducted a high density navigation

channel survey. Evaluation of the survey data determined that a navigation channel meeting the 300 ft width and 9 ft depth was present.

An evaluation was conducted using the Omaha gage data and survey data to project Florence Reef navigation channel depths. Projections were performed for the full service navigation target flow at Omaha of 31,000 cfs and the minimum service flow of 25,000 cfs. During the April 6 to 8 period when the Far West bump occurred, Sioux City flow was about 31,000 cfs while Omaha flow varied from 32,800 to 33,500 cfs. These flows equate to a difference between Sioux City and Omaha of 1,800 to 2,500 cfs during this period. Inflow would be attributed to drainage from the intervening basin including the Little Sioux, Boyer, and Soldier Rivers. Two conditions were examined for navigation channel depths; (1) If tributary inflows become nearly dry, the flow at Omaha could decline to the same as the 31,000 cfs Sioux City target at full service flow. (2) If basin drought conditions persist, Gavins Point Dam releases could be reduced to minimum service levels and Omaha flow could decline to 25,000 cfs.

Using the April channel depth and recent Omaha gage measured data, projected Florence Reef flow depths for each condition are shown in Table 1.

Table 1. Estimated Navigation Channel Depth at Full and Minimum Service Flow

Omaha Gage Height - Interpolated to Navigation Flow Targets			
Nav. Target Flow (cfs)	Design Nav. Target Stage (ft)	Decline From 6 Apr (ft)	Nav. Channel Depth (ft)*
31,000 (Full)	13.8	0.9	9.0
25,000 (Minimum)	11.7	3.0	7.2
* Navigation service levels for Omaha and Sioux City are the same. Navigation channel depth projected to target flow. Projections assume dry conditions with minimal inflow.			

Projecting river levels using Omaha gage data, the Florence Reef flow depth at the Omaha navigation full service flow of 31,000 cfs would be about 9 feet in some areas and safe navigation tow passage would be feasible, but not guaranteed in all locations. Extrapolating the 2021 Omaha gage data to a minimum service flow at Omaha of 25,000 cfs determined an estimated channel depth of 7.2 feet within Florence Reef, which is much less than the authorized 8 foot depth. Future flood event degradation will further impair the ability for the BSNP in this location to provide sufficient navigation depths through the Florence Reef.

To accurately define areas where channel depths were not sufficient in relation to the authorized channel dimensions, multi-beam surveys of the project area were collected on 28 September of 2021 (Q ~ 32.2Kcfs) following completion of Missouri River Project Office efforts to remove material over the summer. Survey efforts utilized an R2 Sonic 2024 multibeam echosounder. The surveys were processed into 1ft x 1ft grid, utilized to identify areas that were too high in elevation, and compared with design surfaces to develop accurate of quantity estimates. Survey extents are illustrated in (Figure 7).

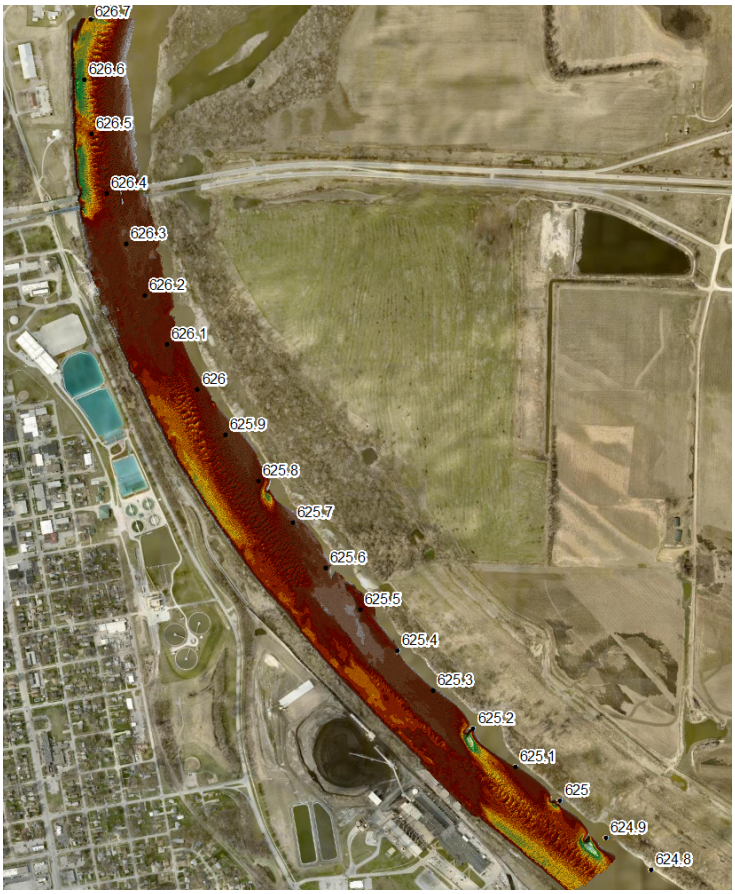

Figure 7. Multibeam Survey Extent

The projected channel depths were used to determine approximate excavation areas through the Florence Reef for the design conditions of the full service flow of 31,000 cfs plus 2 foot of future degradation. Excavation areas (all non-blue shaded areas) are illustrated in (Figure 8). Excavation depths in most areas is less than 2 feet (yellow and green shading). The illustrated areas are approximate. Detailed surveys and design may alter excavation extent.

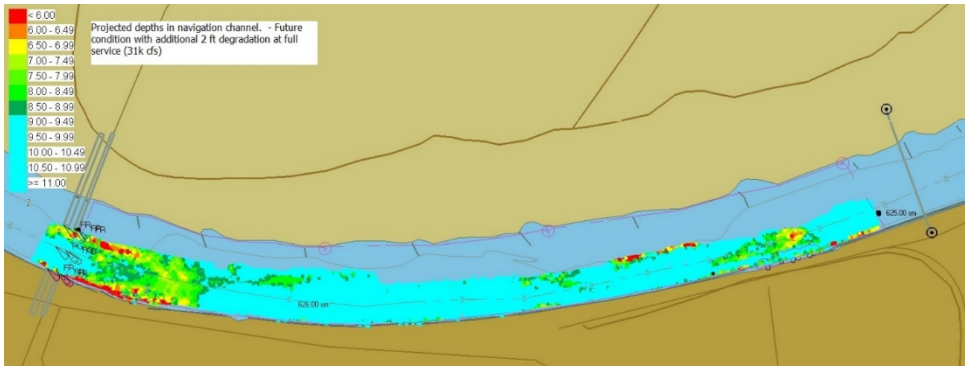

Figure 8. Excavation Areas - April 2021 Survey at Full Service Flow (31Kcfs) and 2 Feet Future Degradation

Projected channel depths were also used to determine excavation areas through the Florence Reef for the design conditions of the minimum service flow of 25,000 cfs plus 2 feet of future degradation. Excavation areas (all non-blue shaded areas) are illustrated in (Figure 9). The excavation extent is significantly greater and excavation depths within the channel center exceeds three feet (red shading).

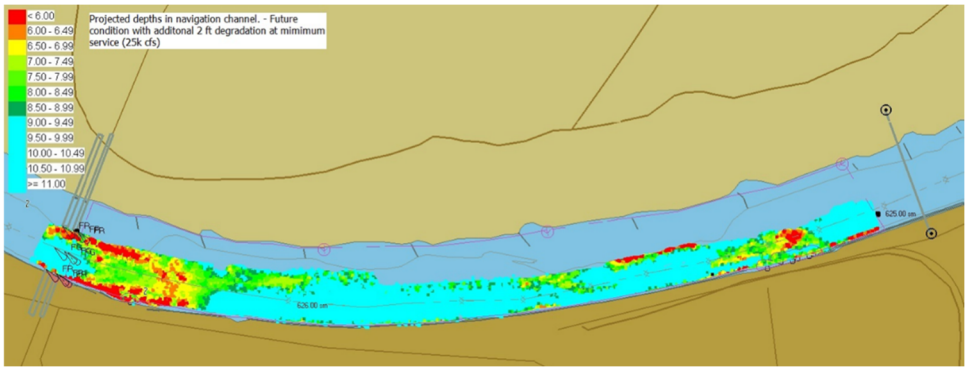

Figure 9. Areas - April 2021 Survey at Minimum Service Flow (25k cfs) and 2 Foot Future Degradation

Geologic Investigation

The United States Army Corps of Engineers (USACE) conducted a drilling investigation to examine the rock and subsurface conditions beneath the Missouri River at Florence Bend. The investigation purpose was to determine the geologic material types present beneath the riverbed and the rippability of materials in order to assess removal techniques.

Between 13 October and 2 November 2021, the USACE drill crew cored 22 sections of the river bed with a Geoprobe 3230 DT drill rig, mounted on a river barge. A diamond impregnated drill bit cored 2.5 inch diameter rock. Geologists characterized the core rock type and fracture characteristics.

Many of the rock quality parameters are for determining stability of tunnels, mines, rock slopes and other factors. The primary parameter for this project is quantifying the rock rippability in order to inform excavation methods. Rippability is often defined by fractures, weathering, moisture, stratigraphy, brittleness, shear strength, and seismic velocity. Caterpillar has produced documents relating seismic velocity to rippability by D-8 or D-9 tractors. The USACE demonstrated the rock was rippable during the excavation performed in April-June 2021 using an excavator with hardened penetrating teeth called “viper teeth”. No hydraulic hammering of river bottom was required by the USACE.

All of the rock quality examinations found the rock to be of poor to very poor quality. Cyclothemic rock is often thinly bedded, and numerous fractures were observed in the upper portions of the bedrock. Cyclothemic rock may have thin layers of shale or sand which may weaken microcrystalline rock such as limestone.

The top several feet of rock is often highly fractured. These factures and broken zones indicate that the rock is not very solid in the near surface. Much of the rock appears weathered or eroded, likely from the action of water on the rock and in fractures.

Due to physical limitations of being unable to see the rock in its entirety, fracture length was unable to be ascertained. The rock in the Minimum (base contract) Excavation Depth and Future Degradation (option 2) Excavation Depth was also too fractured to provide an adequate sample for unconfined compressive strength testing. Two samples were taken from deep core samples and this testing is forthcoming. There is always uncertainty when data sets are incomplete. However, based on the coring study, there is high probability that rock encountered should be rippable and excavatable using sufficiently long excavators and hydraulic hammers with specific energy ratings.

Design Channel

Plan and Profile Development

Reliable navigation depths are the project goal. Future degradation and natural Missouri River channel variability will affect flow depths within the Florence Reef. Excavation within the reef will alter flow conditions and river depths.

The recent Omaha gage measurements were used to develop Omaha Gage Height data as shown in (Table 2).

Table 2. Missouri River Gage at Omaha, NE

Location - Downstream of I-480 bridge, right bank at RM 615.97, Gage Datum 948.97 NAVD 88			
Condition	Flow (cfs)	Gage Height (feet)	Elev. (NAVD 88)
Minimum Service	25,000	11.7	960.67
Full Service	31,000	13.8	962.97
CRP 2021	32,700	14.6	963.57
CRP 2017	32,700	15.1	964.07

The Missouri River at normal flows typically has stage variation during a flow season of 0.5 to 1 foot. Variation is due to a number of factors including bedload, dune height, water temperature, vegetation roughness, and other factors. A value of 1.0 foot was selected to account for normal river variation and uncertainty.

Bedload measurements were conducted by U.S Army Engineer Research and Development Center (ERDC) at several sites on the Missouri River for the purpose of defining sediment-discharge rating curves (Abraham et. al. 2017). Bed-load transport values were computed using the Integrated Section Surface Difference Over Time version 2 (ISSDOTv2) method and compared with the Meyer-Peter Mueller and Einstein bed-load transport functions. Measurements at the Omaha gage site are shown in (Figure 10). The ISSDOTv2 methodology uses surface differences of time sequenced bathymetric data to compute volume changes in moving sand waves to determine bed-load transport rates.

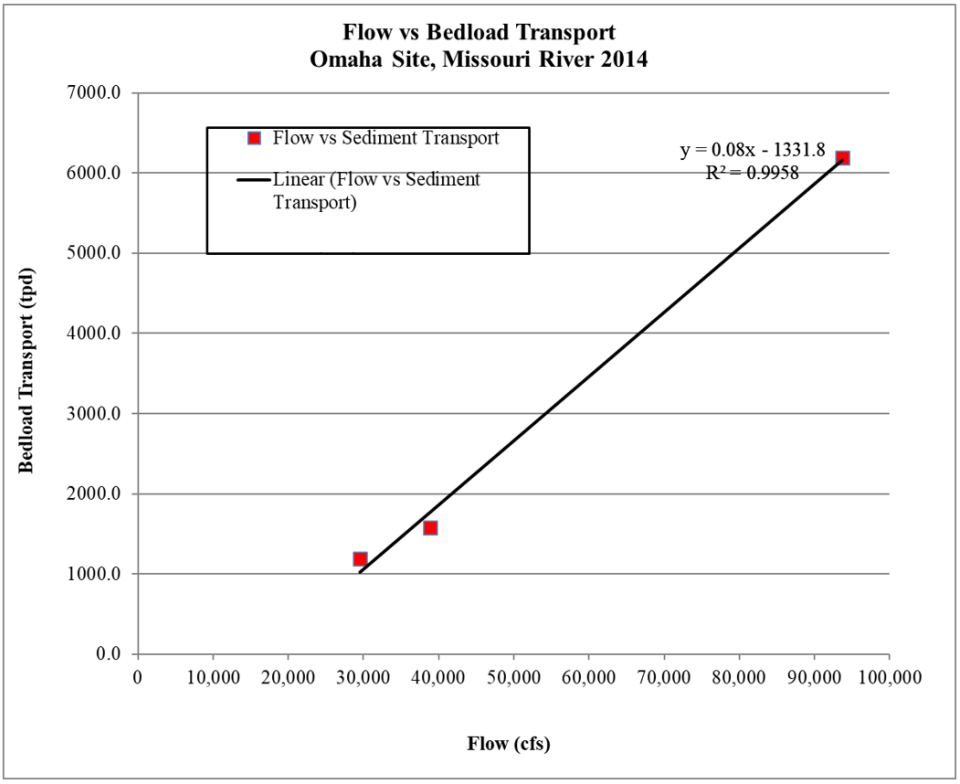

Figure 10. Missouri River at Omaha Gage Site Bedload Measurements (Abraham et. al. 2017)

Bedload measurements indicate that bedload will be in the range of 1200 tons/day at the full service flow of 31,000 cfs. Using the 300 ft width channel as an estimate of the active bedload transport area and a minimum bedload movement rate of 50 to 100 cu ft/day/ft, the bedload layer thickness would be less than 0.2 feet. Dunes will reduce depths above and beyond the impingement of the bedrock.

The various factors were combined with the Omaha gage height and CRP to develop a design invert profile as shown in (Table 3).

Table 3 - Selected Design Invert

Component	31,000 Full Service	25,000 Minimum Service
Nav Channel Depth Below CRP (ft)	9	8
River Variability \ Uncertainty (ft)	1	1
Depth for Bedload (ft)	0.5	0.5
Slope from Gage Location (ft/ft)	0.5	0.5
Target Flow Depth Below CRP (ft)	1.3	3.4
Total Excav. Depth Below CRP (ft)	12.3	13.37
River Mile	2017 CRP (NAVD 88)	25,000 cfs Minimum Service Invert (NAVD 88)
626.4	972.96	959.56
626	972.54	959.14
625.5	971.97	958.57
625	971.40	958.00

624	970.37	956.97

Excavation for the 300 foot wide full service flow channel will follow the existing navigation channel alignment located along the right descending bank. Excavation for the 200 foot wide minimum service flow channel will be located within the full service flow channel.

The excavation centerline examined the current sailing line, the revetment location, and the 1950's excavation extent. Downstream of the I-680 bridge, the preferred industry boat track was used to align navigation traffic through the bridge The alignment for the existing revetment toe was established from surveys. A 10 foot buffer was applied to create the right descending bank edge of cut. The left descending bank cut was determined as 300 foot maximum distance from the right bank.

The resulting excavation will encroach into the 1950's era left descending bank excavation limit in a few locations. It appears that the 1950's excavation did not attain a total 300 ft width channel in all areas. Maximum horizontal distance that must be cut into the higher elevation shelf to attain the 300 ft width is about 40 feet. Excavation depth in these areas is about 3 to 4 feet greater than the surrounding area. The extent where this occurs is limited to a few small areas.

The I-680 bridge piers are adjacent to the left descending edge of the 300 foot wide navigation channel. Plans illustrate that about 50 feet of clearance is maintained from the edge of cut to the bridge pier. A drawing note and coordinates was included to instruct the Contractor to avoid excavation work within 30 feet of the bridge piers.

Estimated Quantities

Excavation quantities were estimated for the removal areas to provide navigation channel flow depth. Quantities were determined for the base and options that provide the navigation channel dimensions at both full service and minimum service flow levels. The excavation plane used to compute quantities matches the current river slope. A summary of the excavation quantities is shown in (Table **4**).

Table **4.** Florence Reef Excavation Quantity Summary

Area	Quantity (cu yds)
Base - 200 ft width at minimum service invert profile	17,800
Option 1 - Expand to 300 ft width at same invert as base	23,400
Option 2 - Lower the 300 ft wide removal area by 2 feet	78,800

Hydraulic Modeling

Simulations were performed utilizing HEC-RAS 6.0 to quantify the effect the proposed modifications to the channel would have on hydraulics. An existing HEC-RAS model of the Missouri River was modified to accomplish the task. Bathymetry of the channel was updated utilizing the multi-beam hydrographic surveys collected in the fall of 2021. Proposed modifications were represented using the channel modification tools available within HEC-RAS' geometry editor.

Existing condition, Basic, Option 1, and Option 2 geometries were utilized in the simulations. Flows simulated included minimum service navigation, full service navigation, and frequency events consisting of the 50%, 10%, 2%, 1%, and 0.2% annual chance of exceedance events.

Simulations revealed that the proposed actions result in slight decreases in water surface (< .2' for all locations & flow rates) and negligible changes to the velocity of flow. Hydraulics changes are negligible

(<.02' change in water surface) approximately 15 miles upstream from the project in the proposed condition.

Future Degradation

As previously discussed, the Missouri River at Florence Bend experienced substantial degradation during the period from 2011 through 2020. Prior to this period, the stage-flow trends at Omaha had been relatively consistent.

Accounting for future degradation is highly dependent on the project flows. 2011 and 2019 were the two highest flow volume years on record since record keeping began in 1898. However, the response to these floods indicates that Gavins Point Dam degradation has progressed downstream to Omaha. Future floods will also likely generate degradation.

Future degradation and lowering of river water levels will occur at Omaha. Between 2010 and 2020, nearly 3 feet of water level decline at the full service navigation flow level occurred. A design value of 2 feet was used in the initial plans for additional excavation to account for future degradation. This value was selected to provide a minimum buffer within project funding constraints.

Construction Equipment and Methods

A summary of construction equipment and methods is provided in the following sections.

Construction methods will use a floating plant for operation and consist of tow vessels, work barges, and spud barges. Equipment will include excavators, trucks for off-site hauling, and support equipment for a typical river operation. Dredge operation equipment may also be used at the Contractor's preference.

The likely Contractor methods for material removal are discussed in the following sections. Florence Reef material properties may affect both removal and disposal methods.

The Florence Reef bedrock is generally a soft limestone or shale. The Missouri River Project Office excavated isolated high spots, or pinnacles, within the Florence Reef between April and June of 2021 to provide 9 foot depth at minimum channel flows. Using an excavator bucket with hardened penetrating teeth called "viper teeth", material was successfully peeled off in layers and then removed with the excavator. An example of material excavated in 2021 is shown in (Figure 11).

Figure 11. Florence Reef Material Removed in 2021

While no hard rock areas were encountered by the Missouri River Project Office during removal in 2021, isolated hard rock areas may exist where peeling with an excavator bucket is not successful. In those areas, removal with the assistance of a hydro-hammer operating underwater will be necessary. A hydro-hammer, or hydraulic hammer, is a cyclic water pump powered by hydropower. It takes in water at one "hydraulic head" (pressure) and flow rate, and outputs water at a higher hydraulic head and lower flow rate. The device uses the water hammer effect to develop pressure and fracture the river material to allow excavator removal. A hydro-hammer is shown in (Figure 12).

Figure 12. Typical Hydro-hammer

While the Geologic investigation found fractured material and the removal operations by the Missouri River Project Office in summer 2021 were successful with using only an excavator, the plans and specifications include language regarding use of a hydraulic hammer. The amount of area excavated with the hydraulic hammer will be dependent on the Contractor means and methods. The Contractor may elect to overuse the hydraulic hammer to speed excavator material removal. However, this could result in removed material being pulverized with less desirable size for placement on the BSNP disposal area revetment structures. The plans and specifications package will limit overuse of the hydraulic hammer to the extent practical without impeding Contractor progress.

Disposal will be dependent on Contractor methods and preference. Florence Reef material properties may affect both removal and disposal methods. All material excavated during operations by the Missouri River Project Office in 2021 was suitable for placement on existing navigation structures or use as small riprap / aggregate.

Excavated material placement may be placed on existing BSNP structures within 10 river miles of the Florence Reef removal area. Disposal would consist of placing material with an excavator on existing navigation structures to restore structure dimensions including revetment layer thickness, top of grade, and dike structure width.

Placement on a given structure is limited to a maximum layer thickness of 4 ft, a maximum elevation of +4' relative to the Missouri River's construction reference plane (CRP), with an average vertical placement height of 12-18 ft from the top of the revetment to the revetment toe. CRP is defined as the elevation equivalent to the 75% exceedance by duration flow during navigation season and is useful in defining maintenance elevations of navigation structures. This results in an approximate placement rate of 5 cy/ft. The angle of material should be similar to that of the existing revetment (~1.5H to 2H:1V) and should not result in material slumping past the existing toe of the structure, discounting the 4 ft layer thickness for the placement. Material disposal will be placed in a manner that will freely drain and not obstruct existing drainages.

Disposal is only allowed on certain revetment structures shown on plans.

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