Appendix J
Structural

Fargo-Moorhead Metropolitan Area Flood Risk Management

Final Feasibility Report and Environmental Impact Statement

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FARGO-MOORHEAD METRO FLOOD RISK MANAGEMENT PROJECT,

FEASIBILITY STUDY, PHASE 4

STRUCTURAL SUMMARY

APPENDIX J

PURPOSE

The following cover the description and selection of the major structural features in the project. The primary objective of this effort was to determine feasibility of design and establish reasonable quantities for the baseline cost estimate. The level of design was conducted to sufficient detail to attain the objective. There are Bridges Appendix E and Hydraulic Structures Appendix F included in Attachment 5. The contents of these appendices are summarized in the following paragraphs:

DESIGN AND ANALYSIS OF STRUCTURAL FEATURES

BRIDGES SUMMARY

The F-M Metro Flood Risk Management Project Feasibility Study, Phase 4 includes the evaluation of two diversion concepts. These include the Minnesota Diversion alternative (Federally Comparable Plan – FCP) and the North Dakota Diversion alternative (Locally Preferred Plan – LPP). This section documents the preliminary bridge design procedure used to develop cost estimates and preliminary bridge layout drawings for the two diversion alternatives under consideration, see Attachment 5, Appendix E. The two diversion alternatives require differing amounts of bridges as follows:

Alignment	No. of Highway Bridges	No. of RR Bridges
FCP	20	4
LPP	19	4

(Crossings at divided highways such as I-94 are counted as two bridges)
The following table shows the locations of the bridges for each of the alignments.

BRIDGE LOCATIONS

FCP	LPP
* Interstate 29 (SB)	County Highway 81 (South)
* Interstate 29 (NB)	Interstate 29 (NB-South)
+ 110th Avenue S	Interstate 29 (SB-South)
State Highway 75 (South)	48th Street SE
RR Bridge 4 near Hwy 75 South	170th Avenue SE
80th Avenue S	RR Bridge 4 near 46th Street N
60th Avenue S	46th Street SE
CSAH 52	44th Street SE
RR Bridge near CSAH 52	41st Street SE
50th Avenue S	Interstate 94 (EB)
Interstate 94 (EB)	Interstate 94 (WB)
Interstate 94 (WB)	RR Bridge 3 near I-94
RR Bridge 2 @ Dilworth Yard	36th Street SE
US Highway 10 (EB)	33rd Street SE
US Highway 10 (WB)	RR Bridge 2 near 33rd Street SE
28th Avenue N	31st Street SE
57th Avenue N	28th Street SE
CR 14	Interstate 29 (SB-North)
90th Avenue N	Interstate 29 (NB-North)
100th Avenue N	RR Bridge 1 near Co Hwy 81
State Highway 75 (North)	County Hwy 81 (North)
RR Bridge 1 near Hwy 75 North	25th Street SE
110th Avenue NW	173rd Avenue SE
15th Street NW	

* Wild Rice breakout channel
+ Auxiliary channel

DESIGN BASIS

The conceptual bridge designs were developed in accordance with the following specifications and manuals: AASHTO LRFD Bridge Design Specifications, Current Edition; Current MnDOT LRFD Bridge Design Manual; Current NDDOT LRFD Bridge Design Manual.

The superstructures for all of the bridges are of prestressed concrete girders with cast in place concrete decks. Steel plate girder superstructures were evaluated for comparison, but were found to be more costly than the prestressed concrete bridges, and therefore, are not presented here. The substructures consist of concrete wall piers and concrete abutments supported on steel H-piling. The pile termination elevation was assumed to be approximately 100 feet below existing grade, which is consistent with typical bridges in the area. A typical section and elevation views of the bridge structures are included in Plates 1 through 11 of Attachment 5, Appendix E.

Approach costs were estimated based on raising the roadways to tie into the proposed bridge elevations. Minimum vertical and horizontal (if applicable) curves were designed and fill quantities were estimated based on the difference between proposed and existing grades. Pavement, guardrail, aggregate base, embankment, and other misc. costs were included in the estimates.

Preliminary designs were performed for each type of bridge (based on roadway classification) for both the FCP and LPP alternatives.

The bridge types and associated width are as follows:

MN Divided Highway (I-94 and US 10)	42' clear roadway
MN State Highway	48' clear roadway
MN Local Roads	32' clear roadway
ND Divided Highway (I-29 and I-94)	40' clear roadway
ND Local Roads	28' clear roadway

BRIDGE LENGTH DETERMINATION

Bridge lengths were calculated for each bridge location for each of the alternatives using Excel spreadsheets. The bridge lengths were based on the channel bottom width and elevation, channel slopes consistent with the rest of the channel geometrics (7:1 slopes, bench, then 7:1 slopes), and the estimated deck elevation. The deck elevation was computed by taking the 500-year water surface elevation at the structure and adding freeboard and the superstructure depth. The freeboard was assumed to be 3'-0" and the superstructure depth was approximately 5'-5". The water surface elevations, channel bottom elevations, and existing ground elevations were taken from the HEC-RAS models provided by Moore Engineering, Inc.

For some bridge locations, the calculated deck elevation was lower than the existing ground elevation. In those cases, the bridge length was based on matching the bridge deck elevation to the existing ground elevation.

Exhibit A shows the Bridge Length Determination spreadsheets for the Minnesota Diversion (FCP) and North Dakota Diversion (LPP) alternatives. The calculated bridge lengths were averaged and rounded to the nearest 20 feet.

COST BASIS

A detailed cost estimate was performed for two bridges of varying length and span counts to establish an average superstructure unit cost per square foot of bridge deck. The superstructure unit cost for each bridge type was then applied to the bridge widths and lengths determined for each bridge location. Site specific pier costs were calculated and added to the superstructure cost to account for the various pier heights and span counts found at each bridge. Pier heights for each bridge were assumed to be the same independent of channel slope to be conservative for estimating. The quantities used in the detailed cost estimates were estimated using an Excel spreadsheet, with estimated dimensions of all of the bridge components. The unit prices used in the detailed cost estimates were based on recent average bid prices obtained from websites of the Minnesota and North Dakota Departments of Transportation. See Exhibit B for a Detailed Cost Estimate example spreadsheet.

RAILROAD BRIDGE COST ESTIMATES

The railroad bridge locations for both the Minnesota Diversion (FCP) and North Dakota Diversion (LPP) Alternatives are listed in the above table for reference only. The costs estimates associated with these structures were developed separately and are included in Attachment 5, Appendix G, the Cost Appendix.

HYDRAULIC STRUCTURES SUMMARY

INTRODUCTION

This Appendix F of the February 28, 2011 submittal (Phase 4 report) represents an updated and revised version of the Appendix F included in the August 6, 2010 submittal (Phase 3 report). The updates and revisions have been driven by design modifications primarily associated with changes to the hydrology and hydraulic modeling. The updates and revisions presented include staging of water upstream of the Diversion Channel, construction of an engineered storage area, more detailed hydraulic modeling including use of a HEC-RAS unsteady flow model for project feasibility design, revised hydrology (in particular, for the ND tributaries: Wild Rice River, Sheyenne River, Maple River, Lower Rush River and Rush River), additional fish passage and ice control considerations, new geotechnical information and analysis, different structural design criteria, and enhanced grading development of the hydraulic structures. Furthermore, the updates and revisions incorporate the majority of the comments received from the U.S. Army Corps of Engineers (USACE) Project Delivery Team (PDT), USACE Agency Technical Review (ATR), USACE Independent External Peer Review (IEPR), the City of Fargo (North Dakota), the City of Moorhead (Minnesota), and the Natural Resources Agencies.

This Appendix F of the Phase 4 report presents the feasibility design of the major hydraulic structures required for two alternatives:

- Minnesota Short Alignment 35,000 cfs Alternative (MN Short 35K), Federally Comparable Plan (FCP); and

- North Dakota East Alignment, Locally Preferred Plan (LPP).

The FCP alternative corresponds to a target diversion flow (35,000 cfs when the 500-yr flood event occurs in the Red River of the North) and no staging or storage upstream of the diversion works, which results in some impacts on flood levels downstream of the diversion (henceforth referred to as downstream impacts). Hydraulic structures along the FCP were not redesigned during Phase 4. Feasibility designs of the FCP presented in this Appendix F refer to Phase 3 hydrology using a HEC-RAS steady flow model and are included for completeness. The LPP alternative corresponds to target stages (water surface elevations) at the U.S. Geological Survey (USGS) gage in Fargo for specific design flood events in the Red River of the North, but including staging and storage immediately upstream of the diversion works to eliminate downstream impacts. The major hydraulic structures included in the two alternatives are presented in Table F1, and their approximate locations are presented in Figure F01.

The design presented here has been carried out to a feasibility level using general hydrologic, hydraulic, environmental, geotechnical, structural and civil design considerations. Given the constraints imposed by the amount and quality of the information available and the timeframe to complete the feasibility study of the project, these designs are deemed sufficient to develop Class 3 cost estimates (see Appendix G) for congressional budgetary appropriation per USACE Engineer Regulation ER 1110-2-1302. However, it is acknowledged that additional investigations on fish passage, ice engineering and sediment transport; future updates to the hydrology; refinements of the HEC-RAS unsteady flow model; physical modeling of some of the hydraulic structures; detailed structural design; and additional site specific information (e.g., topography, soil borings, soil mechanics laboratory tests, field-scale pile driving tests) that become available for further evaluation of the alternative selected in the next stage of study and design may result in changes to the proposed configuration and functioning of the hydraulic structures.

Federally Comparable Plan (FCP)
The following information regarding the FCP was previously presented as part of Appendix F in the Phase 3 report, and is included here for completeness. The FCP results and hydraulic structure designs discussed below refer to the HEC-RAS steady flow models developed as part of the Phase 3 feasibility analysis.

Section F2.1 of Appendix F (included in attachment 5) discusses the feasibility design of the Control Structure and Fishway on the Red River of the North and Inlet Structure of the Diversion Channel for the FCP. The flows to divert from the Red River of the North into the FCP Diversion Channel for the Year 0, 25 and 50 hydrology are presented in Figure F17, whereas the general layout and cross sections of these diversion structures are presented in Drawings S-401 through S-405.

Section F2.1 also discusses the feasibility design of the Outlet to the Red River of the North from the FCP Diversion Channel. The general layout of this structure is presented in Drawing S-406.

Control Structure on Red River of the North, (FCP)
The general design considerations discussed below also apply to the Red River Control Structure for the LPP.

For the FCP, a Control Structure located on the Red River of the North immediately downstream of the Inlet Structure of the Diversion Channel is necessary to limit the amount of water flowing into the Protected Area (i.e., the Cities of Fargo, ND and Moorhead, MN). Another design goal for this structure is to avoid increasing water surface elevations upstream in the Red River of the North for the 100-yr and 500-yr flood events, while minimizing differences in water surface elevations between existing conditions and with-project for smaller flood events. Because of the former consideration, using gates that are raised from the bottom of the Red River of the North, as in the Manitoba Floodway, is not a feasible option. Maintaining the rating curve upstream of the diversion would help to keep the observed (natural) runoff storage in the floodplain upstream of the study area, and consequently, to keep the associated peak flow attenuation effect. In addition, maintaining the rating curve upstream of the diversion should help to reduce the potential for adverse morphologic impacts in the Red River of the North (e.g., development of head cutting along the main channel as a result of increased flow velocities due to stage reduction without discharge reduction). See attachment 5, Appendix F, Section F2.1.1, for detailed discussion and description of the design.

Fish Passage on Red River of the North, (FCP)
The general design considerations discussed below also apply to the fish bypass channel on the Red River of the North for the LPP.

Fish passage consisting of multiple parallel channels of alternating pools and riffles would allow fish to move upstream of the Control Structure for flows up to the 50-yr flood event on the Red River of the North. Additional details, tables, and figures regarding the design of fish passages at the FCP Control Structure are presented in Exhibit G. See attachment 5, Appendix F, Section F2.1.2, for detailed discussion and description of the design.

Inlet Weir on Red River of the North, (FCP)
The configuration of the Inlet Structure on the Diversion Channel depends on the configuration of the Red River Control Structure. Different combinations of proposed configurations for these two hydraulic structures are presented in Exhibit B, including a qualitative assessment of the advantages and disadvantages of each concept in terms of hydraulic performance, handling of flood flows and low flows, potential environmental impacts, permitting, and operation and maintenance. For this feasibility design, the concept selected for the Inlet Structure on the Diversion Channel is the one that (when combined with the Red River Control Structure) would better accomplish the project goals outlined above. This concept consists of a passive (i.e., no gates or movable parts) compound weir with a crest elevation approximately 0.5 ft above the water surface elevation for the 3.6-yr event (9,600 cfs). The compound weir has been selected to maximize diversion efficiency for the different return periods analyzed while not modifying flood elevations upstream of the Control Structure. See Attachment 5, Appendix F, Section F2.1.3, for detailed discussion and description of the design.

Outlet to Red River of the North, (FCP)
Similar to the design for the Breckenridge Diversion Project, the Outlet of the FCP Diversion Channel into the Red River of the North consists of riprap over approximately the downstream 300 ft of the Diversion Channel. See Attachment 5, Appendix F, Section F1.1.4, for detailed discussion and description of the design.

Locally Preferred Plan (LPP)
The feasibility design of the LPP hydraulic structures was developed together with the feasibility design of the LPP Diversion Channel (see Figures F02 and F04; or for more details see Consultant's Appendix C), such that the incorporation of staging and storage immediately upstream of the diversion works

(see Figure F03) would not only allow to meet the stages at the USGS gage in Fargo that were met in Phase 3 (i.e., project benefits in Phase 4 would be the same as in Phase 3), but would also help to eliminate downstream impacts. Thus, the overall concept of the LPP evolved from diversion only in Phase 3 to diversion and staging/storage in Phase 4.

Control Structure on Red River of the North, (LPP)

For the LPP, a Control Structure located on the Red River of the North immediately downstream of the Connecting Channel (but upstream of the confluence with the Wild Rice River) is necessary to limit the amount of water flowing into the Protected Area (i.e., the Cities of Fargo, ND and Moorhead, MN). Another design goal for this structure is to increase water surface elevations upstream in the Red River of the North during flood events, in order to eliminate downstream impacts. As indicated in Appendix C, one main objective of the Fargo Moorhead diversion project is to lower stages sufficiently on the Red River of the North to significantly reduce flood damages in the Protected Area and thus to provide benefits that would justify the relatively elevated project cost. Therefore, a great level of active control and management (through gates operation) of the flows that pass into the cities is warranted.

The configuration of the Red River Control Structure (and also that of the Wild Rice River Control Structure) depends on the configuration of the primary Diversion Inlet Structure (see Section F2.2.3). Different combinations of proposed configurations for these two hydraulic structures are presented in Exhibit B, including a qualitative assessment of the advantages and disadvantages of each concept in terms of hydraulic performance, handling of flood flows and low flows, potential environmental impacts, permitting, and operation and maintenance. For this feasibility design, the concept selected for the Red River Control Structure is the one that would better accomplish the project goals outlined above. This concept consists of a concrete gravity dam with three 50 ft-wide bays (other possible gates configurations are presented in Exhibit D), each including a lower ungated area and an upper gated area per bay (using primary tainter gates, and secondary bulkheads in case the tainter gates malfunction), and wingwalls. In addition, a gated secondary by-pass channel for fish passage (i.e., the fishway) will be located on one of the sides of the primary Control Structure. Following discussions with the USACE-PDT, the Control Structure is recommended to be built off the existing Red River of the North channel. See attachment 5, Appendix F, Section F2.2.1, for detailed discussion and description of the design.

Fish Passage on Red River of the North, (LPP)

A fish passage channel was designed to allow fish to travel from downstream to upstream of the Red River Control Structure when the gates are partially closed and flow velocities are very high at the primary bays. The fish passage would allow fish migration for flows up to the 50-yr flood event on the Red River of the North. Fish passages at the Red River Control Structure (and also at the Wild Rice River, Lower Rush River and Rush River) are designed with consideration to several criteria based on discussions with the USACE-Environmental, the Natural Resources Agencies, and the feasibility design in the USACE‟s Lock and Dam 22 Fish Passage Improvement Project Implementation Report – Appendix H. See attachment 5, Appendix F, Section F2.2.2, for detailed discussion and description of the design.

Diversion Inlet Structure, (LPP)
Because of the upstream staging required in the Phase 4 feasibility design, the Wild Rice River east and west weirs considered in Phase 3 have been dropped in Phase 4. It is also important to indicate that the Connecting Channel between the Red River of the North and Wild Rice River and the one between the Wild Rice River and the Diversion Inlet Structure are mostly intended to facilitate drainage during average flow to frequent flood events rather than to enhance hydraulic conveyance in these areas during the larger design floods. See Attachment 5, Appendix F, Section F2.2.3, for detailed discussion and description of the design.

Control Structure on Wild Rice River, (LPP)
For the LPP, a Control Structure located on the Wild Rice River north (immediately downstream) of the Connecting Channel (but upstream of the confluence with the Red River of the North) is necessary to limit the amount of water flowing into the Protected Area (i.e., the cities of Fargo and Moorhead). The design goal for this structure is similar to that for the one on the Red River of the North, and the qualitative assessment of alternative concepts presented in Exhibit B also applies to this structure.

For this feasibility design, the concept selected for the Wild Rice River Control Structure is the one that would better accomplish the project goals, with the understanding that a single large pool will form upstream of the Control Structures at the Red River of the North and Wild Rice River, from which water will be diverted through the Diversion Inlet Structure into the LPP Diversion Channel. The concept for the Wild Rice River Control Structure consists of a concrete gravity dam with two 30 ft-wide bays (using primary tainter gates, and secondary bulkheads in case the tainter gates malfunction), and wingwalls. In addition, a gated secondary by-pass channel for fish passage (i.e., the fishway) will be located on one of the sides of the primary Control Structure. Following discussions with the USACE-PDT, the Control Structure is recommended to be built off the existing Wild Rice River channel. See Attachment 5, Appendix F, Section F2.2.4, for detailed discussion and description of the design.

Fish Passage on Wild Rice River, (LPP)
A fish passage channel was designed to allow fish to travel from downstream to upstream of the Control Structure for flows up to the 50-yr flood event on the Wild Rice River. The feasibility design considerations used to size the fish passage facility on the Wild Rice River are very similar to those on the Red River of the North. Therefore, they will not be repeated here, except for some specifics applicable to this facility. Details, tables, and figures regarding the design of fish

passages at the LPP Control Structure are presented in Exhibit G. See Attachment 5, Appendix F, Section F2.2.5, for detailed discussion and description of the design.

Diversion Channel Transition and Aqueduct at the Sheyenne River, (LPP)
A combination of three hydraulic structures is proposed at the LPP Diversion Channel crossing of the Sheyenne River; a transition on the Diversion Channel, and an aqueduct and a spillway on the tributary. An aqueduct structure was chosen for three main reasons: there is a significant difference in the elevations (approximately 15 ft) of the thalweg in the Sheyenne River and the invert of the Diversion Channel, local sponsors prefer to minimize the number of "active operation" structures, and it provides a good solution for fish and ice passage. One intention of these structures is to allow conveyance of the entire tributary flow into the Protected Area for flows up to the local 2-yr flood event in the Sheyenne River. Allowing flows up to the 2-yr event will minimize impacts to aquatic ecosystems, fish passage, sediment transport and channel morphology upstream and downstream of the proposed diversion. On the other hand, the other intention of these structures is to maximize diversion of tributary flows into the LPP Diversion Channel for flows larger than the local 2-yr flood event in the Sheyenne River. During these times when a portion of the flow is diverted, the structures will allow a fraction of the Sheyenne River flow (somewhat greater than the local 2-yr flow) to pass through the aqueduct to the Protected Area while maximizing flows diverted (through the spillway) to the diversion channel. See Attachment 5, Appendix F, Section F2.2.6, for detailed discussion and description of the design.

Spillway at Sheyenne River, (LPP)
A weir spillway has been selected to divert waters from the tributary into the LPP Diversion Channel. The main design criteria used for designing the weir spillway are:

- The crest of the weir spillway will be set, as a minimum, at the water surface elevation on the tributary associated with the 2-yr local flood event, allowing the entire 2-yr flow to pass into the Protected Area of the tributary;
- The length of the weir spillway will be such to maximize diversion flows into the LPP Diversion Channel, hence to minimize the maximum flow into the Protected Area of the tributary during the occurrence of the 500-yr local flood event; and
- The weir spillway can maximize diversion flows from the tributary into the LPP Diversion Channel for coincidental events, when the anticipated head available could be less than for local events.

See Attachment 5, Appendix F, Section F2.2.7, for detailed discussion and description of the design.

Diversion Channel Transition and Aqueduct at Maple River, (LPP)

A combination of three hydraulic structures is proposed at the LPP Diversion Channel crossing of the Maple River; a transition on the Diversion Channel, and an aqueduct and a spillway on the tributary. An aqueduct structure was chosen for three main reasons: there is a significant difference in the elevations (approximately 7 ft) of the thalweg in the Maple River and the invert of the Diversion Channel, local sponsors prefer to minimize the number of “active operation” structures, and it provides a good solution for fish and ice passage. One intention of these structures is to allow conveyance of the entire tributary flow into the Protected Area for flows up to the local equivalent 2-yr flood event in the Maple River. The term equivalent is used here because the 2-yr local flows along the Rush River and Lower Rush River are included in this quantity. The Lower Rush and Rush Rivers are entirely diverted into the Diversion Channel. Therefore, the 2-yr equivalent flow from those rivers (717 cfs combined) is added to the Maple River 2-yr local flow (970 cfs) to obtain the equivalent 2-yr local flow (1,687 cfs). Allowing flows up to the 2-yr event will minimize impacts to aquatic ecosystems, fish passage, sediment transport and channel morphology upstream and downstream of the proposed diversion. On the other hand, the other intention of these structures is to maximize diversion of tributary flows into the LPP Diversion Channel for flows larger than the equivalent 2-yr flood event in the Maple River. During these times when a portion of the flow is diverted, the structures will allow a fraction of the Maple River flow (somewhat greater than the equivalent 2-yr flow) to pass through the aqueduct to the Protected Area while maximizing flows diverted (through the spillway) to the Diversion Channel. See Attachment 5, Appendix F, Section F2.2.8, for detailed discussion and description of the design.

Spillway at Maple River, (LPP)

A weir spillway has been selected to divert waters from the tributary into the LPP Diversion Channel. The main design criteria used for designing the weir spillway are:

- The crest of the weir spillway will be set, as a minimum, at the water surface elevation on the tributary associated with the equivalent 2-yr local flood event, allowing the entire 2-yr flow to pass into the Protected Area of the tributary;
- The length of the weir spillway will be such to maximize diversion flows into the LPP Diversion Channel, hence to minimize the maximum flow into the Protected Area of the tributary during the occurrence of the 500-yr local flood event; and
- The weir spillway can maximize diversion flows from the tributary into the LPP Diversion Channel for coincidental events, when the anticipated head available could be less than for local events.

The design concept for the spillway from the Maple River to the LPP Diversion Channel is similar to that used for the spillway from the Sheyenne River to the LPP Diversion Channel. See Attachment 5, Appendix F, Section F2.2.9, for detailed discussion and description of the design.

Drop Structure at Lower Rush River, (LPP)

The type of structure recommended for the Lower Rush River is a stepped concrete spillway that will divert all flows directly into the LPP Diversion Channel. Fish passage between the upstream portion of these rivers and the LPP Diversion Channel would be accommodated by a separate low flow channel. The existing portions of the Lower Rush River and Rush River downstream of the Diversion Channel are primarily straight drainage channels and do not display many characteristics typically associated with natural streams. Downstream of the confluence of the Lower Rush fish passage and the LPP Diversion Channel, habitat enhancements and low flow channel meandering would be implemented, thereby increasing the quality and quantity of habitat in these rivers, when compared to existing conditions. This is further discussed in Exhibit K. See Attachment 5, Appendix F, Section F2.2.10, for detailed discussion and description of the design.

Fish Passage on Lower Rush River, (LPP)

Fish passage consisting of a single channel of alternating pools and riffles allows fish to move between the Diversion Channel and the Lower Rush River for events ranging up to approximately the 10-yr event on the Red River. Additional details, tables, and figures pertaining to the design of fish passage at the Lower Rush River Drop Structure is included in Exhibit G. See Attachment 5, Appendix F, Section F2.2.11, for detailed discussion and description of the design.

Drop Structure at Rush River, (LPP)

The design of the drop structure at the Rush River is similar to the design for the Lower Rush River outlined in Section 2.2.10. Exhibit D presents the hydraulic design for the diversion structures on the Rush River. The rise and run of the drop structure steps are 1.1 and 1.7 ft, respectively. The stepped spillway is placed several feet upstream of the confluence of the river bed and the LPP Diversion Channel side slope. The stilling basin downstream of the stepped spillways has been sized by calculating the head loss over the steps under skimming flow during 10-yr floods and larger events. Tailwater effect was not incorporated in sizing the stilling basins. The channel bed from downstream of the stilling basin to the bed of the LPP Diversion Channel is assumed to be lined with riprap. The resulting designs are presented in Table F10. See attachment 5, Appendix F, Section F2.2.12, for detailed discussion and description of the design.

Fish Passage on Rush River, (LPP)

The design considerations used for the fish passage at the Rush River are similar to those at the Lower Rush River (see Section F2.2.11), and they will not be repeated here except for some specifics applicable to this facility. Additional details, tables, and figures regarding the design of fish passages at the Rush River Drop Structure are presented in Exhibit G. See Attachment 5, Appendix F, Section F2.2.13, for detailed discussion and description of the design.

Outlet Structure to Red River of the North, (LPP)

The Phase 3 Outlet of the Diversion Channel into the Red River of the North consisted of riprap over the downstream 300 ft of the Diversion Channel. This outlet configuration was possible because the Outlet Structure elevation was near the bottom of the Red River. However, with the introduction of staging in Phase 4, the peak flows diverted through the Diversion Inlet Structure was reduced from 35,000 cfs down to 19,000 cfs. As a result the cross sectional area of the Diversion Channel was reduced and the bottom invert was raised. As a consequence of these changes, the drop into the Red River at the Outlet Structure has increased from approximately 11 ft to 20 ft. See Attachment 5, Appendix F, Section F2.2.14, for detailed discussion and description of the design.

Storage Area 1, (LPP)

The hydraulic design of Storage Area 1 focused on assessing alternatives inlet and outlet controls. Exhibit E presents the feasibility design analysis for Storage Area 1. This feasibility design is also presented in Drawings S-414 and S-418 through S-420. The footprint of Storage Area 1 is 4360-acres. The peak storage during the 100-yr and 500-yr design flood events is over 55,000 acre-ft. During flood events water enters and leaves Storage Area 1 through the 1400-ft wide Inlet-Outlet Opening near the Wild Rice River Control Structure at the southeast corner of the storage area. The hydraulic analysis of Storage Area 1 evaluated the benefits of different opening widths, inlet elevations and locations along the south side of the storage area.

The inlet elevation generally has the largest effect on smaller flood events. A higher inlet elevation delays the point at which Storage Area 1 begins receiving water from the diversion system. It also increases the amount of water that is retained in the storage area after the flood has passed. Existing ground elevations set the practical lower limit for an inlet elevation. The existing ground along the southern portion of Storage Area1 ranges from elevation 911 to 915. The preliminary design uses an elevation of 910, with the assumption that some grading will be required to facilitate internal drainage within the storage area and also provide a way for water to enter the area that is slightly below existing grades. By setting the inlet elevation as low as feasibly possible, the storage area can be utilized during smaller flood events as well as large ones. See Attachment 5, Appendix F, Section F2.2.15, for detailed discussion and description of the design.

Wolverton Creek Control Structure, (LPP)

For the LPP, a Control Structure located on Wolverton Creek is necessary to limit the amount of water flowing into the Protected Area (i.e., the cities of Fargo and Moorhead). The proposed Wolverton Creek Control Structure functions as an open-close structure and is shown in Drawings S-411 and S-412. In other words, the Control Structure remains completely open during low flow events when it is desirable to have little impact on flows and water surface elevations during the smaller, more frequent flood events. During larger flood events the gates are completely closed. The flows on Wolverton Creek are very small compared to flows on the Red River and Wild Rice River which determine how high water is staged upstream of the project. For this reason, the gates on Wolverton Creek are fully closed, and flows conveyed into the Protected Area are controlled by the gates located on the Red River and Wild Rice River. The gates at the Wolverton Creek Control Structure would be opened following the flood event. See Attachment 5, Appendix F, Section F2.2.16, for detailed discussion and description of the design.

Local Drains Drop Structure, (LPP)

The design of the drop structure at Drain 14 is similar to the design for the Rush River and Lower Rush River (see Sections F2.2.10 and F2.2.12). Exhibit F presents the hydraulic design for the stepped drop structure. The drop structure is also shown in Drawing S-430. The rise and run of the drop structure steps are 0.7 and 1.5 ft, respectively. The stilling basin downstream of the stepped spillway has been sized by calculating the head loss over the steps under skimming flow during 10-yr floods and larger events. Tailwater effect was not incorporated in sizing the stilling basins. The channel bed from downstream of the stilling basin to the bed of the LPP Diversion Channel is assumed to be lined with riprap. See Attachment 5, Appendix F, Section F2.2.17, for detailed discussion and description of the design.

Standard Project Flood (SPF) Analysis

The tie-back levees south of the project were determined by analysis of the Standard Project Flood (SPF). Levee heights were selected so that during an SPF event, which is larger than the 500-yr event, flows will overtop County Road 17 and be conveyed west prior to overtopping the main east-west levee and flowing into the Protected Area. SPF hydrographs were provided by the USACE in order to set the levee heights south of the project.

The top of the north-south levee along County Road 17 was set at elevation 923, or the elevation to which water is staged during floods larger than the 100-yr event. The top of the east-west levee (i.e., the main levee that runs through the Control Structures on the Wild Rice River, Red River, and Wolverton Creek) was set at elevation 927. See Attachment 5, Appendix F, Section F2.2.18, for detailed discussion and description of the design.

GEOTECHNICAL ENGINEERING

The geotechnical engineering of the hydraulic structures, including description of available geotechnical data, seepage analysis, slope stability and pile capacity, are described below. See Attachment 5, Appendix F, Section F3.0, for detailed discussion and description of the design.

STRUCTURAL DESIGN

The structural design of the hydraulic structures, including loads, load combinations, reinforced concrete design, pile design, sheet piles, and assumptions are described below. The structural design performed for this Phase 4 study is at the feasibility level only, to support feasibility cost estimates for the proposed project. See Attachment 5, Appendix F, Section F4.0, for detailed discussion and description of the structural design.

CIVIL DESIGN AT HYDRAULIC STRUCTURES

The purpose of this section of Appendix F is to provide general information related to the siting and civil site design of the hydraulic structures associated with this project. After providing some general background data related to the sources of the data used in the civil design the discussion will address each major structure. Structures addressed will include:

- The Red River and Wild Rice River Control Structures
- The Sheyenne and Maple River Aqueducts
- The Lower Rush and Rush River drop structures
- The connecting channel weir, the primary Inlet Structure to the Diversion and Outlet Structure to the Red River of the North
- Additional structures related to Wolverton Creek, Drain 14, and Storage Area 1
- Storage Area 1

See Attachment 5, Appendix F, Section F5.0, for detailed discussion and description of the design.

ICE IMPACTS ON PRELIMINARY DESIGNS

An independent study on the impact of ice on the preliminary structural design was conducted by the Ice Engineering Group, part of the US Army Engineer Research and Development Center. The report and figures are included In Attachment 5, Appendix F, Exhibit J-Ice.

- Although peak stages on the Red River of the North (RRN) are often ice-affected, the ice breakup on the RRN is typically gradual with little dynamic movement of ice floes. Ice jams do occur however, and when the river is already at or above flood stage, these jams can greatly exacerbate the situation. During the peak floods 1997 and 2009, much flow was out of bank with short sections of sheet ice remaining in the channel bends.

- The long-term RRN gage data suggest an increasing trend in annual peak discharge magnitude and variability, with the bulk of the peak flow events occurring during the ice season. If it is decided that these trends are real, some conservatism may need to be added to design to accommodate increased future peak discharges.

- Under flood conditions, in the area of the proposed diversion structure, the 40-50 ft depths and low approach velocities will cause sheet ice and large floes to accumulate upstream of the structure without passing the gates. Provided the floes accumulate edge-to-edge and do not thicken into a multi-layer ice accumulation, this does not pose a problem in terms of ice passing into the diversion channel, provided the ice can be retained in the RRN (see Item 4 below).

  Ice may pass the gates at the 2 and 5 year discharges provided the ice floes do not arch and stop upstream of the gate opening(s).

- The project design must include provisions to prevent RRN ice floes from entering the diversion canal(s). This might consist of rows of piers or piles to retain the floes in the main channel of the RRN. Depending on hydraulic conditions it may be possible to retain the ice floes in the main river channel using the less expensive alternative of ice booms. The necessity and design of ice retention schemes will depend on further analysis of expected ice conditions and ice processes in the vicinity of the canal entrances need to be examined in detail.

- The crossing structure at the Wild Rice River will have similar ice issues as the RRN diversion structure. It is predicted that the gated structure will retain Wild Rice river ice under all but the lowest flood discharges. At the Sheyenne and Maple crossing structures, ice accumulations are possible at the transitions from the natural channels to the aqueducts. This will be acceptable as long as the accumulated ice does not shove-thicken into a multi-layer ice jam. As with the RRN diversion structure, provisions will be needed retain ice in tributary channels and prevent it from passing into the diversion canal.

- Changes in the breakup period hydrograph as a result of the project, and how the bypassed flow re-enters the RRN need to be examined, particularly in terms of causing ice jams where none occurred before.