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Distributed Storage Alternative
Final Report

Prepared for:

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1.0 Summary

The Fargo-Moorhead Metropolitan Area (Metropolitan Area) has a long history of extreme flooding with the frequency of such flooding events increasing in the recent past. Local governmental units and the U.S. Army Corps of Engineers (USACE) are in the process of designing and reviewing a project to mitigate the potential flood disasters in the area (Project). The goals and purpose of the Project are stated in the Final Scoping Decision Document (FSDD) (February 2014) and presented in Section 2.0-Background in this report. The project purpose will be evaluated relative to Federal Emergency Management Agency (FEMA) requirements and standards for a riverine flood mitigation project.

This report focuses on the Distributed Storage Alternative (DSA) which examines utilizing potential storage areas within the upstream contributing major subwatersheds to reduce flow rates through the Metropolitan Area in combination with structural and non-structural measures to reduce flood risk. The DSA was conceptualized during the public comment and alternative screening process as part of the State of Minnesota environmental review for the Project.

This report is intended to provide a preliminary review and analysis of the available information relevant to the DSA as it relates to its ability to achieve FEMA accreditation and meet the project's purpose. The discussion is focused on helping make an informed decision on whether the DSA meets the purpose and objectives of the Project. Applicable FEMA requirements and standards for a riverine flood mitigation project were used to evaluate the DSA and compare it to the Project purpose and objectives. Additional documents referenced in this report are provided in Section 5.0-References. The following summarizes the primary findings from the DSA analysis.

Summary of Primary Findings on the Distributed Storage Alternative

Project Purpose and Objectives	Effectiveness of Distributed Storage and Phase 2 Levee System
Reduce flood risk potential associated with a long history of frequent flooding on local streams including the Red River of the North, Sheyenne, Wild Rice (ND), Maple, Rush, and Lower Rush Rivers passing through or into the Metropolitan Area	• The Phase 2 levee system combined with distributed storage provides protection to downtown areas of the Fargo and Moorhead Metropolitan Area along the mainstem of the Red River. • The levee system does not protect the western Fargo area. • Distributed Storage has minimal to no impact on the peak flows along the Sheyenne River, therefore has no impact on reducing flood risk from this major tributary river. • Building levees along the Sheyenne River is not feasible due to lack of high ground to tie into and break out flows along the upstream reaches of the river.

Project Purpose and Objectives	Effectiveness of Distributed Storage and Phase 2 Levee System
Qualify substantial portions of the Metropolitan Area for 100-year flood accreditation by the Federal Emergency Management Agency (FEMA), under the National Flood Insurance Program (NFIP)	• When combined with upstream distributed storage, the Phase 2 levee system can marginally meet the 3-feet freeboard requirement for FEMA accreditation for the downtown areas of the cities of Fargo and Moorhead for the 100-year flow on the Red River. • FEMA accreditation requires certification of the levee system and will have to be completed by the USACE. The USACE certification is based on risk and uncertainty, and requires the levees to provide protection up to the 90 percent assurance flow rates. • As distributed storage would have little impact on reducing peak flow rates on the Sheyenne, minimal impact can be achieved in FEMA accreditation for areas flooded by the Sheyenne River and tributaries. • Building levees along the Sheyenne River is not feasible due to lack of high ground to tie into and break out flows along the upstream reaches of the river.
Reduce flood risk of floods exceeding the 1 percent event (100-year or greater), given the importance of the Metropolitan Area to region and recent frequencies of potentially catastrophic flood events	• The Phase 2 levee system can provide reduction in flood risk for higher than 100-year flows on the Red River for the downtown areas of Fargo and Moorhead when combined with distributed storage and upstream staging. • Risk of levee overtopping along the Red River increases substantially for higher than 100-year flow events. • The DSA cannot provide flood protection from the Sheyenne, Maple, and Rush River tributaries for higher than 100-year events as distributed storage does not reduce the break out flows that can contribute to flooding. • Immediate upstream staging is critical when considering the Phase 2 levees for flood protection for flows higher than the 100-year event; therefore land use management such as zoning, easements or declaration of a floodway to match the existing 100-year flood extent upstream of the levees along the Red and Sheyenne Rivers would be needed.

2.0 Background

2.1 PURPOSE AND NEED FOR THE PROJECT

The Fargo-Moorhead Metropolitan Area has a long history of flooding due to the unique hydrology of the area. Three large rivers, the Red River of the North, the Wild Rice River (ND), and the Sheyenne River, converge in the Metropolitan Area and contribute to extensive flooding. Additionally, the Maple, Rush and Lower Rush are tributary rivers to the Sheyenne and join the Sheyenne River immediately west of Fargo. The geographic characteristics of the area and the large watershed draining through the Red River contribute to the higher flood risk for the two cities and surrounding area. Average annual economic flood damage in the Metropolitan Area is estimated to exceed $195 million. The flooding poses a serious risk of damage to urban and rural infrastructure and disrupts transportation throughout the area. Figure 1 shows the location and general layout of the Metropolitan Area.

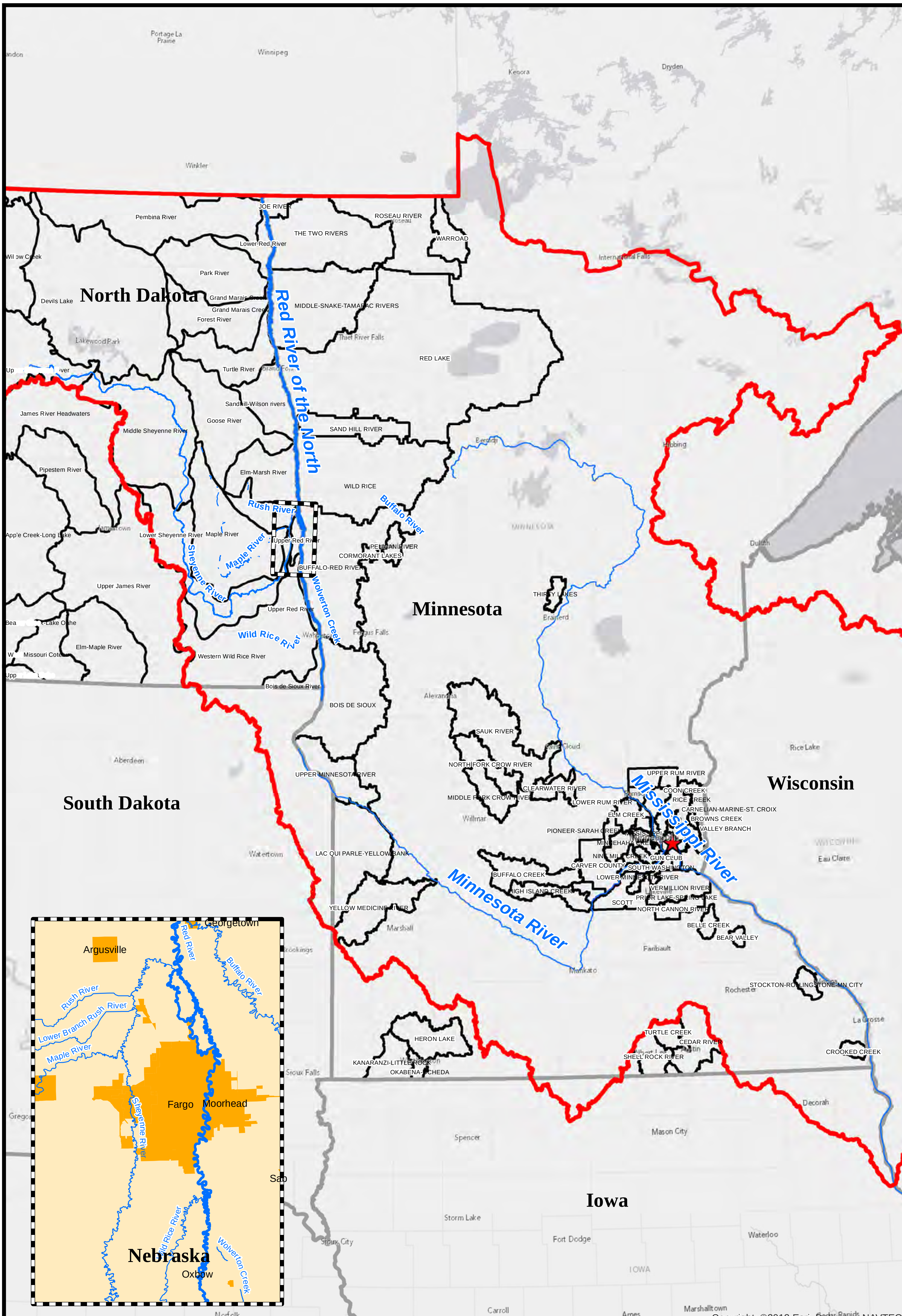
The Red River has exceeded flood stage close to half the time during the past century with flooding typically occurring during March through April. The recent past has seen a higher frequency of large flood events with 2009 being a record setting year with a flood stage of 40.8 feet at the Fargo gage. Many measures have been taken over the years to combat the flooding in the area, manage flood risk, and save lives and property. These include structural, non-structural, and emergency measures.

As defined in the FSDD (February 2014), the purpose of the Project is to reduce flood risk, flood damages and flood protection costs related to flooding in the Fargo-Moorhead Metropolitan Area. To the extent technically and fiscally feasible, the Project will:

- Reduce flood risk potential associated with a long history of frequent flooding on local streams including the Red River of the North, Sheyenne, Wild Rice (ND), Maple, Rush, and Lower Rush Rivers passing through or into the Metropolitan Area,
- Qualify substantial portions of the Metropolitan Area for 100-year flood accreditation by the Federal Emergency Management Agency, under the National Flood Insurance Program (NFIP), and
- Reduce flood risk of floods exceeding the 1-percent event (100-year or greater), given the importance of the Metropolitan Area to region and recent frequencies of potentially catastrophic flood events.

This report is intended to provide a review and analysis of the available information relevant to the DSA as it relates to whether the DSA meets the purpose of the Project. Applicable FEMA requirements and standards for a riverine flood mitigation project were used to evaluate the DSA and compare it to the Project purpose and objectives. This report does not specifically address cost of the DSA or concerns about the timeframe required for implementation of all the distributed storage projects throughout the watersheds. Timing and cost are significant factors, along with feasibility of each of the storage sites and other factors that would need to be evaluated in detail subsequent to a decision on whether the DSA adequately meets the Project purpose and objectives.

Figure 1: Project Location Map



Legend

- ST. PAUL DISTRICT OFFICE
- Rivers
- USACE St. Paul District Civil Works Boundary
- ND Watersheds/MN WD's

Document Path: L:\1472\09\mxd\DSA\Project Location Map.mxd

N

0 15 30 60 Miles

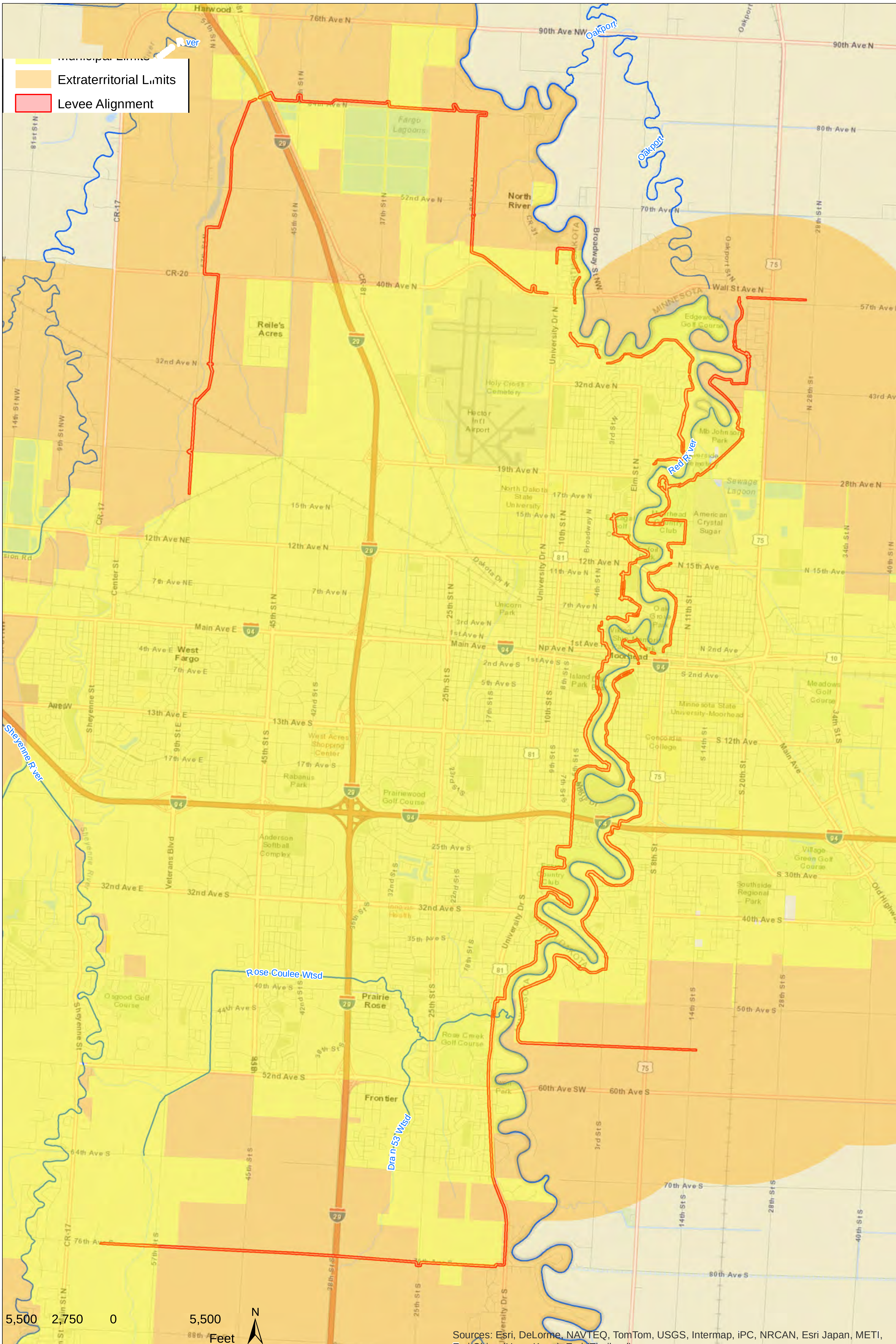
Prepared for MDNR by Wenck Associates
Source: USACE or Flood Diversion Authority

Figure 1
Project Location Map

Fargo-Moorhead Flood
Risk Management Project
Flood Diversion Authority

April 2014

Figure 2: Levee Alignment



MN DNR	Wenck	APR 2014
Levee Alignment	Engineers - Scientists Business Professionals www.wenck.com 1800 Pioneer Creek Center Maple Plain, MN 55359-0429 1-800-472-2232	Figure 2

2.2 DESCRIPTION OF THE DISTRIBUTED STORAGE ALTERNATIVE

The DSA utilizes potential storage areas within the upstream contributing major subwatershed to reduce flow rates through the Metropolitan Area along with structural and non-structural measures to reduce flood risk and meet the defined purpose of the Project. The DSA includes a combination of flood barriers, wetland/grassland restoration, non-structural measures, and upstream watershed storage to achieve the desired flood protection for the Metropolitan Area. Flood barriers include the levee alignment presented as part of the Phase 2 design by the USACE (Figure 2). The upstream watershed storage aspects are based on the recent Halstad Upstream Retention Study (HUR) completed by the Red River Basin Commission (RRBC) in December 2013. The HUR Study was intended to quantify potential benefits of storage within the upstream watersheds.

2.3 DEVELOPMENT OF ALTERNATIVE

The DSA was conceptualized during the public comment and alternatives screening process as part of the State of Minnesota environmental review process for the Project. The Alternatives Screening Report, Fargo-Moorhead Metropolitan Area Flood Risk Management Project (December 2012) has details on the alternatives considered and the screening criteria used to select alternatives that could meet Project purpose while providing other potential benefits. The DSA is listed as Alternative 12 in the report and was one of two additional alternatives recommended for further study through the State Environmental Impact Statement (EIS) process.

2.4 FEMA REQUIREMENTS

The DSA includes a levee component that requires accreditation by FEMA with certification by a registered professional engineer to meet 44 CFR Section 65.10. The required minimum freeboard is described in paragraph (b)(1)(i) and is stated as three feet above the baseflood water surface elevation for riverine systems. The reference baseflood for the EIS is the 1-percent probability event or the 100-year event. FEMA also requires that all openings, such as road crossings, along the levee system must be provided with closure devices that are structural components of the system during operation and must be designed to meet engineering standards. The closure devices must be operated according to an officially adopted operating plan and must include documentation of a flood warning system along with provisions for periodic testing. Sandbags and other temporary measures can be used only as a means to achieve freeboard at designated closures, but will not be certified as part of the levee.

Freeboard as presented by FEMA, is a factor of safety usually expressed in feet above a flood level for purposes of floodplain management. Freeboard tends to compensate for the many unknown factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and hydrologic and hydraulic modeling uncertainties. For example, a flood profile for a certain flow frequency, such as a 500-year flow, shown to be below a levee profile, but with minimal freeboard, does not provide complete protection for that 500-year event.

2.5 US ARMY CORPS OF ENGINEERS CERTIFICATION REQUIREMENTS

FEMA requires that a levee be certified by appropriate engineers, which in the case of the Phase 2 levee system would be the USACE. The USACE uses levee certification criteria where it requires the levee to provide a level of protection at a 90 percent assurance for the 1-percent chance flood event. This means that the levee has to contain the flow rate that is within the 90 percent level of uncertainty for the 1-percent chance event. Uncertainty analysis completed by the USACE, as documented in Appendix A-2 of the Hydrology attachment of the Final Feasibility Report and Environmental Impact Statement (FFREIS), indicates that the flow rate for the 95 percent level of uncertainty is approximately 70,000-cfs (Table 1). The 90-percent confidence interval flow would be somewhat less and probably very close to the 500-year event flow rate.

Table 1: Five Percent Confidence Interval Flow Rates

5 % CONFIDENCE LIMIT FOR CLIMATE FUTURE AND EQUIVALENT YEARS			
Exceedance Frequency	WET 68 yrs Flow, cfs	25-yr 59 yrs Flow, cfs	50-yr 52 yrs Flow, cfs
0.002	108,987	113,187	117,406
0.004	90,904	93,588	96,382
0.010	69,566	70,558	71,764
0.020	55,163	55,081	55,283
0.040	42,296	41,375	40,801
0.100	27,620	26,003	24,802
0.200	18,257	16,465	15,122
0.300	13,457	11,720	10,437
0.500	8,078	6,601	5,556
0.700	4,843	3,693	2,924
0.800	3,552	2,593	1,974
0.900	2,302	1,576	1,134
0.950	1,599	1,034	708
0.990	789	454	281
0.999	342	170	92

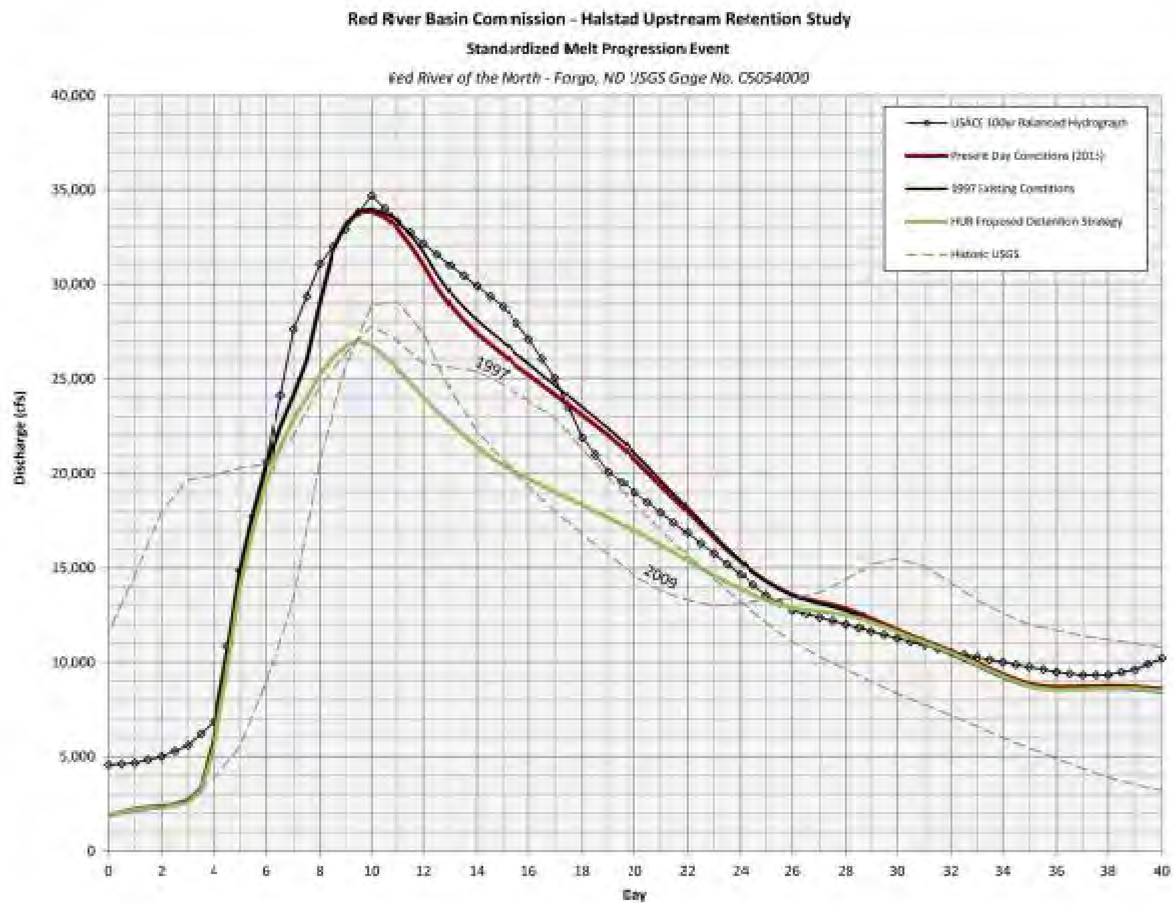
Source: USACE FFREIS, 2011, Table 35 in Appendix A-2

Therefore, USACE certification requirements essentially need to provide a 500-year level of protection for the Phase 2 levee system. As discussed in more detail in Section 2.6, the HUR Study did not explicitly model the 1-percent or the 0.2-percent probability events (100 and 500-year events respectively). Therefore, the level of benefit that can be directly applied to the flow rates relevant to the USACE levee certification requirements have not been quantified. The USACE certification requirements and the variability between the Phase 7 hydrology and the HUR hydrology are further discussed in Section 2.7

2.6 THE HALSTAD UPSTREAM RETENTION STUDY AND ITS IMPACT AND RELEVANCE TO THE DSA

The HUR Study is a result of the continuing efforts of the Basin Wide Flow Reduction Strategy, a component of the Long Term Flood Solutions report that was developed by the RRBC after the devastating floods of 1997. The goal of this strategy was to reduce peak flows along the Red River by 20 percent for the simulated 1997 flood. Since the initial evaluation of impoundment sites within the upstream watershed, new data and more refined models have been developed. Highly detailed tributary hydrologic models along with the unsteady state hydraulic model of the river systems in the area enabled a detailed update on the original strategy of distributed storage to reduce peak flow and volume in the Red River. The HUR Study (December 2013) has detailed information on the retention sites, the hydrologic modeling completed, development and calibration of the snow melt hydrograph, and the hydraulic modeling to route the flows along the Red River.

Figure 3: Hydrograph at Fargo gage with HUR impacts, previous flood events, and 100-yr flow.



Source: Halstad Upstream Retention Study, 2013

The HUR Study identified 96 potential impoundment sites, shown in Figures 4.1 and 4.2 of the HUR. The HUR Study shows that 20 percent reduction in flow can be achieved for the particular runoff event that was modeled for the study if all of the identified retention volume is made available. Note that the runoff event modeled in the HUR Study is different from the hydrology and flow analysis that is being used for the Project. This comparison of flows is further discussed in Section 2.7. Figure 3 (Figure 6.3 from the draft HUR) shows the comparison of hydrographs with and without the upstream storage implementation for flows at the Fargo gage.

The HUR Study takes advantage of work that was done from a watershed by watershed basis, with the Lower Sheyenne River Watershed Comprehensive Detention Plan (Sheyenne Study) (October 2013) being an example of the various detailed detention studies completed for the individual Red River watersheds. The Sheyenne Study looked at twenty sites within the Sheyenne River watershed to evaluate for benefits in managing peak flow and volume in the Sheyenne River.

These studies and the evaluation of distributed storage have a direct influence on how flood mitigation can be achieved in Fargo, North Dakota and Moorhead, Minnesota. Any reduction in flow rate during low frequency hydrologic events in the Red River and its tributaries can translate to a decrease in stage through the Metropolitan Area. A decrease in flood stage would have a direct impact on the options considered, levee heights, operation of flood control structures, and cost of flood fighting. Sections 3.0 and 4.0 review the impacts of including upstream watershed-wide distributed storage on flow and stage along the Red River mainstem and Sheyenne River at the cities of Fargo and Moorhead.

2.7 COMPARISON OF PHASE 7 AND HUR STUDY HYDROLOGY

Similarities and differences between the hydrologic conditions relevant to the modeling and analysis for the Project and HUR Study is important to consider. The current Phase 7 hydrology and hydraulics for the Project is extensively documented starting with the FFREIS (April 2011). Appendix 4b of the FFREIS documents the current hydrology which was completed as Phase 4. The Supplemental Environmental Assessment (EA) (September 2013) describes the updated Phase 7 modeling that reflects the latest changes to the alignment and upstream staging. The HUR Study documented the hydrologic and snow melt analyses used to evaluate the effectiveness of upstream storage.

The Phase 4 hydrology was developed to provide inflow hydrographs for the unsteady state HEC RAS model and is based on gage data distributed at various points along the tributary rivers and the Red River. Use of distributed gage data implicitly includes the spatial variability of runoff in the watersheds that contribute to the peak flows at the Fargo gage. Phase 4 updates also developed coincident flow hydrographs along the tributary rivers when the Red River experiences peak flow rates and vice versa. The Phase 4 hydrology is carried through the hydraulic updates to the current Phase 7 and is now referred to as the Phase 7 modeling conditions.

The hydrology for the HUR Study is based on the Red River Basin Standardized Snow Melt Progression Event Analysis, which is part of the HUR Study. This analysis looked at the 100-year 10-day runoff event based on NRCS TR-60, and developed the equivalent precipitation event. The runoff depth is listed as varying from 4.5 inches to 6.5 inches moving from west to east. The variation of the precipitation is shown in Figure 6 of the Snowmelt study report attached to the HUR study. The precipitation amounts were converted to a grid that was applied to the detailed HEC HMS models that were developed for the tributaries during previous efforts completed in December 2011.

As mentioned above, the Phase 7 hydrographs are based on statistical analysis of gage data while the HUR Study is based on precipitation/runoff models. These are different methods of hydrologic analysis and the results cannot be directly compared. The HUR Study assumes that the entire Red River watershed upstream of Fargo generates a 100-year, 10-day runoff. This assumption implies that all upstream storage sites are optimized to provide maximum benefit during this runoff event. In contrast, the 100-year hydrograph at Fargo can occur with one portion of the watershed generating more than the 100-year runoff, while other portions of the watershed generate less than the 100-year runoff. This difference can have a significant impact on the actual effectiveness of the upstream storage sites because not all of the upstream storage will provide the maximum benefit.

3.0 Red River Features and Impacts

As previously described in Section 2.0, the DSA includes structural measures to reduce flood risk potential for the cities of Fargo and Moorhead. For this evaluation, the structural measures are defined as the Phase 2 levee alignment developed by the USACE (Figure 2). Flow profiles were developed using the detailed unsteady state HEC RAS models developed for the existing and proposed conditions by the Diversion Authority and the USACE.

3.1 FLOW PROFILES THROUGH TOWN

The level of detail involved with the hydrologic and hydraulic modeling associated with flooding in the Red River is unprecedented and has evolved through many phases of development and refinement. The unsteady state HEC RAS model includes distributed hydrograph loading for the 100-year flow and connections to hydrologic modeling done in highly detailed HEC HMS models for extreme events. The hydraulic model also includes detailed modeling of floodplain storage and the interconnected nature of some of the breakout flows between the tributary rivers in the area. The following profiles are generated from these detailed hydraulic models that have been developed for the Project.

Figure 3a compares the 100-year and 500-year profiles through Fargo and Moorhead with and without the Phase 2 levees in place. The redline shows the levee height through the town that was set during the Phase 2 analysis for the FDEIS. The height and alignment of the levee were based on geotechnical analysis for slope stability, the 500-year profile (flow rates prior to current updated hydrology), and tie-in points to high ground on the North Dakota side of the Project. This profile also matches the existing flood wall at the Veterans Affairs (VA) hospital, along with matching high ground based on current LiDAR contours. This levee profile is considered the 'maximum possible levee height' through the Cities due to the above factors and that further increase in height would extend the tie-in point an unreasonable distance (Fargo Moorhead Metro Feasibility Study Phase 2 Appendix B). A complete independent review of the Phase 2 levee alignment was not done for this report as it is outside the current scope of work. Figure 3a and Table 1 show there are some areas that do not meet the current 3-feet FEMA requirement for the 100-year flow rate.

The dashed green line and black line show the 500-year and 100-year profiles through the Cities when immediate upstream staging is available (see Section 3.2 for further discussion on the upstream staging impacts). As noted in the peak flow call outs, the upstream staging reduces the peak flow through the Cities (61,700 to 44,900 cfs for the 500-year event, and 34,700 to 31,300 cfs for the 100-year event). The dotted green and black lines in Figure 3a show the 500-year and 100-year profiles if the immediate upstream staging areas is not available. These profiles show the flood stage when the full peak flow is constricted within the levee, indicating the Phase 2 levees are overtopped for the 500-year event in this condition.

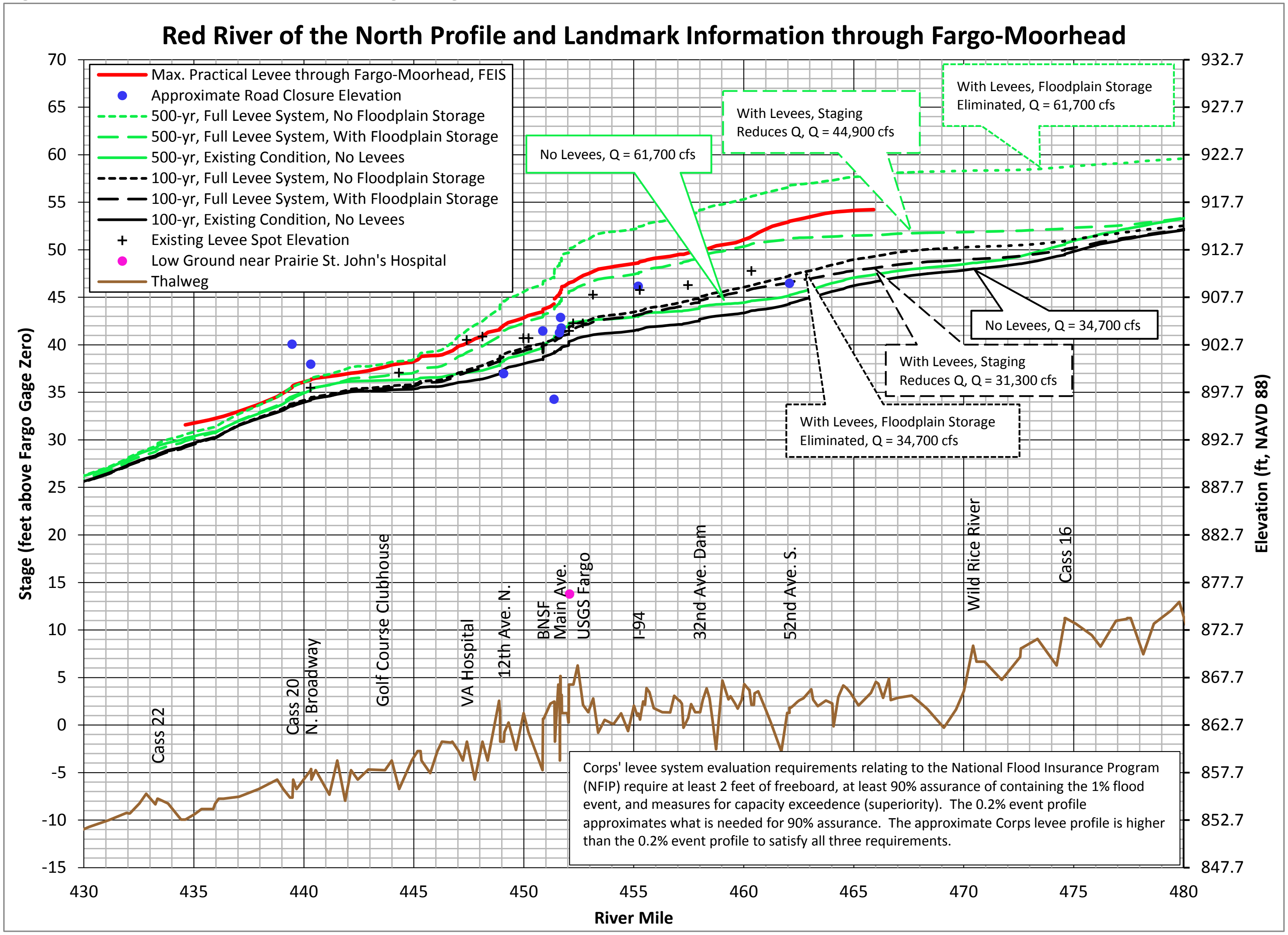
Figure 3a also shows there would be at least seven road closures required during the 100-year event. Some of the roads would require significant closure, such as 12th Avenue and Main Avenue where 2- feet plus freeboard and 7-feet plus freeboard would be required to protect from the 100-year flow. Proper structural barriers would be required as part of this overall levee system in order to provide the adequate level of protection and meet FEMA standards. Alternatively, these roads could be raised above the 100-year water surface elevation (WSE) to avoid the road closure.

Table 2 provides an explanation of the terms listed in Figures 3c, 3d and Table 3.

Table 2: Explanation of Modeling Conditions With Upstream Distributed Storage

Legend Call Out	Explanation
Existing Conditions –no protection	This represents conditions with existing levees (as of 2009)in place but without emergency protection in place.
Existing Conditions –full protection	This represents the above condition with emergency protection in place.
HUR Base model (no protection)	This represents the HUR 100-yr hydrograph model run with existing conditions without emergency protection.
HUR Base Model (full Protection)	This model run includes emergency protection measures.
HUR w/retention (no protection)	This is existing condition without emergency protection combined with upstream distributed storage.
HUR w/retention(full protection)	This condition includes existing conditions with emergence protection and upstream distributed storage.
HUR w/retention +USACE levee from feasibility	This model run represents the condition when the Phase 2 levees are in-place combined with upstream distributed storage for the HUR 100-yr hydrograph.

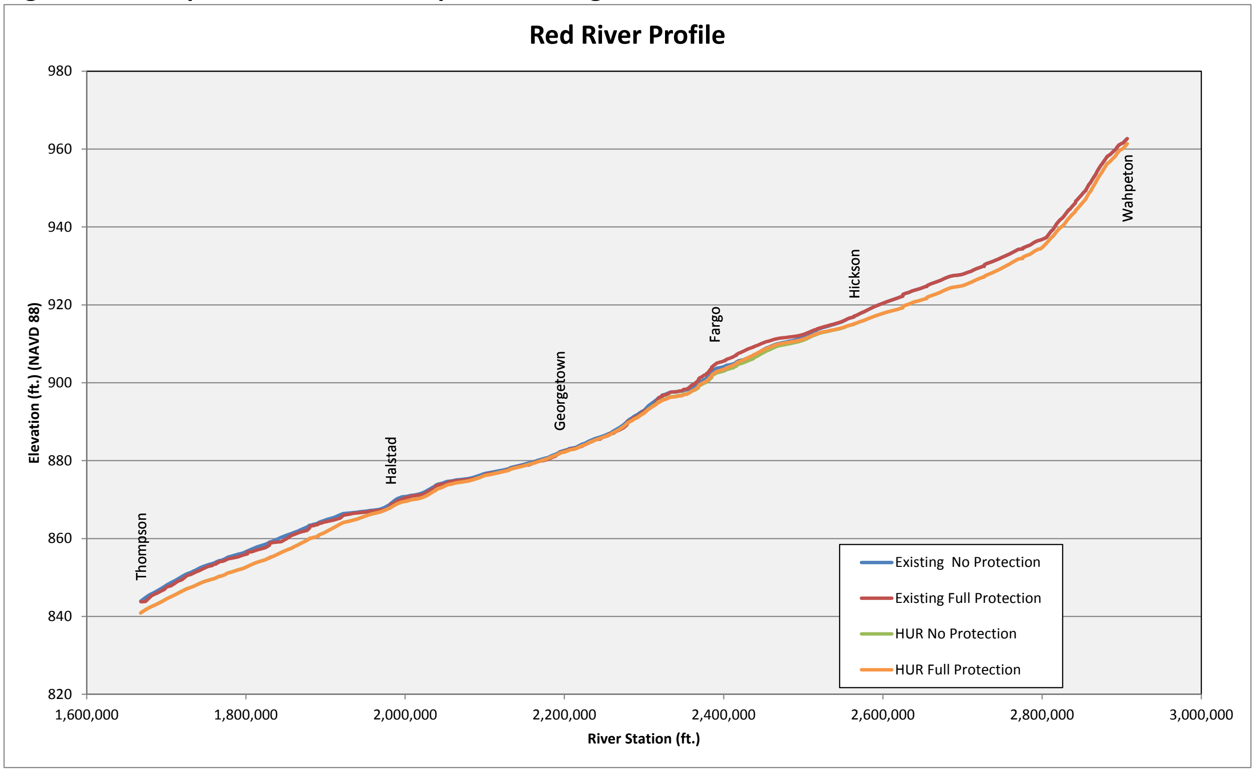
Figure 3a: Water Surface Profiles through Fargo-Moorhead with and without levees.



Source: USACE, 2013

Figure 3b shows the HUR study flow profiles with and without upstream distributed storage along the Red River.

Figure 3b: Comparison of HUR flow profiles along the Red River



Source: Houston Engineering.

Figure 3c shows the inundation areas with the HUR hydrologic conditions for base and distributed storage implemented with Phase 2 levees in place. This scenario assumes all of the HUR storage areas have been implemented and maximum benefit is achieved. Additionally, since the figure shows the levees are providing protection, it assumes the Phase 2 levees have been certified by the USACE and accredited by FEMA. This figure also shows areas that are used for retention along the Maple River which is why the HUR with retention scenario shows added areas of inundation (orange areas) while there are other areas clear of flooding.

Figure 3d shows the comparison of flooding for Phase 7 hydrology with and without the Phase 2 levee in place. The orange areas show the additional upstream flooding areas that would result from the increase in WSE due to the levees. Figure 3d also shows that staging is caused along the Sheyenne River along Route 17 when Phase 2 levees are in place. Note that Figure 3d shows flooding for peak flows along the Red River with coincident flows along the tributaries. This staging results in an increase in the flooded area and depth along the Sheyenne River on the unprotected side of the Phase 2 levee alignment. Figure 3d shows that the downtown areas of Fargo and Moorhead are protected by the levee system from Red River flooding when comparing the blue area within the Cities for existing conditions and the purple area that shows the flooding with the levees. The levees also provide a limited amount of protection from flooding from the Sheyenne, specifically for the Reile's Acres area north of the City. The developed area west of Route 17 would remain unprotected with the levees in place. As stated, there would be added depth and area of flooding upstream along the Red River and the Sheyenne River with the levees in place (orange areas).

Figure 3c: Phase 7 HUR 100 Year Model

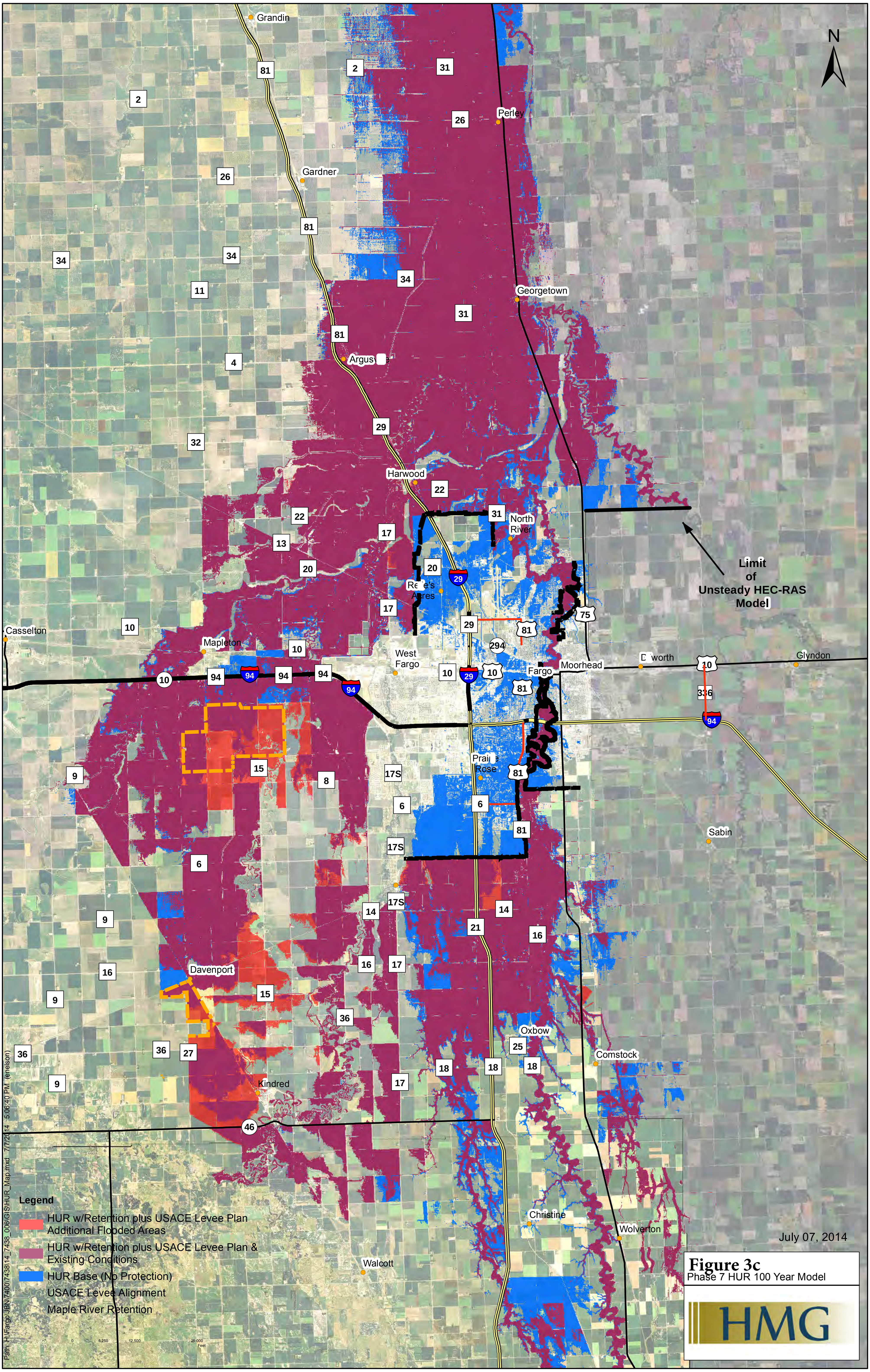
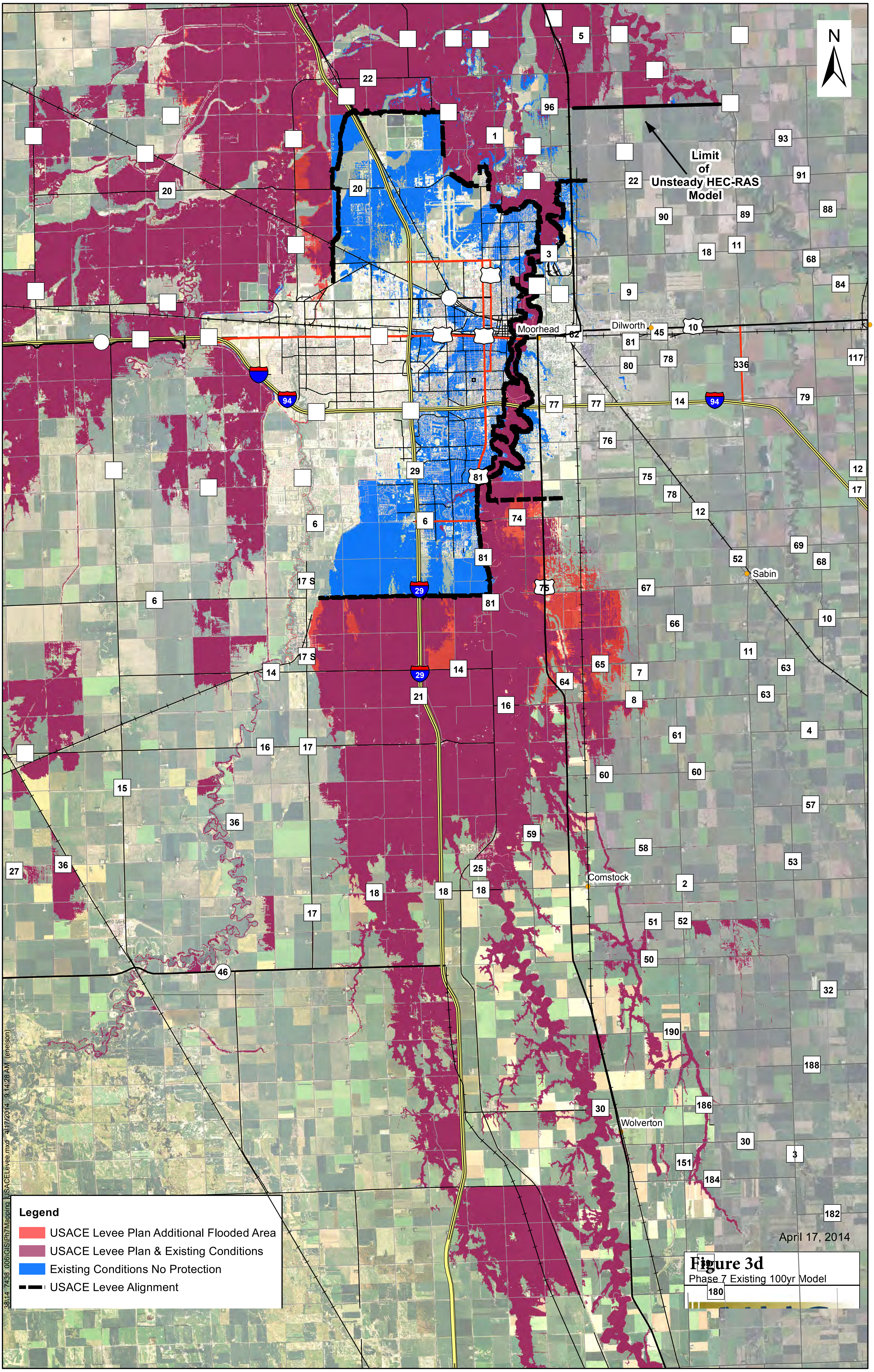


Figure 3c
Phase 7 HUR 100 Year Model

Figure 3d: Phase 7 Existing 100yr Model



April 17, 2014

Figure 3d
Phase 7 Existing 100yr Model

Table 3 provides a comparison of water surface elevations relative to the Phase 2 levee profile through the cities of Fargo and Moorhead. The data presented is from the information used to prepare Figure 3a along with the corresponding key landmarks for reference provided by USACE. Note that the 200-year WSE information is taken from model runs completed prior to the updated Phase 7 hydrology and is presented only to illustrate the relative freeboard that can be achieved for higher than 100-year events with the Phase 2 levees through the Cities. Table 3 presents freeboard levels available for the 100-year flows and reviews the impact of adding the potential benefits of upstream distributed storage.

Appendix C examines profile comparisons for HUR conditions with and without distributed storage (data provided by Houston Engineering). Comparison of the 'existing full protection' profile (flows without distributed storage implemented) and the 'HUR full protection' profiles (HUR flows with upstream distributed storage implemented) indicate that on average the profiles drop approximately 1.7 feet between river mile 430 and river mile 480.

As previously discussed, there are differences between the hydrologic analysis methods used in the HUR Study and the Phase 7 hydrographs, and therefore, it is not appropriate to directly compare the results and impacts. However, evaluation of the data from these studies suggests that there is potential for upstream distributed storage to have similar impacts on reducing the Phase 7 peak flow rates at the Fargo gage. The actual amount of impact cannot be determined without extensive additional modeling efforts. Data provided in Table 3 indicates the minimum amount of additional freeboard needed to meet FEMA requirements is 1.5 feet at river mile 480. Based upon the assumption that distributed upstream storage can impact the peak flow rates enough to reduce the flood stage by 1.5 feet through the Cities, the Phase 2 levee system could meet the FEMA criteria of 3-foot minimum freeboard for levees. As this is a broad assumption, it is more appropriate to state that combining distributed storage with the Phase 2 levees has the potential to marginally meet FEMA freeboard criteria. As mentioned previously, this assumes that the Phase 2 levees have been certified by the USACE.

Table 3: Comparison of Water Surface Elevation and Phase 2 Levee Height.

Table 3
Comparison of Water Surface Elevation and Phase 2 Levee Height.

Landmark Name	RM	Invert Elev	Max. Practical Levee through Fargo-Moorhead, FEIS	100-yr, Full Levee System, No Immediate U/S Storage	100-yr, Full Levee System, With Immediate U/S Storage	HUR USACE Levees Phase 2	200-yr(ph2), Full Levee System,	100 yr full levee Available freeboard with u/s storage	Possible Freeboard with 1.5-ft from HUR Impacts	Freeboard 100 yr Full Levee without u/s staging with 1.5-ft HUR impacts	200 yr freeboard
Cass 22	433.35	855.00	893.9	891.14	891.06	890.26	892.63	2.9	4.4	4.3	1.3
436	436.00	855.00	894.8	892.98	892.90	891.92	893.58	1.9	3.4	3.4	1.3
438	438.00	856.00	896.5	895.10	895.01	893.60	895.16	1.5	3.0	2.9	1.3
Cass 20	439.47	855.10	898.3	896.53	896.41	894.76	896.57	1.9	3.4	3.3	1.8
N. Broadway	440.32	858.10	899.1	897.15	897.01	895.22	897.23	2.1	3.6	3.4	1.8
Golf Course Clubhouse	443.56	858.06	900.0	898.18	898.01	896.09	898.08	2.0	3.5	3.3	1.9
VA Hospital	447.41	859.00	902.7	900.10	899.86	897.65	900.27	2.9	4.4	4.1	2.5
12th Ave N.	449.09	862.00	904.8	901.79	901.51	899.14	901.99	3.3	4.8	4.5	2.8
BNSF	450.87	863.40	906.5	901.90	901.90	900.19	903.37	4.6	6.1	6.1	3.1
Main Ave.	451.71	865.90	908.6	904.00	903.65	901.04	904.87	4.9	6.4	6.0	3.7
USGS Fargo	452.69	869.00	909.7	905.20	904.82	902.18	905.82	4.9	6.4	6.0	3.9
I-94	455.21	866.60	911.4	906.31	905.91	903.24	907.43	5.4	6.9	6.5	3.9
32nd Ave Dam	457.98	855.90	912.7	907.81	907.40	904.78	908.73	5.3	6.8	6.4	4.0
52nd Ave. S.	462.08	871.50	915.7	910.07	909.34	906.80	911.67	6.4	7.9	7.2	4.1
Wild Rice River	470.43	870.90	917.2	913.07	911.76	910.20	913.69	5.5	7.0	5.6	3.5
Cass 16	474.60	873.40	917.7	913.69	912.76	911.29	914.53	4.9	6.4	5.5	3.2

3.2 REQUIRED UPSTREAM STAGING AREA

Both Figures 3a and Table 3 show there would be an increase in WSE with the Phase 2 levees in place. This increase results from constricting the flows within the levees on either side of the River as shown in Figure 3d. The increase in WSE propagates upstream which results in a wider inundation area as well as an increase in the depth of inundation upstream of the levees. The resulting storage in the upstream staging area effectively reduces the peak flow rate through the Cities with the levees in place. If this reduction in flow rate is not available, the WSE raises to the level shown in dotted lines in Figure 3a.

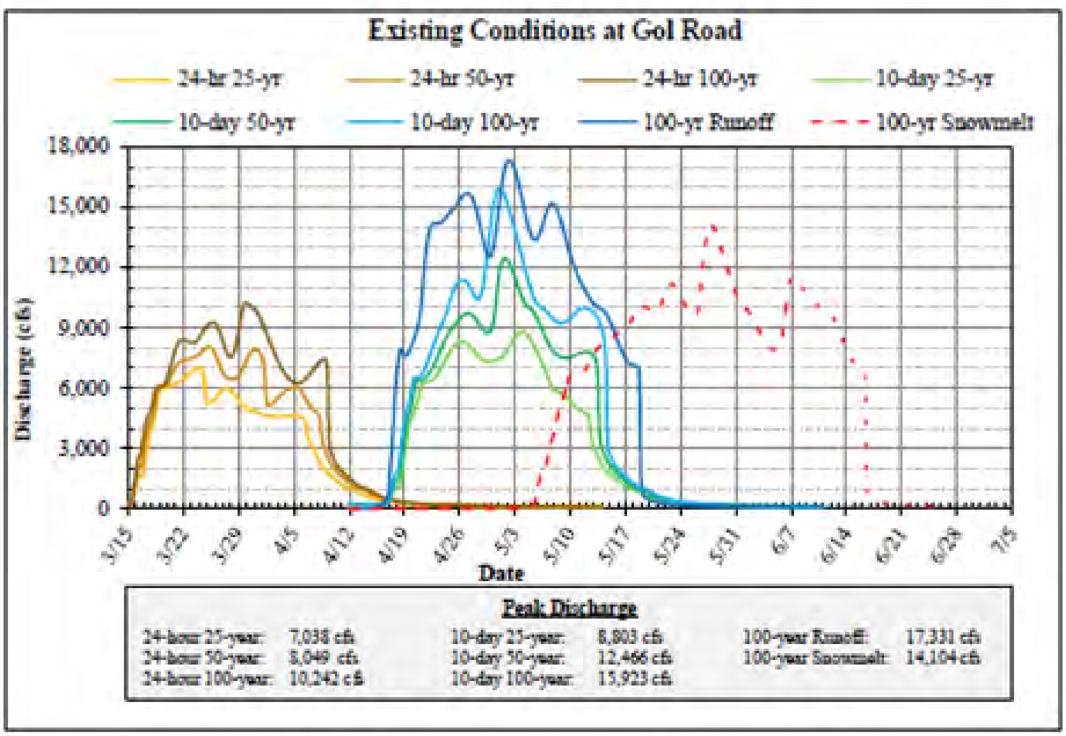
Land use planning methods such as zoning, easements or declaring a floodway would be required for the inundation areas through the upstream staging area so the level of protection could be maintained with the levees. An area wide enough to encompass the total area needed to maintain adequate storage (flood extents shown in Figure 3d for USACE levee plan) would be required. Comparison of the dashed and dotted lines for the 100-year and 500-year profiles indicate that the 100-year profile would be impacted less due to the loss of upstream storage. When combined with the above assumption of 1.5 feet of stage reduction due to HUR conditions, the FEMA freeboard requirements could still be marginally met with the full 100-year flow (no impact of immediate upstream storage) through the levee system (see Table 3). However, the objective of the levee system providing a higher than 100-year level of protection as stated in the Project purpose can be compromised if the upstream staging area is not maintained as part of the DSA.

4.0 Sheyenne River Features and Impacts

4.1 SHEYENNE RIVER EXISTING CONDITIONS

The Sheyenne River is a major tributary to the Red River, joining the Red River immediately downstream or north of the cities of Fargo and Moorhead. The Maple, Rush, and Lower Rush Rivers form tributaries to the Sheyenne, with confluences west of Fargo. The perched nature of the Sheyenne River (see sample cross sections in Appendix A) results in unique hydraulic and flooding conditions in the area and makes flood mitigation a challenge. The Sheyenne Study (October 2013), completed for the Southeast Cass Water Resource District in North Dakota, provides detailed discussion on the nature of flows, break outs from the main channel, and impacts of watershed distributed storage. The hydrographs shown in Figure 4a show the peak flow rates at Gol Road near Kindred, North Dakota, identified as one of the major break out points along the Sheyenne River.

Figure 4a: Hydrographs on the Sheyenne River at Gol Road.



Source: Lower Sheyenne River Watershed Comprehensive Detention Plan

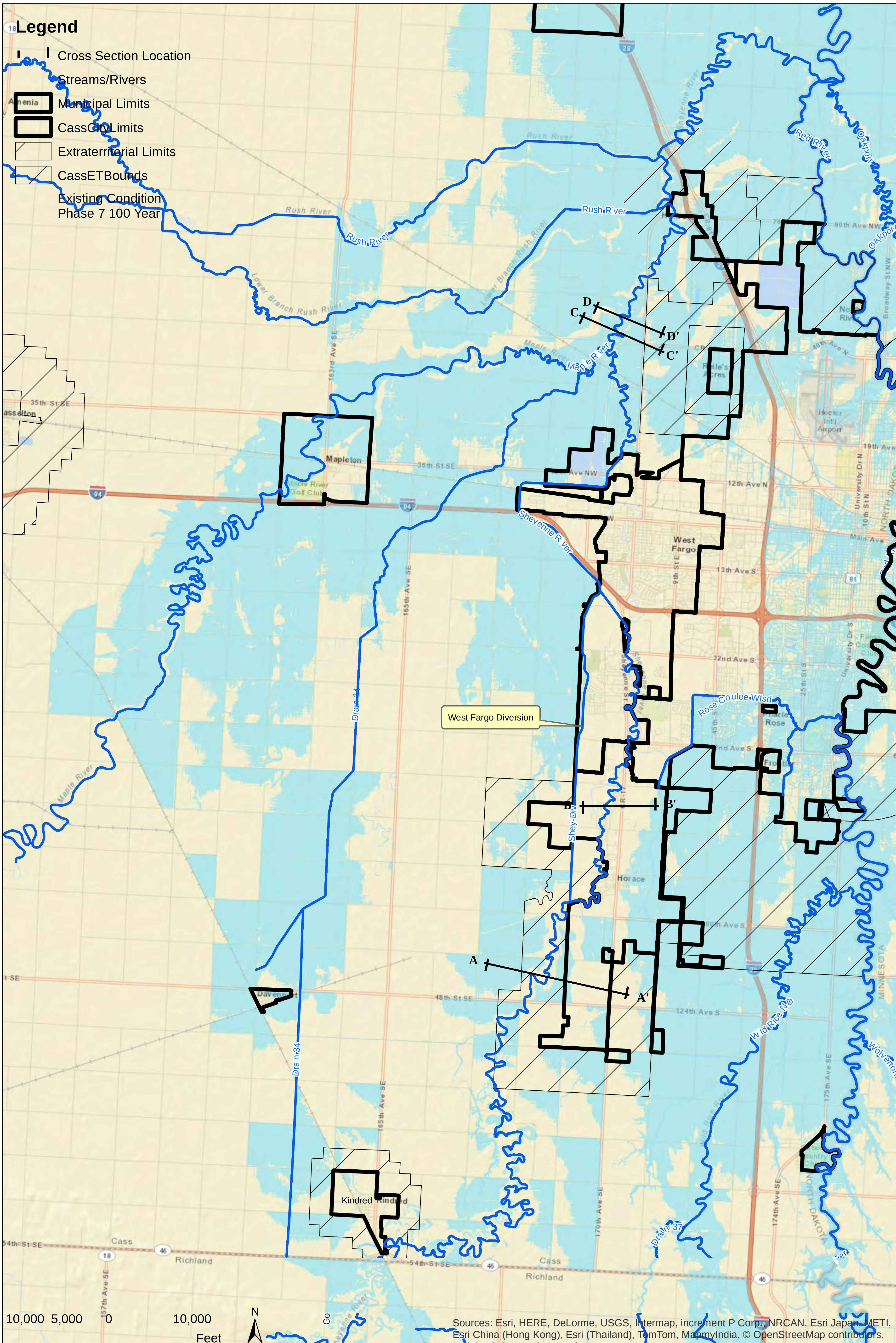
The study explains that the flow within the mainstem of the river is highly regulated and is sensitive to outflow from Baldhill Dam, which usually occurs after the local flows have contributed to the flow in the river. Figure 4a shows the hydrographs where the 100-year 24-hr peak flow rate is approximately three days after the first peak has passed through. Furthermore, the perched nature of the Sheyenne results in break out flows into the floodplain at relatively low flow rates which adds to the challenge of flood mitigation along the river. The study states that flow breaks out at Kindred, downstream of Gol Road, when the peak flows reach 3,500-cfs. The breakout flows from the Sheyenne contribute to the flows along the Wild Rice, Maple and Rush Rivers and add to the flooding in the northwest part of the City of Fargo in the Reile's Acres area. As shown in Figures 4b and 4c, the West Fargo Diversion channel prevents flood waters spreading towards the City of West Fargo for the 100-year event.

4.2 DISCUSSION OF IMPACT ALONG SHEYENNE RIVER DUE TO UPSTREAM DISTRIBUTED STORAGE

Hydraulic and hydrologic modeling, previous reports, and analysis available for the DSA suggest that distributed storage would have a minimal impact on peak flow rates along the Sheyenne River. As mentioned in Section 4.1, the peak flow in the Sheyenne River is governed by outflow from Baldhill Dam which results in a second peak a few days after the local flows from the lower Sheyenne watershed have passed. The Sheyenne study indicates that little additional storage is available upstream of the Dam and has minimal effect on the flows outleting from the Dam during high flow conditions. The Sheyenne Study shows that distributed storage has benefits for localized flood mitigation within the lower Sheyenne River watershed, but would have little impact on the peak flow in the river itself. The break out flows from the Sheyenne River flow toward the Wild River and the Maple Rivers. These flows can add to peak flow rates in the Wild Rice and Maple Rivers in North Dakota, as well as result in overland flows that can affect flooding in western portions of the Fargo area.

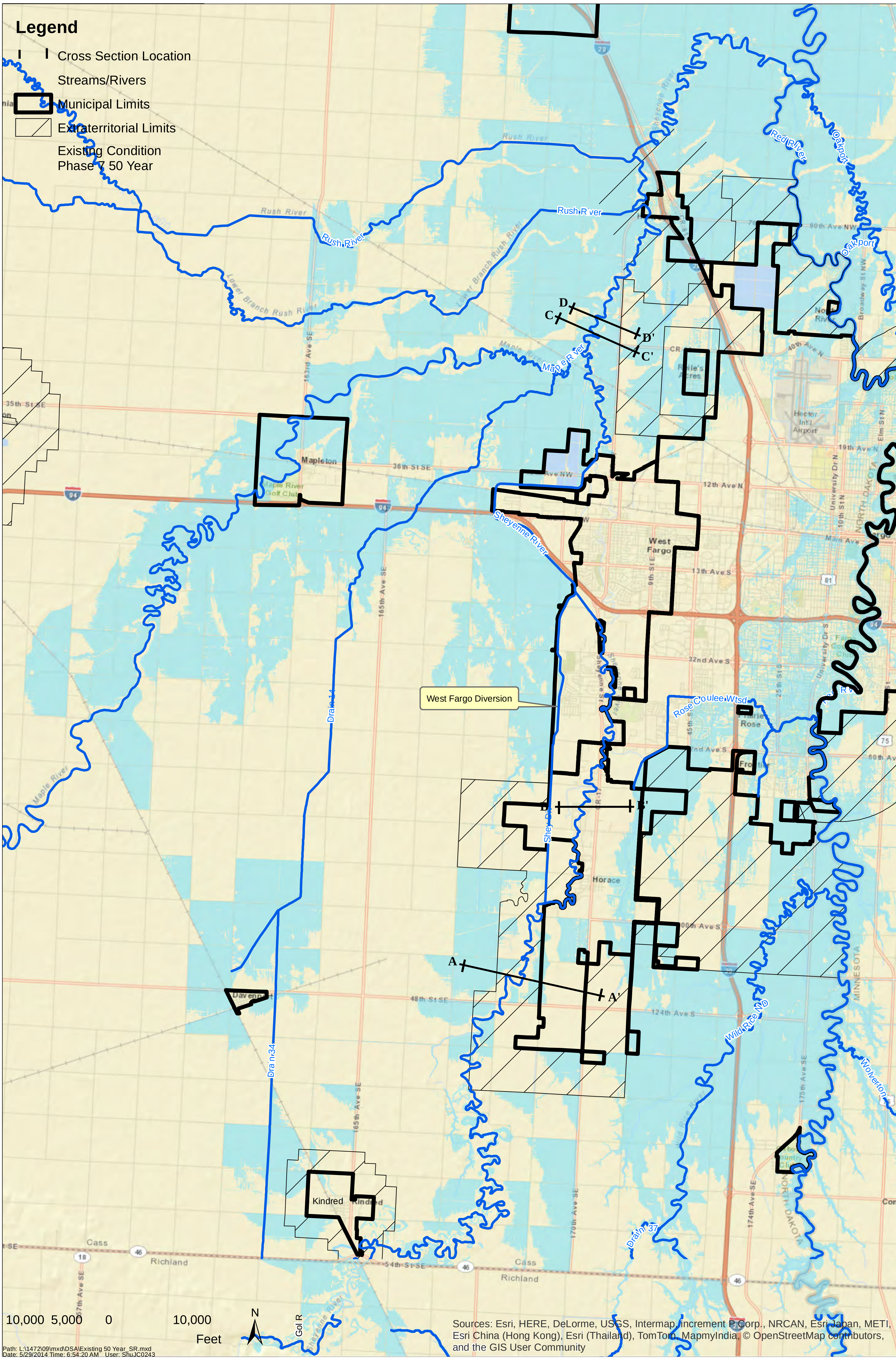
Figures 4b and 4c show 100-year and 50-year event inundation areas for the Metropolitan Area. Comparison of these figures shows minimal change in the inundation area between the two flow frequencies.

Figure 4b: Existing Inundation for 100 Year



MN DNR	Wenck	APR 2014
Existing Inundation for 100 Year	Engineers - Scientists Business Professionals www.wenck.com 1800 Pioneer Creek Center Maple Plain, MN 55359-0429 1-800-472-2232	Figure 4b

Figure 4c: Existing Inundation for 50 Year



MN DNR	Wenck Engineers - Scientists Business Professionals www.wenck.com 1800 Pioneer Creek Center Maple Plain, MN 55359-0429 1-800-472-2232	APR 2014
Existing Inundation for 50 Year		Figure 4c

Figure 4d shows WSE profiles along the Sheyenne River with and without HUR impacts. In contrast to the WSE profiles along the Red River, the Sheyenne River profiles show minimal change when HUR storage is included in the analysis.

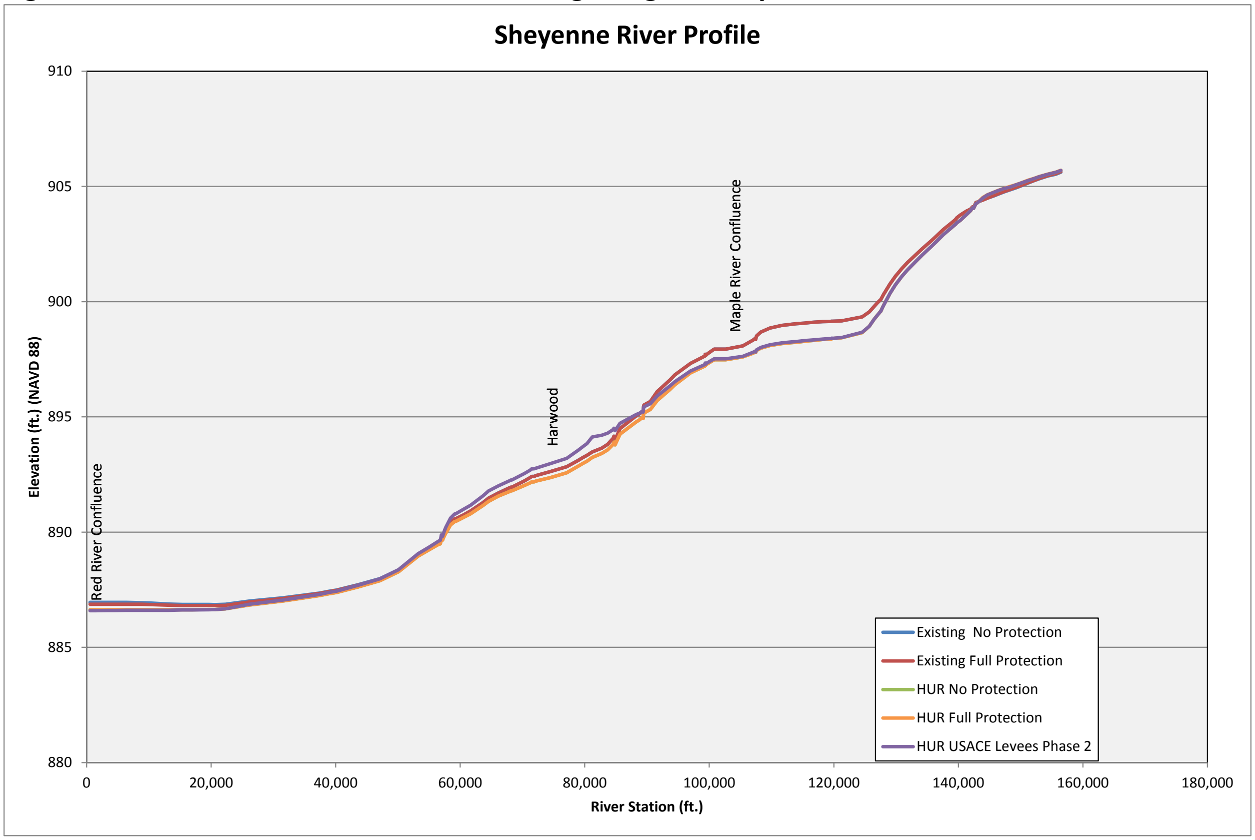
Table 32 of Appendix A-2 of the Supplemental Feasibility Report and Environmental Impact Statement (2011) shows the coincidental peak flow rates for the Sheyenne River compared to events along the Red River. This table lists Sheyenne River flow at the confluence with the Red River (including Maple, Rush and Lower Rush Rivers) as:

- 100-year 26,500 cfs (20% reduction = 21,300 cfs)
- 50-year 22,300 cfs

The stated goal of the HUR is a 20 percent reduction in peak flow rates and volumes. A 20 percent reduction in the 100-year flow along the Sheyenne River would result in a flow of approximately 21,300 cfs, which is about the same as the 50-year flow rate at the same location. Comparing Figure 4b as the 100-year inundation and Figure 4c as inundation with 20 percent reduction in flow illustrates that even if peak flows in the Sheyenne River can be reduced by 20 percent, the resulting reduction in inundation area in Fargo would be minimal.

Figures B-1 and B-2 (Appendix B) which are taken from the HUR Study show the distribution of watershed-wide upstream storage and total storage acres utilized. Tables 32 in Appendix A-2, as previously described, indicate the total watershed area of the Red River at the confluence of the Sheyenne River with the Red River is approximately 11,300 square miles. The watershed area draining through the Sheyenne, Maple, and Rush Rivers is approximately 4,800 square miles, about 40 percent of the total watershed. Figure B-1 shows that only 20 percent of the total storage included in the HUR was distributed within the Sheyenne/Maple/Rush River watershed. This could indicate that available watershed-wide distributed storage is already utilized and locating additional storage would be a challenge. This lack of additional storage capacity, though a contributing factor, is likely a secondary factor to explain the minimal impact shown in the HUR Study along the Sheyenne River.

Figure 4d: Flow Profiles from HEC RAS modeling along the Sheyenne River.



Source: Houston Engineering, 2013

4.3 LEVEES ALONG THE SHEYENNE RIVER

Qualitative and cursory assessment of the conditions on the Sheyenne River indicate that developing a feasible levee alignment along the Sheyenne River is a challenge due to the terrain features along the river and the floodplain. The offset of the alignments along the river and levee height needed to provide effective protection makes a levee option that would meet FEMA requirements infeasible for the Sheyenne River. The perched river makes it a challenge to find adjoining high ground to tie the levees into existing terrain. As mentioned in the Sheyenne Study, break outs from the main river occur at relatively low flow levels, which would likely require the levee alignment to extent all the way to Kindred from the Metropolitan Area. Lack of adjoining high ground to tie in the levees, the break out flows upstream, and the river profile is not conducive to developing a cost effective levee system that can provide the required level of protection and be certified by FEMA.

4.4 EFFECTS OF DISTRIBUTED STORAGE ON TRIBUTARY RIVERS

The information and analysis presented above shows that distributed storage has little or no impact on reducing flood risk along the Sheyenne River and flooding caused by flows from the tributaries. The break out flows from the Sheyenne River, which present a significant challenge to mitigate, occur at a low flow rate and combine with flows in the Wild Rice and Maple Rivers that can contribute to flooding in the Fargo area. The existing West Fargo diversion channel helps to mitigate this effect by preventing flooding during the 100-year event for the city of West Fargo, and therefore, the majority of the flooding from the Sheyenne, Maple and Rush River tributaries occurs close to the Reiles Acres area and north of the city of Fargo.

5.0 References

Federal Emergency Management Agency (FEMA). Mapping of Areas Protected by Levee Systems. 44 CFR Section 65.10 of the National Flood Insurance Program (NFIP) regulations. October 1, 2006.

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Moore Engineering, Inc. 2013. Lower Sheyenne River Watershed Comprehensive Detention Plan. Prepared for Southeast Cass Water Resources District. October 2013.

USACE. 2011. Appendix A-2 Hydrology – Fargo-Moorhead Metropolitan Area Flood Risk Management Supplemental Draft Feasibility Report and Environmental Impact Statement. April 2011.

USACE. 2011. Final Feasibility Report and Environmental Impact Statement Fargo-Moorhead Metropolitan Area Flood Risk. July 2011.

USACE. 2013. Supplemental Environmental Assessment – Design Modifications to the Fargo Moorhead Metropolitan Area Flood Risk Management Project. September 2013.

Wenck Associates, Inc. 2012. Draft Alternatives Screening Report Fargo-Moorhead Metropolitan Area Flood Risk Management Project. Prepared for Minnesota DNR. October 2012.

USACE, 2010 Fargo Moorhead Metro feasibility Study Phase 2 Appendix B.

USACE, 2013 Fargo Moorhead Comparison of Water Surface Elevation and Phase 2 Levee Height. (Table 3)

Houston Engineering, Comparison of Water Surface Elevation with and without Distributed Storage with HUR conditions. (Appendix C)

USACE, 2011 Fargo-Moorhead Metropolitan Area Flood Risk Management Supplemental Draft Feasibility Report and Environmental Impact Statement Appendix A-2, Hydrology.

Appendix A

The following cross sections are taken from the Digital Elevation Model for the Project using GIS. The cross section lines are shown in Figure 4b and is intended to illustrate the terrain features along the river reach.

Figure A-1: Cross Section of Sheyenne River at Location A-A

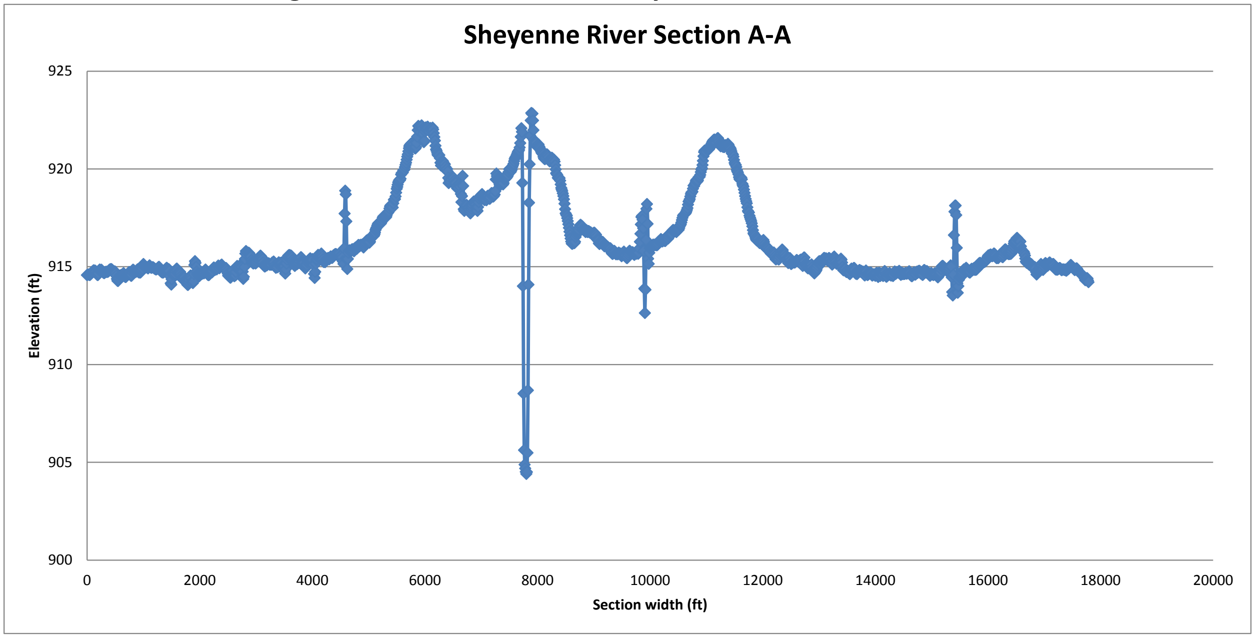


Figure A-2: Cross Section of Sheyenne River at Location B-B

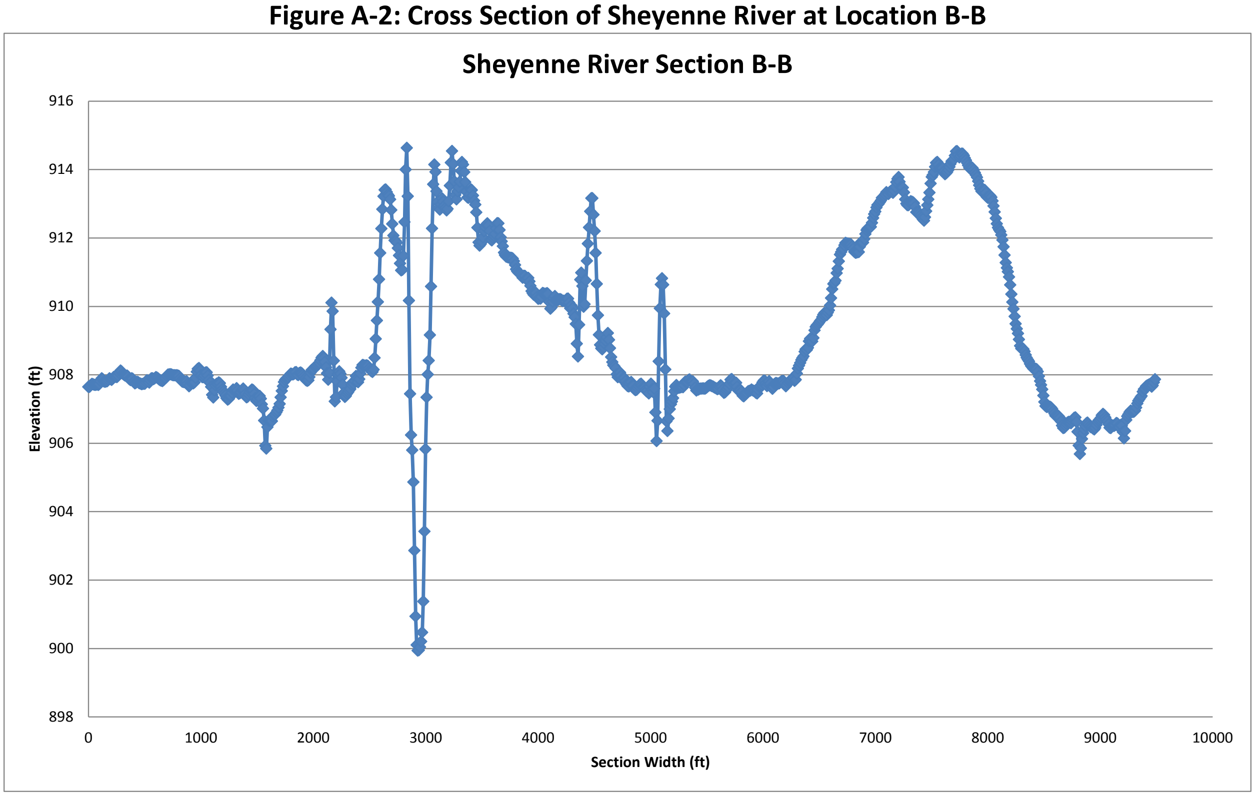


Figure A-3: Cross Section of Sheyenne River at Location C-C

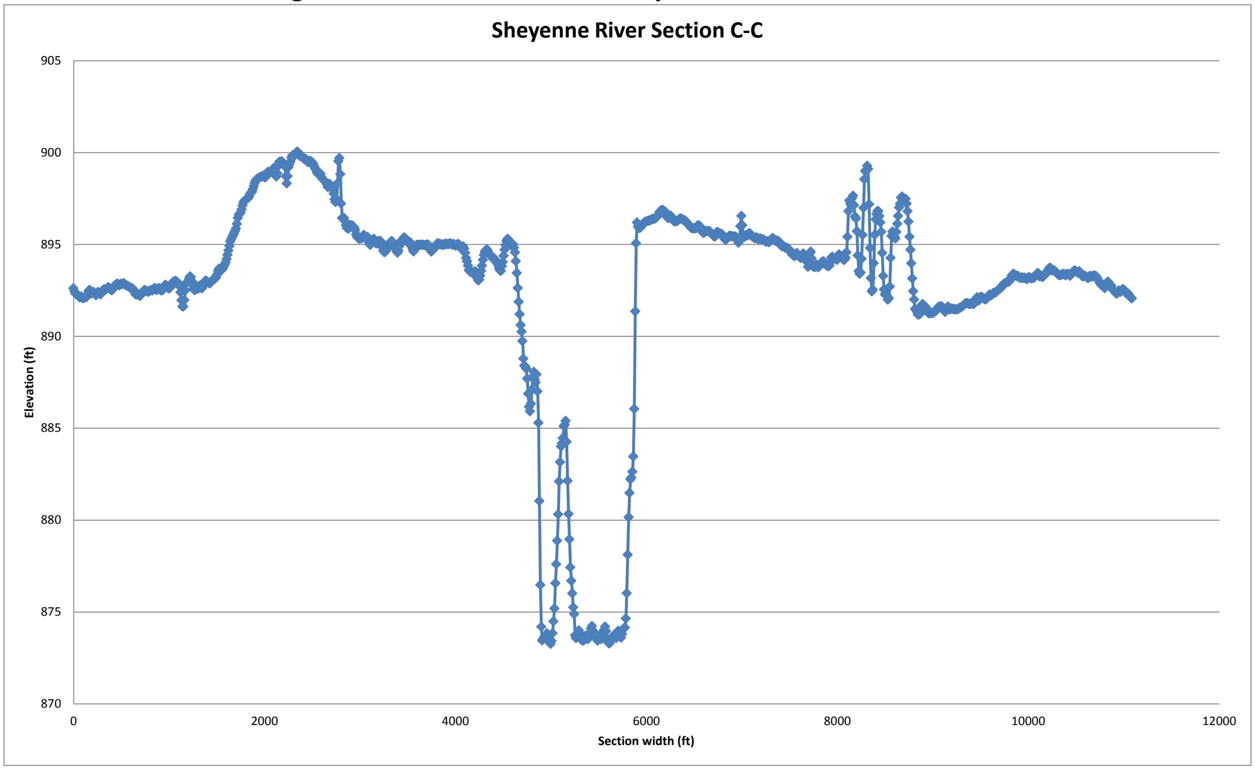
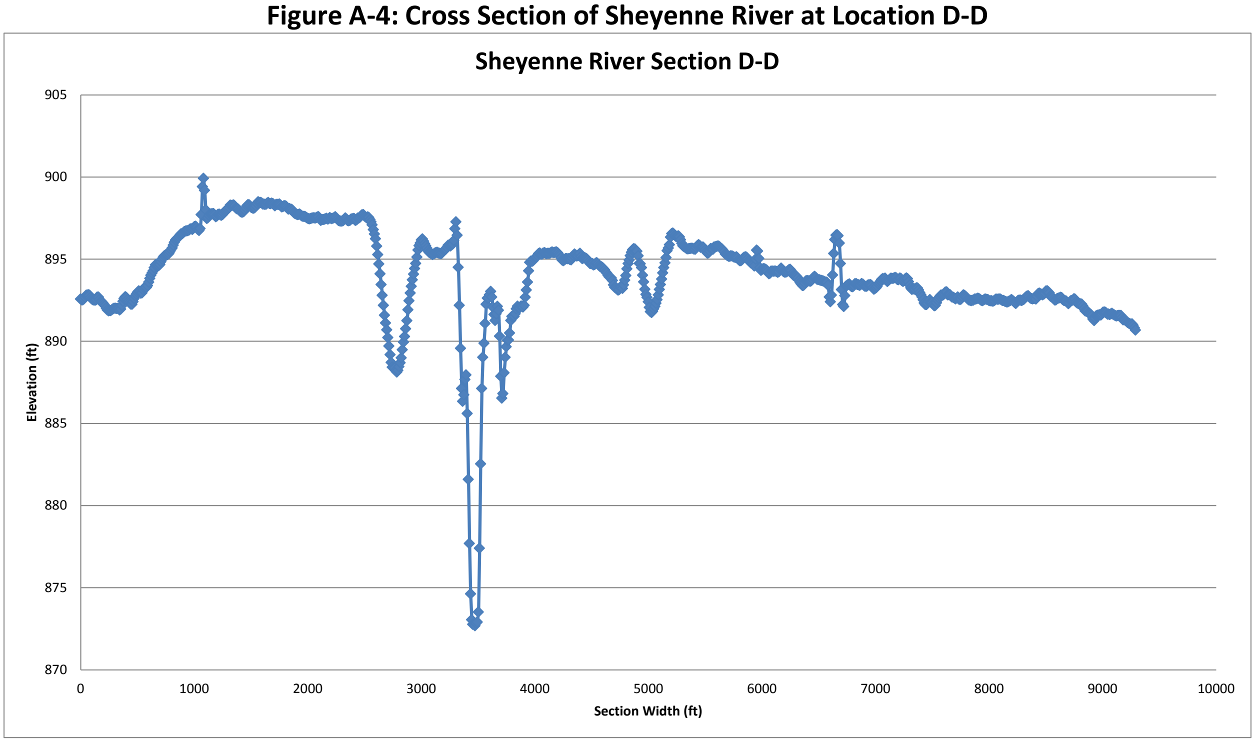


Figure A-4: Cross Section of Sheyenne River at Location D-D



Appendix B

Figures from HUR Study

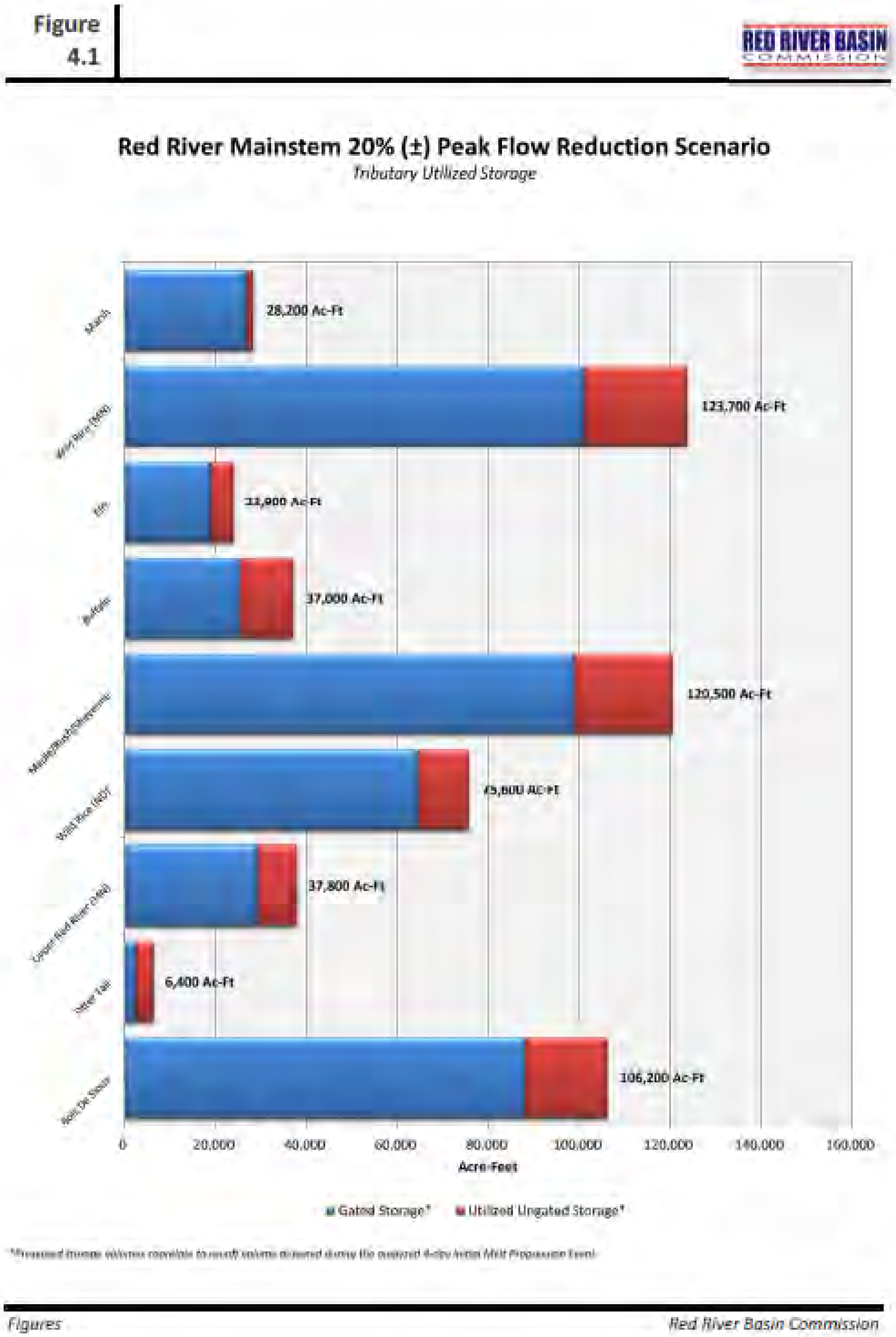
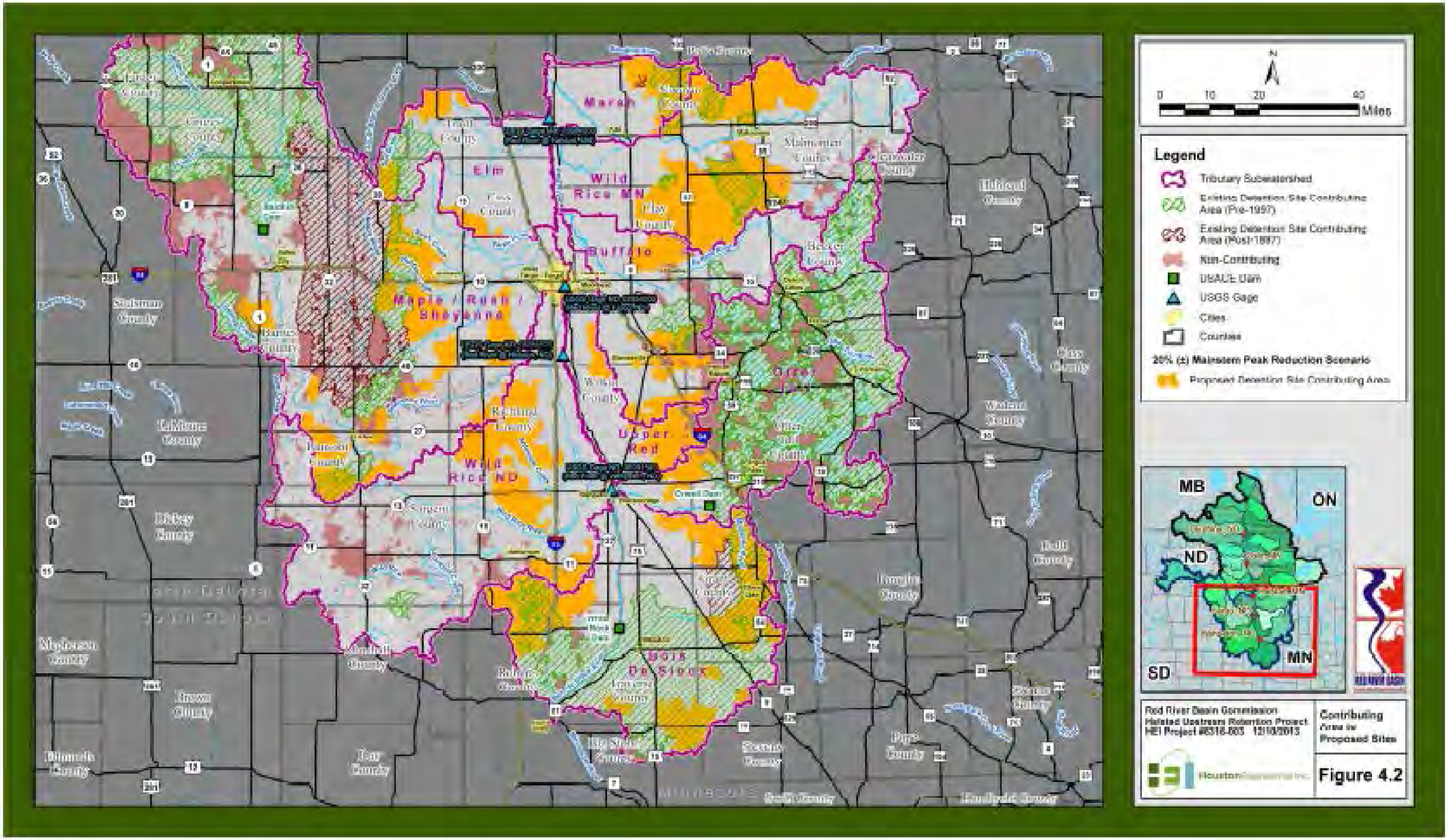


Figure B-1: Total Storage Within Each Watershed

Source: Figure 4.1 - HUR, 2013



Red River Basin Commission Halstad Upstream Retention Study

Figures

Figure B-2: Upstream Contributing Area to Distributed Storage Sites

Source: Figure 4.2 – HUR, 2013

Appendix C

Comparison of Water Surface Elevation with and without Distributed Storage
with
HUR conditions

Comparison of Water Surface Elevation with and without Distributed Storage with HUR conditions

River Mile	River Station	Halstad Upstream Retention		Halstad Upstream Retention			
		Existing No Protection	Existing Full Protection	HUR No Protection	HUR Full Protection	HUR USACE Levees Phase 2	WSE reduction between HUR and existing with full protection
487.1	2620684	921.93	921.93	918.99	919	918.98	2.93
486.9	2619494	921.84	921.85	918.93	918.93	918.92	2.92
485.9	2614209	921.44	921.45	918.62	918.63	918.61	2.82
484.4	2605861	920.86	920.87	918.16	918.17	918.15	2.7
483.2	2599647	920.38	920.39	917.78	917.79	917.77	2.6
481.4	2589817	919.59	919.61	917.11	917.13	917.1	2.48
480.1	2582760	918.91	918.93	916.55	916.58	916.55	2.35
478.9	2576691	918.23	918.26	916.02	916.05	916.01	2.21
478.4	2573803	917.99	918.02	915.82	915.85	915.82	2.17
477.8	2570417	917.67	917.71	915.59	915.62	915.59	2.09
477.4	2568232	917.43	917.47	915.4	915.44	915.4	2.03
477.0	2566320	917.23	917.28	915.26	915.3	915.26	1.98
476.6	2563980	917.07	917.11	915.14	915.18	915.14	1.93
476.6	2563876	917.05	917.1	915.13	915.17	915.13	1.93
476.5	2563754	917.01	917.06	915.09	915.13	915.09	1.93
476.5	2563654	917	917.05	915.08	915.12	915.08	1.93
476.5	2563577	916.86	916.91	914.97	915.02	914.97	1.89
476.2	2561706	916.75	916.8	914.89	914.94	914.89	1.86
475.3	2557350	916.5	916.56	914.69	914.74	914.69	1.82
474.9	2554719	916.28	916.35	914.51	914.57	914.51	1.78
474.5	2552977	916.06	916.13	914.35	914.41	914.35	1.72
473.7	2548627	915.66	915.75	914.06	914.12	914.06	1.63
473.1	2545349	915.4	915.49	913.86	913.93	913.86	1.56
472.4	2541269	915.14	915.24	913.66	913.73	913.66	1.51
471.9	2538562	914.98	915.08	913.54	913.62	913.55	1.46
471.0	2534128	914.72	914.84	913.35	913.44	913.36	1.4
470.5	2531315	914.53	914.66	913.21	913.3	913.22	1.36
470.1	2529397	914.42	914.55	913.12	913.22	913.13	1.33
469.4	2525228	914.19	914.34	912.95	913.05	912.96	1.29
468.9	2522697	914.02	914.18	912.84	912.94	912.85	1.24
468.3	2519665	913.78	913.97	912.65	912.76	912.66	1.21
468.2	2518900	913.73	913.92	912.59	912.7	912.61	1.22
468.2	2518734	913.73	913.92	912.59	912.7	912.61	1.22
468.2	2518705	913.72	913.92	912.59	912.7	912.61	1.22
467.9	2517451	913.63	913.84	912.5	912.62	912.52	1.22
467.7	2516193	913.47	913.7	912.36	912.49	912.38	1.21
467.0	2512417	913.19	913.47	912.11	912.25	912.13	1.22
466.6	2510314	912.93	913.27	911.88	912.04	911.92	1.23
465.9	2506444	912.47	912.93	911.49	911.69	911.54	1.24
465.4	2503969	912.18	912.73	911.26	911.48	911.33	1.25
465.4	2503890	912.13	912.69	911.22	911.44	911.29	1.25
465.4	2503794	912.06	912.63	911.19	911.42	911.27	1.21
465.4	2503730	912.06	912.63	911.19	911.42	911.27	1.21
465.0	2501883	911.92	912.53	911.08	911.31	911.16	1.22
464.2	2497284	911.47	912.25	910.71	910.99	910.83	1.26
463.5	2493379	911.18	912.06	910.49	910.79	910.62	1.27
463.4	2493300	911.16	912.05	910.48	910.79	910.61	1.26

Source: Houston Engineering

Comparison of Water Surface Elevation with and without Distributed Storage with HUR conditions

River Mile	River Station	Halstad Upstream Retention		Halstad Upstream Retention			
		Existing No Protection	Existing Full Protection	HUR No Protection	HUR Full Protection	HUR USACE Levees Phase 2	WSE reduction between HUR and existing with full protection
463.4	2493142	911.19	912.05	910.49	910.8	910.63	1.25
462.6	2488717	910.93	911.89	910.27	910.61	910.43	1.28
461.8	2484618	910.74	911.79	910.1	910.47	910.27	1.32
461.5	2482630	910.65	911.74	910.01	910.4	910.2	1.34
461.3	2481848	910.65	911.74	910.01	910.4	910.2	1.34
460.9	2479658	910.5	911.66	909.87	910.28	910.08	1.38
460.5	2477737	910.42	911.61	909.79	910.21	910.01	1.4
460.0	2474822	910.31	911.55	909.7	910.13	909.94	1.42
459.3	2470898	910.16	911.45	909.56	910.01	909.82	1.44
458.9	2469024	910.06	911.38	909.44	909.91	909.71	1.47
458.6	2467068	909.97	911.31	909.34	909.82	909.62	1.49
457.9	2463769	909.74	911.15	909.07	909.59	909.38	1.56
457.6	2462090	909.61	911.05	908.93	909.47	909.24	1.58
457.6	2461667	909.56	911.01	908.87	909.42	909.19	1.59
457.3	2460207	909.44	910.93	908.74	909.3	909.07	1.63
457.1	2459121	909.35	910.86	908.64	909.22	908.98	1.64
457.0	2458511	909.29	910.82	908.58	909.16	908.92	1.66
456.8	2457329	909.18	910.74	908.45	909.05	908.81	1.69
456.2	2454343	908.96	910.59	908.21	908.84	908.58	1.75
455.8	2452325	908.78	910.47	908.01	908.66	908.39	1.81
455.7	2451471	908.66	910.39	907.9	908.56	908.29	1.83
455.5	2450666	908.53	910.3	907.78	908.45	908.18	1.85
455.3	2449505	908.42	910.21	907.67	908.35	908.08	1.86
455.1	2448359	908.29	910.12	907.55	908.24	907.96	1.88
455.0	2448001	908.27	910.1	907.53	908.23	907.95	1.87
454.7	2446513	908.08	909.97	907.35	908.07	907.78	1.9
454.4	2444613	907.82	909.79	907.11	907.85	907.55	1.94
454.2	2443410	907.68	909.69	906.98	907.73	907.43	1.96
454.1	2443019	907.64	909.66	906.94	907.7	907.39	1.96
453.7	2441091	907.43	909.51	906.73	907.52	907.21	1.99
453.6	2440177	907.32	909.45	906.63	907.43	907.12	2.02
453.5	2439730	907.25	909.41	906.56	907.37	907.05	2.04
453.3	2438725	907.13	909.33	906.45	907.27	906.95	2.06
453.2	2438085	907.06	909.28	906.38	907.21	906.89	2.07
453.1	2437853	907.03	909.26	906.35	907.19	906.86	2.07
453.1	2437686	906.96	909.2	906.3	907.12	906.8	2.08
453.0	2437221	906.89	909.15	906.21	907.06	906.73	2.09
452.8	2435818	906.74	909.04	906.06	906.93	906.6	2.11
452.3	2433346	906.52	908.87	905.83	906.7	906.4	2.17
452.0	2431931	906.44	908.76	905.73	906.56	906.28	2.2
451.7	2430241	906.35	908.63	905.62	906.4	906.11	2.23
451.6	2429392	906.3	908.56	905.56	906.31	906.02	2.25
451.5	2429241	906.3	908.56	905.56	906.31	906.02	2.25
451.4	2428641	906.25	908.5	905.51	906.25	905.96	2.25
451.3	2428089	906.18	908.42	905.45	906.18	905.89	2.24
451.3	2427989	906.17	908.41	905.43	906.17	905.88	2.24
451.1	2426874	906.04	908.28	905.3	906.06	905.77	2.22

Source: Houston Engineering

Comparison of Water Surface Elevation with and without Distributed Storage with HUR conditions

River Mile	River Station	Halstad Upstream Retention		Halstad Upstream Retention			
		Existing No Protection	Existing Full Protection	HUR No Protection	HUR Full Protection	HUR USACE Levees Phase 2	WSE reduction between HUR and existing with full protection
451.0	2426311	905.99	908.22	905.24	906	905.71	2.22
450.8	2425307	905.93	908.14	905.17	905.92	905.63	2.22
450.7	2424705	905.91	908.09	905.14	905.87	905.58	2.22
450.5	2423616	905.85	907.99	905.06	905.77	905.48	2.22
450.4	2423097	905.84	907.95	905.04	905.74	905.45	2.21
450.1	2421660	905.75	907.76	904.92	905.55	905.26	2.21
449.8	2420117	905.69	907.68	904.84	905.46	905.17	2.22
449.7	2419332	905.63	907.6	904.77	905.39	905.1	2.21
449.5	2418565	905.58	907.53	904.71	905.32	905.03	2.21
449.4	2417863	905.51	907.44	904.63	905.24	904.95	2.2
449.3	2416977	905.41	907.32	904.51	905.12	904.83	2.2
449.1	2416271	905.37	907.28	904.47	905.08	904.79	2.2
449.1	2416131	905.35	907.26	904.45	905.07	904.78	2.19
449.1	2416111	905.16	907.05	904.25	904.87	904.58	2.18
449.1	2415915	905.14	907.04	904.24	904.85	904.56	2.19
448.9	2415117	905.1	907	904.2	904.82	904.53	2.18
448.7	2414114	905.01	906.91	904.1	904.73	904.44	2.18
448.6	2413447	904.94	906.82	904.02	904.64	904.35	2.18
448.4	2412334	904.86	906.72	903.92	904.54	904.25	2.18
448.3	2411901	904.79	906.62	903.82	904.45	904.16	2.17
448.2	2411386	904.79	906.6	903.82	904.43	904.14	2.17
448.2	2411151	904.78	906.59	903.82	904.42	904.13	2.17
448.0	2410099	904.73	906.48	903.74	904.31	904.02	2.17
447.8	2409084	904.7	906.43	903.7	904.27	903.98	2.16
447.4	2407195	904.6	906.24	903.57	904.09	903.8	2.15
447.1	2405219	904.54	906.13	903.48	903.97	903.68	2.16
446.9	2404132	904.5	906.05	903.43	903.9	903.6	2.15
446.7	2403465	904.46	905.98	903.39	903.83	903.54	2.15
446.7	2403092	904.41	905.92	903.34	903.77	903.48	2.15
446.6	2402645	904.34	905.82	903.26	903.67	903.38	2.15
446.4	2401848	904.25	905.72	903.19	903.59	903.3	2.13
446.4	2401602	904.23	905.73	903.17	903.6	903.31	2.13
446.4	2401417	904.16	905.67	903.1	903.53	903.24	2.14
446.3	2401224	904.2	905.7	903.14	903.56	903.27	2.14
446.2	2400425	904.12	905.59	903.04	903.45	903.16	2.14
445.9	2399041	904.04	905.49	902.95	903.35	903.07	2.14
445.6	2397339	903.95	905.38	902.84	903.24	902.95	2.14
445.3	2395607	903.88	905.3	902.76	903.15	902.86	2.15
445.2	2395173	903.86	905.27	902.73	903.12	902.83	2.15
444.9	2393417	903.8	905.17	902.65	903.02	902.73	2.15
444.6	2391827	903.75	905.06	902.57	902.91	902.62	2.15
444.4	2390638	903.67	904.9	902.47	902.77	902.48	2.13
444.1	2389466	903.53	904.68	902.3	902.57	902.28	2.11
443.9	2388223	903.44	904.57	902.2	902.47	902.18	2.1
443.7	2386941	903.3	904.36	902.03	902.28	901.99	2.08
443.5	2385855	903.08	904.12	901.81	902.07	901.79	2.05
443.3	2384858	902.94	904	901.68	901.95	901.67	2.05

Source: Houston Engineering

Comparison of Water Surface Elevation with and without Distributed Storage with HUR conditions

River Mile	River Station	Halstad Upstream Retention		Halstad Upstream Retention			
		Existing No Protection	Existing Full Protection	HUR No Protection	HUR Full Protection	HUR USACE Levees Phase 2	WSE reduction between HUR and existing with full protection
443.3	2384804	902.92	903.99	901.67	901.94	901.66	2.05
443.3	2384779	902.53	903.58	901.28	901.56	901.27	2.02
443.3	2384724	902.51	903.56	901.27	901.54	901.26	2.02
443.2	2384446	902.48	903.54	901.24	901.51	901.23	2.03
443.1	2383756	902.39	903.47	901.16	901.44	901.15	2.03
443.0	2383108	902.34	903.42	901.12	901.39	901.11	2.03
442.9	2383066	902.33	903.42	901.11	901.39	901.11	2.03
442.9	2382966	902.23	903.29	901.04	901.32	901.04	1.97
442.9	2382883	902.17	903.24	900.99	901.27	900.99	1.97
442.9	2382813	902.21	903.27	901.02	901.3	901.02	1.97
442.9	2382768	902.13	903.2	900.95	901.23	900.95	1.97
442.9	2382669	902.12	903.2	900.95	901.23	900.95	1.97
442.9	2382582	902.16	903.23	900.98	901.26	900.98	1.97
442.8	2382478	902.08	903.15	900.92	901.2	900.92	1.95
442.8	2382271	902.04	903.11	900.89	901.17	900.89	1.94
442.6	2381440	901.78	902.83	900.65	900.93	900.65	1.9
442.6	2381351	901.87	902.89	900.73	900.98	900.7	1.91
442.6	2381238	901.72	902.69	900.62	900.86	900.59	1.83
442.4	2380360	901.58	902.56	900.51	900.74	900.47	1.82
442.1	2378726	901.35	902.38	900.33	900.59	900.32	1.79
442.1	2378626	901.34	902.38	900.32	900.58	900.31	1.8
442.1	2378596	901.14	902.25	900.19	900.45	900.19	1.8
442.1	2378504	901.09	902.21	900.15	900.41	900.15	1.8
441.5	2375089	900.77	901.9	899.87	900.12	899.87	1.78
441.3	2373952	900.61	901.72	899.71	899.96	899.7	1.76
440.9	2372068	900.4	901.46	899.5	899.72	899.46	1.74
440.6	2370340	900.25	901.29	899.36	899.56	899.31	1.73
440.4	2369321	900.04	901.1	899.19	899.4	899.14	1.7
440.4	2369204	900.03	901.09	899.18	899.39	899.14	1.7
440.4	2369150	899.99	901.06	899.13	899.35	899.1	1.71
440.3	2369050	899.97	901.05	899.12	899.34	899.09	1.71
440.2	2368335	899.79	900.86	898.95	899.17	898.91	1.69
440.2	2368283	899.81	900.88	898.97	899.18	898.93	1.7
440.2	2368233	899.5	900.56	898.66	898.88	898.63	1.68
440.2	2368086	899.52	900.57	898.68	898.9	898.64	1.67

Source: Houston Engineering

Wenck

Engineers • Scientists
Business Professionals