Appendix A
Hydrology

Fargo-Moorhead Metropolitan Area Flood Risk Management

Supplemental Draft Feasibility Report and Environmental Impact Statement

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US Army Corps of Engineers®

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Executive Summary

Need For Study. The Red River of the North has exceeded the National Weather Service flood action stage of 17 feet in 50 of the past 106 years at USGS gage site 05054000 located at Fargo, ND and every year from 1993 through 2010. Given the high risk of flooding along the Red River of the North, the St. Paul District of the US Army Corps of Engineers is completing a feasibility study of alternative measures to reduce flood risk in the Fargo –Moorhead Area. Appendix A of the Fargo-Moorhead Metro Feasibility Study (FMMFS) covers the hydrological analyses used to provide for economic analysis, identify design parameters and develop hydraulic modeling for this study.

Study Limits. The adopted Fargo-Moorhead Study limits for Hydrological analysis are from Hickson, ND to Emerson, Manitoba, Canada. The adopted study limits are reflected in Appendices A-2 through A-4 of the Fargo Moorhead Metro Feasibility Study Report. In Phase I of the study, it was thought that Wahpeton, ND was the most upstream limit and therefore analysis between Wahpeton and Hickson was included in Appendix A-1. Analysis upstream of Hickson was not carried forward in the remaining Appendices after the Expert Opinion Elicitation.

Project Evolution. The USACE carried out the Hydrological analysis for the FMMFS in four phases. The first phase of the study began with a draft report issued by the United States Army Corps of Engineers (USACE) in March of 2009, and since that time published multiple reports and updates as the study has progressed. The table below shows a summary of this progression:

Study Phase	Report Date	Description	Sub-Appendix
Phase 1	March 2009/ August 2009	Draft Report- Hydrological Analysis based on the period of record	Appendix A-1A
Phase 2a	October 2009	Expert Opinion Elicitation	Appendix A-1B
Phase 2b	February 2010	HEC Report	Appendix A-1C
Phase 3	May 2010	Hydrology Updated for Wet and Dry Cycles	Appendix A-2
Phase 3.1	July 2010	Study Area Extended	Appendix A-3
Phase 3.2	July 2010	Hydrology Amended- Fargo to Halstad	Appendix 4A & 4B
Phase 4	January 2011	Hydrological Analysis in Support of Unsteady RAS Modeling and Design	Appendix 4B

Phase 1: Period of Record Analysis. In August 2009, a report entitled "Fargo-Moorhead Metro Flood Risk Management Project, Feasibility Report" was completed. The hydrological analysis carried out for this phase of the study consists of developing the needed inputs to steady and unsteady water surface profile models (HEC-Ras) for the Red River of the North through the City of Fargo, ND. The steady flow model required synthetic events derived from a discharge-frequency analysis. The unsteady flow-model requires balanced hydrographs. Flow-frequency analysis for the Red River of the North watershed between Wahpeton, ND and Grand Forks, ND was carried out for the full period of record. Balanced hydrographs were developed in support of the unsteady flow model for selected frequency events as well as coincidental balanced hydrographs for major tributaries. Analysis was carried out for both the regulated and unregulated condition. At the time this analysis was carried 2009 flow data was still provisional.

Phase 2a: Expert Opinion Elicitation. There has been an increasing amount of evidence indicating that the flow records at the Fargo gage can no longer be considered stationary. To address this issue, the Corps project delivery team (PDT) organized an expert opinion elicitation (EOE) in September of 2009. The EOE was established to provide the PDT with specific actions that should be taken, if any, to account for the suspected non-stationarity and uncertainty associated with the flow recorded in the Fargo-Moorhead metropolitan area and assess possible future climatic change impacts. In October 2009 a report was published describing EOE recommendations. The panel concluded that the Red River peak stream flows exhibited non-stationarity in the form of two flow regimes, a wet period and a dry period, and that this result should be incorporated in development of the flow frequency curves for the Fargo Moorhead Metro Feasibility Study.

Phase 2b: HEC Analysis- WET/DRY Analysis. A contract was drafted between the St. Paul District and the Corps Hydrologic Engineering Center (HEC) to implement the recommendations of the EOE. HEC developed a methodology that could be used to generate separate flow frequency curves for the wet and dry periods. The flow record was divided into two segments based on a test to determine the break point providing the strongest statistical evidence of separate homogenous data sets. The resulting break point of 1941 defined the WET portion of the period of record as 1942-2009. The WET and DRY frequency curves were combined to reflect the likelihood of experiencing either the wet or dry flow regime in future years (25 year look ahead and 50 year look ahead).

Phase 3: Hydrology Updated for WET/DRY Cycles. In May 2010 the hydrological analysis carried out in Phase 1 was updated for the Red River reach between Hickson, ND and Grand Forks, ND. This analysis generates three frequency curves: one for the present climate condition labeled as WET, a second labeled as a combination of WET and DRY with 80% weight for WET and 20% weight for Dry, and a third frequency curve combination with a weight of 65% Wet and 35% DRY. The WET curve represents year one in the planning period transitioning to the second combination curve in 25 years and again a transition to the third combination curve at the end of the 50-yr planning period. Flow-frequency curves were updated as inputs to the steady flow model. Balanced hydrographs were updated as inputs to the unsteady flow model. Analysis was carried out for both the regulated and unregulated condition.

Phase 3.1: Study Area Extended Downstream. Initially hydraulic modeling of the Red River of the North only extended to Halstad, MN. After carrying out initial analysis, the PDT determined that the downstream impacts associated with proposed project extend beyond Halstad, MN. To try to fully define downstream impacts, analyses had to be carried further downstream and the study reach was extended to Emerson, Canada. Flow-frequency and balance hydrograph analysis was carried out downstream for the WET portion of the period of record.

Phase 3.2: Hydrology Amended- Fargo to Halstad. With the May 2010 submittal, it was noted that Phase 3 hydrology significantly increased flows through Fargo, yet the flows further downstream, at locations such as Halstad and Grand Forks did not increase significantly. Further refinement of the hydrology particularly with the Sheyenne River coincidental flows resulted in improved results. Given the important impact the Sheyenne River has on project parameters, a revision to the Phase 3 Hydrology was developed. Revisions of the Sheyenne River hydrology consisted of developing a Lower Sheyenne River model to carry out flow-frequency analysis for the Rush River, Maple River, and at points of interest in the Lower Sheyenne River Watershed for the WET portion of the period of record. Based on this frequency analysis, balanced hydrographs could then be generated at points of interest within the Lower Sheyenne River Basin. This analysis required the development of an HMS model that takes into account the effects of breakouts and regulatory structures within the Sheyenne River watershed and extending HMS routing along the Red River between Fargo and Halstad.

Phase 4: Hydrological Analysis in Support of Unsteady RAS Modeling and Design. After the downstream impacts of the project developed in earlier phases of analysis were analyzed it was determined that they were not fully definable and another approach was needed. The USACE and local project sponsors decided to pursue an option that included raising water levels, or staging, upstream of the Fargo-Moorhead Metro area. This proposal would include constructed storage areas as well as natural storage options. To develop a design that incorporates the benefits of upstream storage and staging, an unsteady flow model was required for the study area. The unsteady model requires synthetic balanced hydrographs representative of points of interest in the basin as boundary conditions. Further balanced hydrographs were developed for locations within the Lower Sheyenne River Basin as boundary conditions to the Unsteady RAS model.

Coincidental discharge frequency values and balanced hydrographs are determined for the 500-, 100-, 50, and 10-yr events for locations upstream and downstream of Fargo in order to develop design parameters for appurtenant structures on the Sheyenne, Maple and Rush River tributaries.

Analysis Results Summary. A master table summarizing the results of all flow-frequency analysis carried out to date for the Fargo-Moorhead Metro Study is displayed in the following table**.** This table summarizes the flows for the discharge-frequencies on the mainstem of Red River of the North. Significant tributary discharge-frequencies values are also shown in terms of coincidental flow-frequencies. Locations that have a USGS streamflow gage are shaded in green.

Summary Discharge-Frequencies; Red River

	Drainage	DISCHARGES in cfs													
	Area	Recurrence Interval											Reference		
LOCATION	***sq. mi.***	**2-YR**	**4-YR**	**5-YR**	**10-YR**	**20-YR**	**50-YR**	**100-YR**	**200-YR**	**500-YR**	**1000-yr**	**10000-yr**	**Appendix**	**Sections**	**Tables**
Emerson	30,030	27,937		50,081	66,650	83,572	106,697	124,815	143,483	169,000			A-3	2.1.3, 2.2	18, 20
Pembina River Coinc.	3,950	1,002		3,640	5,728	7,399	8,831	9,189	9,308	9,427			A-3	4.3.2	36, 37
U/S Pembina River, ND	26,040	26,935		46,441	60,922	76,173	97,866	115,626	134,175	159,573					
D/S Two Rivers, MN	26,010	26,968		47,227	62,294	77,991	99,976	117,693	136,156	161,428					
Two Rivers Coinc.	1,230	1,082		3,149	4,625	5,806	6,691	6,790	6,888	6,986			A-3	4.2.2	33, 34
U/S Two Rivers, MN	24,780	25,886		44,078	57,669	72,185	93,285	110,903	129,268	154,442					
Drayton	24,670	26,009		47,027	62,847	79,061	101,292	118,757	136,789	161,486			A-3	2.1.2, 2.2	17, 20
D/S Park River, ND	24,100	25,329		47,441	64,630	82,603	106,697	125,252	143,672	168,702					
Park River Coinc.	1,010	550		1,700	2,800	4,300	6,000	7,000	7,500	8,000			A-3	3.2.3	22, 26
U/S Park River, ND	23,090	24,779		45,741	61,830	78,303	100,697	118,252	136,172	160,702					
D/S Snake River, MN	23,060	24,742		45,763	61,927	78,494	100,989	118,602	136,545	161,094					
Snake River Coinc.	950	342		1,174	2,004	2,921	3,912	4,592	5,084	5,694			A-3	3.2.2	22, 24
U/S Snake River, MN	22,110	24,400		44,589	59,923	75,573	97,077	114,010	131,460	155,399					

Summary Discharge Table. Continued.

	Drainage	DISCHARGES in cfs													
	Area	Recurrence Interval											Reference		
LOCATION	*sq. mi.*	2-YR	4-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR	1000-yr	10000-yr	Appendix	Sections	Tables
D/S Forest River, ND	22,080	24,363		44,611	60,020	75,765	97,370	114,363	131,836	155,794					
Forest River Coinc.	900	210		750	1,300	1,800	2,350	2,700	2,850	3,000			A-3	3.2.1	22, 23
U/S Forrest River, ND	21,180	24,153		43,861	58,720	73,965	95,020	111,663	128,986	152,794					
Oslo	21,105	24,056		43,920	58,970	74,459	95,773	112,569	129,950	153,811			A-3	2.1.1, 2.2	15, 20
D/S Turtle River, MN	21,105	24,056		43,920	58,970	74,459	95,773	112,569	129,950	153,811					
Turtle River Coinc.	635	547		1,282	1,885	2,524	3,422	4,132	4,867	5,868			A-3	3.1.1	21
U/S Turtle River, MN	20,319	23,509		42,638	57,086	71,935	92,351	108,437	125,083	147,943					
Grand Forks	20,015	23,295		42,139	56,354	70,956	91,026	106,838	123,201	145,675			A-3	1.1.6	9
d/s Red Lake	20,015	23,295		42,139	56,354	70,956	91,026	106,838	123,201	145,675					
Red Lake Coinc.	3,800	7,379		11,604	13,399	15,437	18,128	20,073	22,200	24,595			A-3	1.1.4, 1.1.6	7, 8, 9
u/s Red Lake	16,215	15,916		30,535	42,955	55,519	72,898	86,765	101,001	121,080					
Thompson	16,095	15,792		30,535	42,899	55,519	72,898	86,765	101,001	121,080			A-3	1.1.6	9
d/s Sand Hill River	16,015	15,709		30,535	42,862	55,519	72,898	86,765	101,001	121,080					
Sand Hill River Coinc.	430	763		1,801	2,700	3,451	4,000	4,226	4,367	4,532			A-3	1.1.3, 1.1.6	5, 6, 9
u/s Sand Hill River	15,585	14,946		28,734	40,162	52,068	68,898	82,539	96,634	116,548					

Summary Discharge Table Continued.

LOCATION	*Drainage Area* sq. mi.	2-YR	4-YR	5-YR	10-YR	20-YR	50-YR	100-YR	200-YR	500-YR	1000-yr	10000-yr	Appendix	Reference Sections	Tables
		DISCHARGES in cfs Recurrence Interval													
d/s Marsh River	15,375	14,734		28,734	40,067	52,068	68,898	82,539	96,634	116,548					
Marsh River Coinc.	150	712		1,511	2,420	3,145	3,996	4,709	5,151	5,543			A-3	1.1.2, 1.1.6	3, 4, 9
u/s Marsh River	15,225	14,022		27,223	37,648	48,923	64,902	77,830	91,484	111,005					
d/s Goose River	15,225	14,022		27,223	37,648	48,923	64,902	77,830	91,484	111,005					
Goose River Coinc.	1,160	657		1,964	2,650	3,908	5,596	7,032	8,612	11,292			A-3	1.1.1, 1.1.6	1, 2, 9
u/s Goose River	14,065	13,365		25,259	34,998	45,014	59,306	70,798	82,872	99,713					
Halstad	13,775	13,074	22,261	25,260	34,871	45,014	59,306	70,798	82,872	99,713	113,103	162,000	A-3	1.1.6	9
d/s Wild Rice, MN	13,735	13,051	22,232	25,229	34,830	44,962	59,238	70,715	82,794	99,638	113,028	161,928			
Wild Rice River, MN coinc.	1,650	2,348	4,089	4,647	6,393	8,165	10,547	12,450	12,600	12,950	13,200	13,700	A-2	5.3, 5.3.3	19, 22
u/s Wild Rice, MN	12,085	10,703	18,143	20,582	28,437	36,797	48,691	58,265	70,194	86,688	99,828	148,228			
d/s Elm	12,055	10,687	18,123	20,560	28,409	36,761	48,644	58,206	70,138	86,632	99,771	148,172			
u/s Elm	11,655	10,472	17,854	20,267	28,028	36,271	48,004	57,418	69,381	85,876	99,006	147,414			
d/s Buffalo	11,305	10,282	17,614	20,006	27,688	35,834	47,433	56,714	68,704	85,199	98,319	146,733			
Buffalo River coinc.	1,190	1,312	2,615	3,061	4,431	5,809	7,604	9,100	9,275	9,600	9,850	10,450	A-2	5.3, 5.3.2	19, 20, 21
U/S Buffalo	10,115	8,970	14,999	16,945	23,257	30,025	39,829	47,614	59,429	75,599	88,469	136,283			

Summary Discharge Table Continued.

	Drainage					DISCHARGES in cfs									
	Area					Recurrence Interval								Reference	
LOCATION	*sq. mi.*	**2-YR**	**4-YR**	**5-YR**	**10-YR**	**20-YR**	**50-YR**	**100-YR**	**200-YR**	**500-YR**	**1000-yr**	**10000-yr**	**Appendix**	**Sections**	**Tables**
d/s Sheyenne	9,905	8,857	14,860	16,795	23,062	29,776	39,503	47,212	59,029	75,188	88,047	135,849			
Sheyenne River coinc.	4,850	2,949	3,834	4,177	5,446	6,985	9,163	11,242	11,488	12,048	12,530	13,203	A-2	6.3.2	32, 33, 34
u/s Sheyenne	5,055	5,908	11,026	12,618	17,616	22,791	30,340	35,970	47,541	63,141	75,517	122,646			
Fargo	4,625[1] 3,220[2]	5,600	10,600	12,150	17,000	22,000	29,300	34,700	46,200	61,700	74,000	121,000	A-2	5.1.2	7 - 12
d/s Drain 53	3,165	5,564		12,022	16,844	21,810	29,058	34,398	45,774	61,099					
Drain 53 coincidental	30	26		70	113	158	213	252	289	336					
u/s Drain 53	3,135	5,538		11,952	16,731	21,652	28,845	34,146	45,485	60,763					
d/s Wild Rice	3,080	5,508		11,823	16,600	21,514	28,679	33,927	45,110	60,160					
Wild Rice River coin @ ABER	1,640	1,419	2,587	3,021	6,185	8,648	11,655	13,780	15,801	18,342			A-2	5.2, 5.3, 5.3.1	17, 18, 19
u/s Wild Rice	1,440	4,089		8,802	10,415	12,866	17,024	20,147	29,309	41,818					
d/s Wolverton	1,430	4,133		7,386	11,005	14,630	19,819	22,999	29,874	38,891					
Wolverton coincidental	105	91	210	250	396	554	746	882	1,012	1,174					
u/s Wolverton	1,325	4,042		7,136	10,609	14,077	19,073	22,117	28,862	37,716					
Hickson	1,310	4,000		7,000	10,500	14,000	19,000	22,000	28,500	37,000			A-2	5.1.2, 5.1.4	7 - 9, 14

[1]4,625 sq. mi. is the total contributing drainage area upstream of Fargo including the area upstream of the dams. This was used in interpolating flows between Fargo and Emerson.
[2]3,220 sq. mi. is the incremental local contributing area between Fargo and the upstream dams. This was used in interpolating flows between Hickson and Fargo.