Fargo-Moorhead Metropolitan Area

Flood Risk Management Project

Draft Operation Plan

5 December 2014

The Draft EIS version of this document was accepted as the Final EIS version. No changes were made to this document.

Purpose

The purpose of this Operation Plan is a supplement to the Minnesota EIS and is to provide a summary of the water control management activities associated with the Fargo-Moorhead Metropolitan Area Project (the Project) as they relate to the hydraulic and hydrologic aspects of the Project, and identify actions that will be included in a Water Control Manual for the Project prior to completion of construction. The water control management activities may be revised as detailed design proceeds, or through the Adaptive Management Monitoring Plan (AMMP) that will be implemented for this Project. The Water Control Manual is required by Corps regulation ER 1110-2-240, "Water Control Management," and includes the water control plan for the project. As stated in the regulation:

> Water control plans include coordinated regulation schedules for project/system regulation and such additional provisions as may be required to collect, analyze and disseminate basic data, prepare detailed operating instructions, assure project safety and carry out regulation of projects in an appropriate manner.

Operation and maintenance activities not directly related to the water control management activities will be included in an Operation, Maintenance, Repair, Replacement and Rehabilitation (OMRR&R) Manual, which will be completed at the end of construction. The Water Control Manual is a separate document from the OMRR&R Manual.

Gate Operation and Staging Area Operation

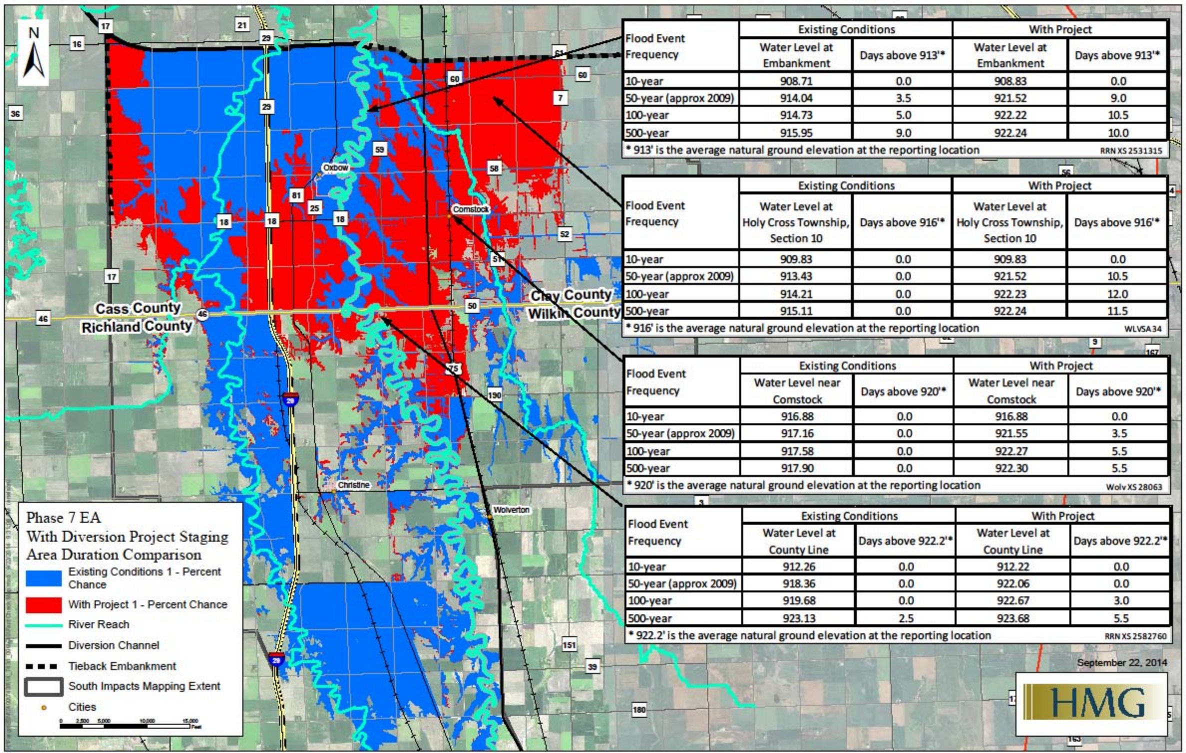
When the Project as defined in the EIS is not in operation the gates at the Red River of the North and Wild Rice River control structures remain fully open and the gates at the diversion inlet control structure remain fully closed. Operation of the Project would begin when it becomes known that a stage of 35.0 feet would be exceeded at the U.S. Geological Survey (USGS) gage in Fargo (the Fargo gage). At this stage, the flow through Fargo would be approximately 17,000 cubic feet per second (cfs). A flow of 17,000 cfs at the Fargo gage is approximately a 10 percent chance or 10-year flood event. The Red River gage at Enloe, ND and the Wild Rice River gage near Abercrombie, ND would be observed (by adding the two flows together) to determine whether 17,000 cfs will occur in Fargo. Historical floods were analyzed to determine the relationship between flow at Enloe/Abercrombie and Fargo. Once the sum at Enloe/Abercrombie reaches 17,000 cfs Project operations would begin unless the hydrographs indicate they may be close to peaking, at which point the flows at the structures will be monitored to be sure 17,000 cfs will occur at Fargo before Project operations would begin. More detailed information is available in Appendix A. Operation begins by partially closing the gates at the Red River and Wild Rice River hydraulic control structures. This starts the process of storing water in the staging area. Flows into the Metropolitan Area would not be adjusted abruptly such that the rise or fall of the river in the benefited area will not exceed natural river stage rise or fall rates.

In addition to monitoring the Enloe and Abercrombie gages, gages on the Sheyenne River and the Maple River would be monitored to assess the proper gate settings to minimize downstream impacts. Detailed modeling indicates that Sheyenne River and Maple River flows entering the diversion channel, through the Maple River peak, need to be mitigated by storing water in the staging area up to the time of the Maple River peak at the diversion. The rate of stage rise in the staging area would exceed natural conditions, but the rate of stage fall would not exceed the natural rate of fall once staging area elevations drop to bank full conditions. This would reduce fish stranding in the staging area to rates comparable with existing conditions. It would also reduce the potential for bank instability. A geomorphology monitoring plan and fish monitoring plan are being developed to assess bank instability and fish passage and mortality issues that may arise.

A maximum stage of 35.0 feet would be maintained at the Fargo gage until the staging area water surface reaches elevation 922.2 feet, at which point the Red and Wild Rice River control structures would be opened as necessary to maintain the upstream staging elevation of 922.2 feet while not exceeding a stage of 40.0 feet at the Fargo gage. Emergency measures would be employed within the Metropolitan Area to reduce flood damages when the stage is between 35.0 feet and 40.0 feet. Once a stage of 40.0 feet is achieved at the Fargo gage, a stage of 40.0 feet would be maintained by first allowing more flow into the diversion channel through the diversion inlet gates and eventually allowing flow to exit the staging area over the overflow embankment (elevation 924.0 feet) until the staging water surface rises to an elevation that provides a minimum acceptable height of freeboard for the tieback embankment. If the upstream staging water surface elevation is forecasted to reach the point of minimum acceptable freeboard, an evacuation order would be issued for the Metropolitan Area. Once the staging area elevation reaches the point of minimum acceptable freeboard, the Red and Wild Rice River control structures would be opened further to maintain the minimum freeboard, and stages would rise above 40.0 feet at the Fargo gage.

During operation, flood waters would inundate properties in portions of southern Clay and Cass Counties and northern Wilkin and Richland Counties. The total inundated area varies depending on the magnitude of the event. The staging area would be drawn down once the flood peak has passed the Project. The inundated area is approximately 30,000 acres for a 1-percent chance (100-year) event. The duration of staging of water varies depending on the location within the staging area and the magnitude of the event. Figure 1 shows the duration of flooding at several locations within the staging area for various events.

The OMRR&R Manual for the project will address staging area operation notifications, including road closures due to impending inundation. The OMRR&R Manual will also address roadway closures and evacuation planning that may be required during extreme flood events, which are events that are much larger than a 0.2-percent chance (500-year) event.



Flood Event Frequency	Existing Conditions		With Project	
	Water Level at Embankment	Days above 913'*	Water Level at Embankment	Days above 913'*
10-year	908.71	0.0	908.83	0.0
50-year (approx 2009)	914.04	3.5	921.52	9.0
100-year	914.73	5.0	922.22	10.5
500-year	915.95	9.0	922.24	10.0

* 913' is the average natural ground elevation at the reporting location RRN XS 2531315

Flood Event Frequency	Existing Conditions		With Project	
	Water Level at Holy Cross Township, Section 10	Days above 916'*	Water Level at Holy Cross Township, Section 10	Days above 916'*
10-year	909.83	0.0	909.83	0.0
50-year (approx 2009)	913.43	0.0	921.52	10.5
100-year	914.21	0.0	922.23	12.0
500-year	915.11	0.0	922.24	11.5

* 916' is the average natural ground elevation at the reporting location WLVSA 34

Flood Event Frequency	Existing Conditions		With Project	
	Water Level near Comstock	Days above 920'*	Water Level near Comstock	Days above 920'*
10-year	916.88	0.0	916.88	0.0
50-year (approx 2009)	917.16	0.0	921.55	3.5
100-year	917.58	0.0	922.27	5.5
500-year	917.90	0.0	922.30	5.5

* 920' is the average natural ground elevation at the reporting location Wolv XS 28063

Flood Event Frequency	Existing Conditions		With Project	
	Water Level at County Line	Days above 922.2'*	Water Level at County Line	Days above 922.2'*
10-year	912.26	0.0	912.22	0.0
50-year (approx 2009)	918.36	0.0	922.06	0.0
100-year	919.68	0.0	922.67	3.0
500-year	923.13	2.5	923.68	5.5

* 922.2' is the average natural ground elevation at the reporting location RRN XS 2582760

September 22, 2014

Figure 1

A ring levee around the communities of Oxbow, Hickson, and Bakke and a ring levee around the City of Comstock would be designed to meet USACE levee certification requirements for the 1-percent chance flood event in the staging area when the Project is completed. The risk to the communities does not increase significantly for a 0.2-percent chance flood event since the water surface elevation in the staging area is essentially the same for the 0.2-percent chance flood event as it is for the 1-percent chance event. The ring levees would include, as necessary, road raises to slightly above the 0.2-percent chance event flood elevation within the staging area to allow access to the communities.

The Oxbow-Hickson-Bakke and Comstock ring levees will be addressed in the OMRR&R Manual. The OMRR&R Manual will address operation of items such as drainage closures, flap gates, and operation of interior flood control features that are part of the permanent levee systems. The OMRR&R Manual will also address roadway closures and evacuation planning that may be required for the ring levees during extreme flood events.

The complete details of the Water Control Plan have not yet been determined, but the details that have been worked out and corresponding flow chart are provided as Appendices A and B.

Diversion Channel Operation and Areas Outside the Diversion Channel

The diversion channel would be constructed along land that generally drains in a northeasterly direction and which includes a number of rivers, drains, and ditches. The diversion channel outlet, located where the diversion channel returns to the Red River would consist of a rock ramp structure with a crest width of 300 feet. The low flow portion of the diversion channel would be constructed with sinuosity from the outlet to the Red River up to near the Maple River crossing as a way of substituting for lost habitat in the Lower Rush and Rush River channels between the diversion channel and the Sheyenne River.

At the Maple River and Sheyenne River crossings, open aqueducts would be constructed that cross over the top of the diversion channel to allow continuous connectivity of these two rivers up through bank-full flows. Fixed-crest weir spillways would direct a portion of flood flows into the diversion channel, with the percentage of flow diverted increasing as the flood flow increases. These structures would be built off the existing channels so that the existing channels would function until the aqueduct and diversion are ready to accept water.

Besides the Maple River and Sheyenne River, all local drainage would be directed into the diversion. At the Lower Rush River and Rush River, the inlets would be open rock ramp structures. The larger drain (Drain 14 and likely Drain 21C) inlets would be rock or concrete drop structures. Existing natural levees or spoil piles along the rivers and drains would prevent widespread back-up flooding from the diversion channel for events up through the 1-percent chance event (100-year). Ditches and smaller inlet structures would be constructed along the diversion channel for smaller drains, ditches, and low areas cut off by the diversion channel. New ditches running outside and parallel to the diversion channel would direct local drainage to a reasonable number of closed inlet locations. Existing ditches, field swales, and drain tile would be directed into these parallel ditches. The closed inlet structures would be culvert structures with flap gates and energy dissipation chambers at the outlet of the culvert in the diversion channel. The culvert flap gates would prevent water from backing up out of the diversion channel after the local peaks have passed.

The project goal is to maintain but not increase the existing 1-percent chance (100-year) event floodplain outside the diversion channel. This maintains floodplain storage and helps minimize downstream impacts. Sizing the inlets to prevent stage increases for the 0.2-percent chance (500-yr) event would be very costly so some stage increases are expected; however the duration of flooding would be reduced due to the presence of the diversion channel and the associated inlet structures. Peak stages and duration of floodplain flooding would be reduced for floods more frequent than the 1-percent chance (100-year) event.

The rock ramp structures at the diversion outlet and the Rush River inlet structure into the diversion are designed to provide fish passage. The boulder weirs within the rock ramp structures would create hydraulic steps approximately 0.6 ft high. The rock ramp structure at the Lower Rush River inlet structure into the diversion would have larger hydraulic steps of approximately one foot. Fish that travel up the diversion (whether they travel up the Rush River, Lower Rush River, or just stay in the diversion) would have the opportunity to head back downstream and exit the diversion. The low-flow channel would be constructed with a positive slope in the downstream direction along the entire length of the diversion, which decreases the likelihood that fish would be stranded as flows recede. It is recognized that the low-flow channel invert would change over time, potentially creating some small pools. However this is no different than what occurs naturally along other smaller rivers, drains, and ditches in the area that can also dry up when flows recede. Runoff entering the diversion from completely captured rivers and drains (Drain 21C, Drain 14, the Lower Rush River, the Rush River, and other smaller un-numbered drains) would result in a gradual tapering off of flow in the diversion. Also, the diversion inlet gates would be operated such that inflows are gradually decreased, further supporting a gradual reduction in diversion flow that would allow fish to sense that they need to swim downstream to the diversion outlet.

The position of the diversion inlet structure, over 3 miles west of the Wild Rice River and about 6 miles west of the Red River, significantly reduces the likelihood that ice or debris would enter the diversion at the inlet structure. The greatest threat for ice and debris comes from the open inlet structures and the spillways allowing greater than bank full flow into the diversion at the Sheyenne River and Maple River aqueducts. The clear opening between bridge piers over the diversion would be at least 50 feet to also minimize any potential for blockage issues.

The openings between the bridge piers under the aqueducts are of greatest concern with regard to blockages. The position of the Sheyenne River aqueduct, a short distance downstream of the diversion inlet and upstream of the entry point of the aqueduct spillway, makes it very unlikely that ice or debris would be present. Blockage is of greatest concern at the conduits under the Maple River aqueduct. Ice and debris control structures would be necessary at the Sheyenne River aqueduct spillway and at the other open inlet structures upstream of the conduits under the Maple River aqueduct. A gap in the left-bank berm along the diversion would also be provided just upstream of the conduits to allow flow out to the west should a major blockage occur.

In-Town Components Operation

As part of design changes included in the September, 2013 Supplemental Environmental Assessment for the Project, the with-Project 1-percent chance base flood event equates to a flood stage of approximately 35 feet at the USGS Fargo stream gage. This change reduces the frequency and duration of Project operation and helps reduce impacts in the staging area.

Components of the In-Town system that are required to accommodate a flood stage of 35 feet include the following existing and planned levee systems:

- Ridgewood/VA Flood Control Project (Fargo)
- Moorhead Country Club Project Area F1 (Moorhead)
- El Zagal Flood Control Project (Fargo)
- Mickelson Field Flood Control Project (Fargo)
- 2nd Street/Downtown Flood Control Project (Fargo)

- Woodlawn Park Flood Control Project (Moorhead)
- 4th Street Levee (Fargo)
- Horn Park Area Flood Control Project (Moorhead)

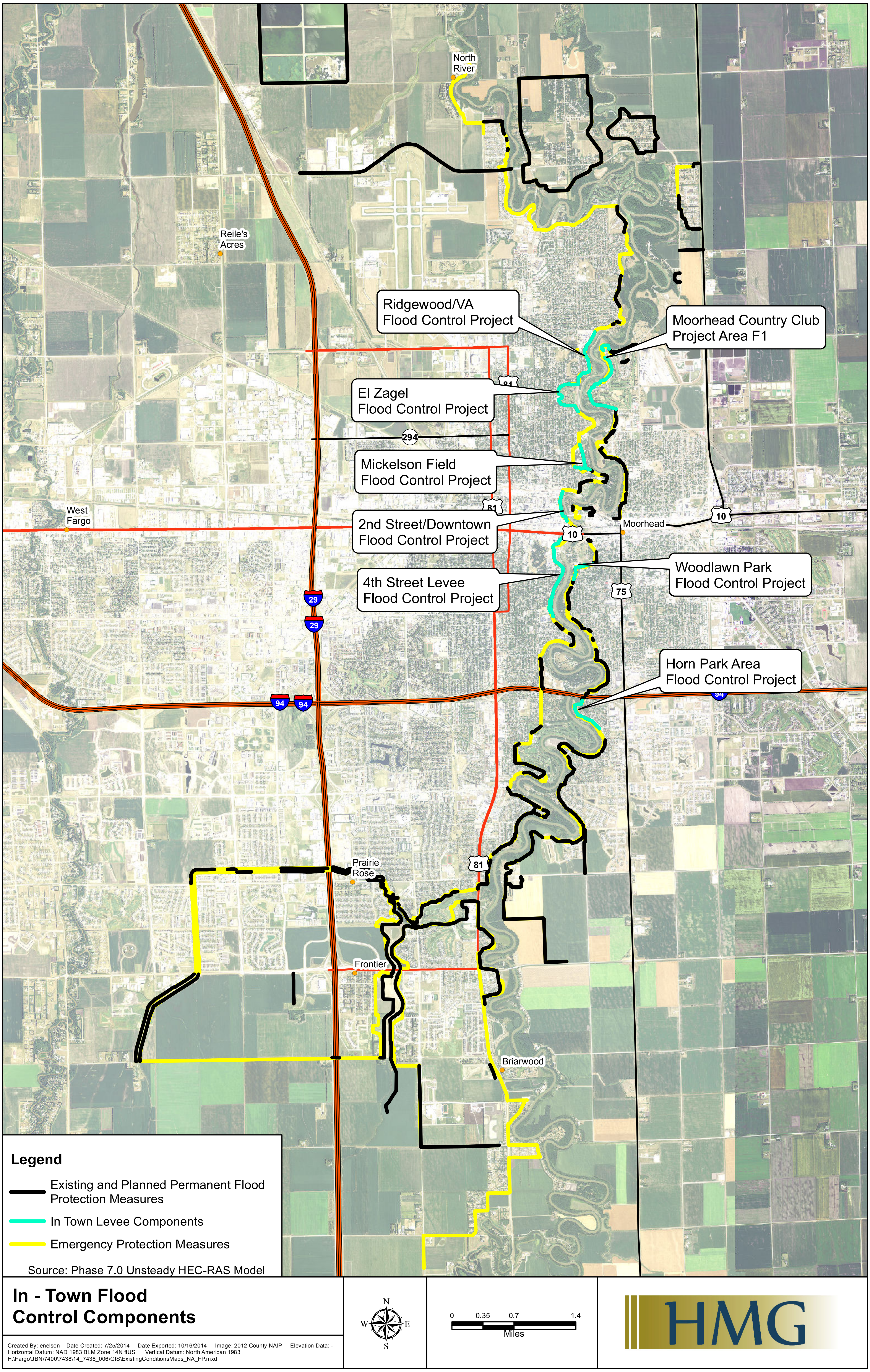
These levee systems are designed to meet USACE levee certification requirements for the Corps' 1-percent chance base flood event on the Red River when the Project is completed, which equates to a flood stage of approximately 35 feet at the USGS Fargo stream gage. To meet USACE risk and uncertainty requirements for the future with-Project condition (Alternative 2, Preferred Alternative), the levee and floodwall system must tie into natural high ground that is at or above the river profile having a stage of 39.5 feet at the USGS Fargo stream gage.

Because of the interim risk of flooding until the Project is complete, the existing and planned permanent levee systems are being designed and constructed to an elevation higher than what is required to accommodate the with-Project (Alternative 2, Preferred Alternative) 1-percent chance flood event. Permanent floodwalls are designed to have a top of protection elevation of flood stage 45.0 feet. Permanent earthen levees are designed to have a top of protection elevation of 43.5 feet.

In addition to the In-Town components required to pass a flood stage of 35 feet that have been identified above, the City of Fargo, ND and City of Moorhead, MN have constructed and/or planned a number of other permanent levee projects. These levee projects are designed to a similar standard to the In-Town components identified above, and would provide interim flood protection until the Project is complete and help increase the level of protection after completion. These levee segments are the same as those included in "Base No Action" alternative as identified by the Minnesota Department of Natural Resources as part of their ongoing EIS. Figure 2 shows the In Town components as well as other existing and planned permanent levee projects in the Project area.

Since additional reaches require levees for stages above 35 feet at the USGS Fargo stream gage and not all the gaps are covered by the other permanent project described in the previous paragraph, some emergency measures would need to be implemented during flood events larger than the 1-percent chance flood event for the with-Project condition (Alternative 2, Preferred Alternative). These emergency measures would consist of a combination of clay levees, sandbags, and other temporary flood protection measures and would fill the gaps between levees as well as extend levees to high ground, where appropriate. The general location of the emergency measures is also shown in Figure 2. While operation of the gates in the staging area would be based upon actual flow, emergency measures (such as road closures, temporary levees, etc.) would be based on a forecast as it would require at least 5 days to build the emergency measures.

The In-Town levee system will be addressed in the OMRR&R Manual. The OMRR&R Manual will address installation of structural closures, flap gates, and operation of interior flood control features that are part of the permanent levee systems. The OMRR&R Manual will also address roadway closures and evacuation planning that may be required during extreme flood events.



Source: Phase 7.0 Unsteady HEC-RAS Model

In - Town Flood Control Components

Created By: enelson Date Created: 7/25/2014 Date Exported: 10/16/2014 Image: 2012 County NAIP Elevation Data: -
Horizontal Datum: NAD 1983 BLM Zone 14N ftUS Vertical Datum: North American 1983
H:\Fargo\JBN\7400\7438\14_7438_006\GIS\ExistingConditionsMaps_NA_FP.mxd

Figure 2

Appendix A

Appendix A

Wild Rice River, Red River, and Diversion Control Structure Operation Plan

Background

The complexity of the flood mitigation for the Red River Basin

- The Staging Area functions as a temporal reservoir to store flood water.
- The dynamics of the Staging Area are controlled by the configuration of the Staging Area, the magnitudes and temporal variations of the Enloe and Abercrombie inflow, and gate operating rules.
- The downstream flow condition is determined by the magnitudes and temporal variations of the Wild Rice River, Red River, and tributary river flows, and gate operating rules.
- This study and involved hydrologic issues are unique in water resource field. The allowable flow to pass downstream from the Staging Area needs the consideration of the mitigations of the Wild Rice River and Red River as well as various tributary inflows.
- Based on the best of our knowledge, there are not available methods or similar studies regarding to the flood mitigation for such complexity system.

Power law relationships in hydrology

Recent studies have shown that the storage-discharge relationship can be characterized by a general power law function, $Q=aV^b$ (Wittenberg, 1999; Wittenberg and Sivapalan, 1999; Harman and Sivapalan, 2009). The power law relationship has be proved to be true by field evidence and physical experiments (Mein et al., 1974, Wittenberg, 1994; Chapman, 1999).

Storage-discharge relationships have been widely used in many hydrology fields:

- Flood estimation (Mein et al., 1974; Georgakakos et al., 1982; Zhang et al., 2000; Rahman and Goonetilleke, 2001; Rezaei-Sadr et al., 2012)
- Rainfall-runoff simulation (Horton, 1938; Dooge, 1973; Nash, 1958; Wang and Gupta, 1981; Hughes and Murrell, 1986; Basha, 2000; Nourani et al., 2009)
- Groundwater flow (Vogel and Kroll, 1992)
- Base flow recession (Cheng, 2008; Aksoy and Wittenberg, 2011; Wang, 2011; Gan and Luo, 2013), and
- Sewer water flow (Gernaey et al., 2011).

The proposed two-step storage-discharge relationships for optimal flood release

- The power law relationship was introduced in this study and associated gate operating rules are developed to calculate optimal flood release from the Staging Area.
- Two power law relationships were developed to characterize and calculate the rising and falling limbs of the available flow to be sent to the downstream from the Staging Area.
- The coefficients of the power law relationships were determined using trial and error method by fitting operated hydrographs with existing hydrographs from Georgetown considering various magnitudes of Enloe, Abercrombie flow, and tributary flow.
- The developed two power law relationships incorporate both configuration properties of the Red River Basin and the mitigation effects of the tributary rivers e.g., Maple River, Sheyenne River, and Rush River.

Wild Rice River, Red River, and Diversion Control Structure Operation Plan

The operation rules for the Wild Rice River Control Structure (WRRCS), Red River Control Structure (RRCS), and Diversion Control Structure (DIVCS) are dynamic, varying with magnitude and timing of flow from the Wild Rice River, Red River, and all tributary rivers. Based on the flood characteristics and the timing of the flood, the real-time gate operation for any flood event is generally guided by six Operation Segments including: No Operation, Gate Preparation, Hold, Rising, Transition, and Falling. The real-time operation is performed following their sequence, and the corresponding allowable flow for WRRCS, RRCS, and DIVCS is calculated.

1. Operation Segment 1 – No Operation

1.1 Record flows from USGS gages:

- 05053000, Wild Rice River at Abercrombie, Q_{ABER}^{t}
- 0505152130, Red River at Enloe, Q_{ENLOE}^{t}

1.2 Sum current flows at Abercrombie and Enloe, Q^{t}_{AE}:

$$Q_{ABER}^{t} + Q_{ENLOE}^{t} = Q_{AE}^{t}$$

1.3 Compare combined flow at Abercrombie and Enloe, Q^{t}_{AE} with 17,000 cfs.

1.4 If the combined flow at Abercrombie and Enloe, Q^{t}_{AE}, is less than 17,000 cfs, WRRCS and RRCS are completely open, and DIVCS is closed.

1.5 Continue the iteration and repeat the procedures for the gate operation in "Operation Segment 1". If the combined flow at Abercrombie and Enloe, Q^{t}_{AE}, is greater than 17,000 cfs, begin "Operation Segment 2".

2 Operation Segment 2 – Gate Preparation

Operation Segment 2 is a one-iteration process, in which initial gate heights for RRCS and WRRCS are set and the flow to hold through town is calculated.

2.1 Record water surface elevations in the Staging Area:

- Wild Rice River, $Z_{STAGING\_AREA\_WRR}^{t}$
- Red River, $Z_{STAGING\_AREA\_RR}^{t}$

2.2 Compute flow through WRRCS and RRCS using rating curves (Tables 1-2) when Q^{t}_{AE} equals 17,000 cfs:

- Record the flow at WRRCS, Q_{WRRCS_HOLD}, when Q^{t}_{AE} equals 17,000 cfs.

$$Q_{WRRCS\_HOLD} = Table\ 1\ (Z_{STAGING\_AREA\_WRR}^{t}) \qquad when\ Q_{AE}^{t} = 17{,}000 cfs$$

- Record the flow at RRCS, Q_{RRCS_HOLD}, when Q^{t}_{AE} equals 17,000 cfs.

$$Q_{RRCS\_HOLD} = Table\ 2\ (Z_{STAGING\_AREA\_RR}^{t}) \qquad when\ Q_{AE}^{t} = 17{,}000 cfs$$

2.3 Compute the total flow to hold through town when Q^{t}_{AE} equals 17,000 cfs, Q_{HOLD}, which will be used in "Operation Segment 3" :

$$Q_{HOLD} = Q_{WRRCS\_HOLD} + Q_{RRCS\_HOLD} \qquad when\ Q_{AE}^{t} = 17{,}000 cfs$$

2.4 Prepare the WRRCS and RRCS gates by setting their gate heights using the following equations and gate inverts*:*

- Gate height at Wild Rice River Control Structure
  $H^t_{WRRCS} = Z^t_{STAGING\_AREA\_WRRCS} - 887.53_{GATE\_INVERT}$
- Gate height at Red River Control Structure
  $H^t_{RRCS} = Z^t_{STAGING\_AREA\_RRCS} - 874.00_{GATE\_INVERT}$

2.5 Begin "Operation Segment 3".

3 Operation Segment 3 - Hold

3.1 Record flows from USGS gages:

- 05053000, Wild Rice River at Abercrombie, Q^t_{ABER}
- 0505152130, Red River at Enloe, Q^t_{ENLOE}
- xxxxxxxxx, Maple River at Durbin, Q^{t-36hr}_{MAPLE}
- 05058980, Sheyenne River at Gol Road, Q^{t-36hr}_{SHEY}
- 05060500, Rush River at Amenia, Q^{t-36hr}_{RUSH}

3.2 Record water surface elevations in the Staging Area*:*

- Wild Rice River, $Z^t_{STAGING\_AREA\_WRR}$
- Red River, $Z^t_{STAGING\_AREA\_RR}$

3.3 Sum current flows at Abercrombie and Enloe, Q^t_{AE}*:*

$$Q^t_{ABER} + Q^t_{ENLOE} = Q^t_{AE}$$

3.4 Record the maximum combined Abercrombie and Enloe flow up to time *t:*

$$Q^t_{AE\_MAX} = Max(Q^t_{AE})$$

3.5 Compute flow reduction for tributary rivers*:*

- Sheyenne River

$$Q^t{}_{SHEY\_REDUC} = \begin{cases} 0 & when \quad Q^{t-36hr}_{SHEY} \le 2{,}000 cfs \\ Q^{t-36hr}_{SHEY} - 2{,}000 & when \quad 2{,}000 \le Q^{t-36hr}_{SHEY} \le 4{,}600 cfs \\ 0.5 \times (Q^{t-36hr}_{SHEY} - 4{,}600) + 2{,}600 & when \quad Q^{t-36hr}_{SHEY} > 4{,}600 cfs \end{cases}$$

- Maple River

$$Q^t{}_{MAPLE\_REDUC} = \begin{cases} 0 & when \quad Q^{t-36hr}_{MAPLE} \le 3{,}000 cfs \\ 0.8 \times (Q^{t-36hr}_{MAPLE} - 3{,}000) & when \quad Q^{t-36hr}_{MAPLE} > 3{,}000 cfs \end{cases}$$

- Rush River

$$Q^t{}_{RUSH\_REDUC} = Q^{t-36hr}_{RUSH}$$

3.6 Compute total flow reduction for tributary rivers*:*

$$Q^t_{REDUCTION} = Q^t{}_{SHEY\_REDUC} + Q^t{}_{MAPLE\_REDUC} + Q^t{}_{RUSH\_REDUC}$$

3.7 Record maximum flow reduction up to time t*:*

$$Q^t_{REDUCTION\_MAX} = Max(Q^t{}_{REDUCTION})$$

3.8 Compute the parameter ***a*** using Table 4*:*

$$a = Table\ 4(Q^t_{AE\_MAX}, Q^t_{REDUCTION\_MAX})$$

3.9 Compute the volume of water in the Staging Area using Table 3*:*

$$V^t_{STAGING\_AREA} = Table\,3(Z^t_{STAGING\_AREA\_RR})$$

3.10 Compute Q_{RISING}*:*

$$Q^t_{\mathrm{RISING}} = a(V^t_{STAGING\_AREA\_RR})^{1.3} - Q^t{}_{REDUCTION}$$

where the unit for volume of water in the Staging Area, $V^t_{STAGING\_AREA,}$ is ac-ft and the unit for $Q^t_{REDUCTION}$ and Q^t_{RISING} is cfs.

3.11 Obtain Q^t_{HOLD}, $Q^t_{WRRCS\_HOLD}$, and $Q^t_{RRCS\_HOLD}$ from “Operation Segment 2”.

3.12 Compare Q_{RISING} with Q^t_{HOLD}. *:*

- If Q_{RISING} is less than Q^t_{HOLD}, continue with the procedures in “Operation Segment 3” Use the flow calculated from procedure 2.2 as the allowable flow to pass WRRCS and RRCS, and the DIVCS is closed.
- If Q_{RISING} is greater than Q^t_{HOLD}*,* begin “Operation Segment 4”.

3.13 Determine the gate opening height for WRRCS and RRCS using the flow from the procedure 3.11 and the Staging Area water surface elevations using Tables 5 & 6*:*

- Gate height at Wild Rice River Control Structure

$$H^t_{WRRCS} = Table\,5(Q^t_{WRRCS}, Z^t_{STAGING\_AREA\_WRR})$$

- Gate height at Red River Control Structure

$$H^t_{RRCS} = Table\ 6\ (Q^t_{RRCS}, Z^t_{STAGING\_AREA\_RR})$$

3.14 Continue the iteration and repeat procedures for the gate operation in “Operation Segment 3”.

4 Operation Segment 4 – Rising

4.1 Record flows from USGS gages:

- 05053000, Wild Rice River at Abercrombie, Q^t_{ABER}
- 0505152130, Red River at Enloe, Q^t_{ENLOE}

4.2 Record the water surface elevations in the Staging Area*:*

- Wild Rice River, $Z^t_{STAGING\_AREA\_WRR}$
- Red River, $Z^t_{STAGING\_AREA\_RR}$

4.3 Sum current flows at Abercrombie and Enloe, Q^t_{AE}*:*

$$Q^t_{ABER} + Q^t_{ENLOE} = Q^t_{AE}$$

4.4 Check Q^t_{AE} curve*:*

- If Q^t_{AE} curve has not crested, skip procedures 4.5-4.10 and continue with procedure 4.11.
- If Q^t_{AE} curve has crested, continue with the procedure 4.5 to check small flood.

4.5 Record the maximum combined Abercrombie and Enloe flow up to time *t:*

$$Q^t_{AE\_MAX} = Max(Q^t_{AE})$$

4.6 Compare $Q^t_{AE\text{-}MAX}$ with 22,000 cfs:

- If $Q^t_{AE\text{-}MAX}$ value is greater than 22,000 cfs, skip procedures 4.7-4.10 and continue with procedure 4.11.
- If $Q^t_{AE\text{-}MAX}$ value is less than 22,000 cfs (i.e., small flood), continue with the procedure 4.7. For the small flood events with $Q^t_{AE\_max}$ less than 22,000 cfs, the operation rule is designed to release the water stored in the Staging Area faster.

4.7 Compute the Q^t_{SF} for small flood event:

$$Q^t_{SF} = \begin{cases} 1.01^{\Delta t} \times Q^{t-1}_{SF} & \textit{when } \; Q^{t-1}_{SF} < Q^{t-1}_{FARGO} \\ 17{,}000 & \textit{when } \; Q^{t-1}_{SF} \geq 17{,}000\, cfs \end{cases}$$

where Δt = number of hours for one operation iteration [hr].

4.8 Compute the allowable flow to pass through WRRCS and RRCS, Q^t_{WRRCS} and Q^t_{RRCS}, respectively, for small flood events. The DIVCS is closed:

- Allowable flow to pass the WRRCS *(Q^t_{WRRCS})*

  $$Q^t_{WRRCS} = \tfrac{1}{3} Q^t_{SF}$$

- Allowable flow to pass the RRCS *(Q^t_{RRCS})*

  $$Q^t_{RRCS} = \tfrac{2}{3} Q^t_{SF}$$

4.9 Determine the gate opening for WRRCS and RRCS using the computed allowable flow and the Staging Area water surface elevation using Tables 5 & 6 for small flood events:

- Gate height at Wild Rice River Control Structure

  $$H^t_{WRRCS} = Table\ 5(Q^t_{WRRCS}, Z^t_{STAGING\_AREA\_WRR})$$

- Gate height at Red River Control Structure

  $$H^t_{RRCS} = Table\ 6\ (Q^t_{RRCS}, Z^t_{STAGING\_AREA\_RR})$$

4.10 Continue and repeat the procedures 4.1-4.10 for small flood events until the computed gate height + gate invert > Staging Area WSE.

4.11 Compare current Staging Area elevation, $Z^t_{STAGING\_AREA\_RR}$, with elevation from previous operation:

- If the $Z^t_{STAGING\_AREA\_RR}$ has crested, begin “Operation Segment 5”.
- If the $Z^t_{STAGING\_AREA\_RR}$ has not crested, continue with the procedures in “Operation Segment 4”.

4.12 Record flows from USGS gages:

- 05053000, Wild Rice River at Abercrombie, Q^t_{ABER} (from procedure 4.1)
- 0505152130, Red River at Enloe, Q^t_{ENLOE} (from procedure 4.1)
- xxxxxxxxx, Maple River at Durbin, Q^{t-36hr}_{MAPLE}
- 05058980, Sheyenne River at Gol Road, Q^{t-36hr}_{SHEY}
- 05060500, Rush River at Amenia, Q^{t-36hr}_{RUSH}

4.13 Sum current flows at Abercrombie and Enloe, Q^t_{AE} (from procedure 4.3).

4.14 Record the maximum combined Abercrombie and Enloe flow up to time *t:*

$$Q^t_{AE\_MAX} = Max(Q^t_{AE})$$

4.15 Compute flow reduction for tributary rivers*:*

- Sheyenne River

$$Q^t{}_{SHEY\_REDUC} = \begin{cases} 0 & when \quad Q^{t-36hr}_{SHEY} \le 2{,}000 cfs \\ Q^{t-36hr}_{SHEY} - 2{,}000 & when \quad 2{,}000 \le Q^{t-36hr}_{SHEY} \le 4{,}600 cfs \\ 0.5 \times (Q^{t-36hr}_{SHEY} - 4{,}600) + 2{,}600 & when \quad Q^{t-36hr}_{SHEY} > 4{,}600 cfs \end{cases}$$

- Maple River

$$Q^t{}_{MAPLE\_REDUC} = \begin{cases} 0 & when \quad Q^{t-36hr}_{MAPLE} \le 3{,}000 cfs \\ 0.8 \times (Q^{t-36hr}_{MAPLE} - 3{,}000) & when \quad Q^{t-36hr}_{MAPLE} > 3{,}000 cfs \end{cases}$$

- Rush River

$$Q^t{}_{RUSH\_REDUC} = Q^{t-36hr}_{RUSH}$$

4.16 Compute total flow reduction*:*

$$Q^t_{REDUCTION} = Q^t{}_{SHEY\_REDUC} + Q^t{}_{MAPLE\_REDUC} + Q^t{}_{RUSH\_REDUC}$$

4.17 Record maximum flow reduction up to time t*:*

$$Q^t_{REDUCTION\_MAX} = Max(Q^t{}_{REDUCTION})$$

4.18 Compute the parameter ***a*** using Table 4*:*

$$a = Table\ 4(Q^t_{AE\_MAX}, Q^t_{REDUCTION\_MAX})$$

4.19 Compute the volume of water in the Staging Area using Table 3*:*

$$V^t_{STAGING\_AREA} = Table\ 3(Z^t_{STAGING\_AREA\_RR})$$

4.20 Compute Q^t_{RISING}*:*

$$Q^t_{\mathrm{RISING}} = a(V^t_{STAGING\_AREA\_RR})^{1.3} - Q^t{}_{REDUCTION}$$

4.21 Compute design flow through town using Table 8*:*

$$Q^t_{FARGO} = Table\ 8(Q^t_{AE\_MAX})$$

4.22 Compare Q^t_{FARGO} with Q^t_{RISING}. If Q^t_{FARGO} is greater than Q^t_{RISING}, use Q^t_{RISING} as the allowable flow. If Q^t_{RISING} is greater than Q^t_{FARGO}, use Q^t_{FARGO} as the allowable flow.

4.23 If Q^t_{FARGO} is greater than Q^t_{RISING}, compute the allowable flow to pass WRRCS and RRCS, Q^t_{WRRCS} and Q^t_{RRCS}, and the DIVCS is closed*:*

- Allowable flow to pass the WRRCS *(Q^t_{WRRCS})*

$$Q^t_{WRRCS} = \tfrac{1}{3} Q^t_{\mathrm{RISING}} \qquad when \quad Q^t_{\mathrm{RISING}} \le Q^t_{FARGO}$$

- Allowable flow to pass the RRCS *(Q^t_{RRCS})*

$$Q^t_{RRCS} = \tfrac{2}{3} Q^t_{\mathrm{RISING}} \qquad when \quad Q^t_{\mathrm{RISING}} \le Q^t_{FARGO}$$

- Allowable flow to pass the *DIVCS (Q^t_{DIVCS})*

$$Q^t_{DIVCS} = 0 \qquad when \quad Q^t_{\mathrm{RISING}} \le Q^t_{FARGO}$$

4.24 If Q^t_{RISING} is greater than Q^t_{FARGO}, compute the allowable flow to pass through WRRCS, RRCS, and DIVCS, Q^t_{WRRCS}, Q^t_{RRCS}, and Q^t_{DIVCS}, *respectively:*

- Allowable flow to pass the WRRCS *(Q^t_{WRRCS})*

$$Q^t_{WRRCS} = \tfrac{1}{3} Q^t_{FARGO} \qquad when \quad Q^t_{\text{RISING}} > Q^t_{FARGO}$$

- Allowable flow to pass the RRCS *(Q^t_{RRCS})*

$$Q^t_{RRCS} = \tfrac{2}{3} Q^t_{FARGO} \qquad when \quad Q^t_{\text{RISING}} > Q^t_{FARGO}$$

- Allowable flow to pass the DIVCS *(Q^t_{DIVCS})*

$$Q^t_{DIVCS} = \begin{cases} Q^t_{\text{RISING}} - Q^t_{FARGO} & when \quad Q^t_{\text{RISING}} < Q^t_{FARGO} + 20{,}000cfs \\ 20{,}000 & when \quad Q^t_{\text{RISING}} - Q^t_{FARGO} \geq 20{,}000cfs \end{cases}$$

4.25 Determine the gate opening height for WRRCS, RRCS, and DIVCS using the computed allowable flow and the Staging Area water surface elevation using Tables 5-7*:*

- Gate height at Wild Rice River Control Structure

$$H^t_{WRRCS} = Table\ 5(Q^t_{WRRCS}, Z^t_{STAGING\_AREA\_WRR})$$

- Gate height at Red River Control Structure

$$H^t_{RRCS} = Table\ 6\ (Q^t_{RRCS}, Z^t_{STAGING\_AREA\_RR})$$

- Gate height at Diversion Control Structure

$$H^t_{DIVCS} = Table\ 7\ (Q^t_{DIVCS}, Z^t_{STAGING\_AREA\_RR})$$

4.26 Continue the iteration and repeat procedures for the gate operation in “Operation Segment 4”.

5 Operation Segment 5 – Transition

5.1 Record the water surface elevations in Staging Area:

- Wild Rice River, $Z^t_{STAGING\_AREA\_WRR}$
- Red River, $Z^t_{STAGING\_AREA\_RR}$

5.2 Record flows from USGS gages:

- 05053000, Wild Rice River at Abercrombie, Q^t_{ABER}
- 0505152130, Red River at Enloe, Q^t_{ENLOE}
- xxxxxxxxx, Maple River at Durbin, Q^{t-36hr}_{MAPLE}
- 05058980, Sheyenne River at Gol Road, Q^{t-36hr}_{SHEY}
- 05060500, Rush River at Amenia, Q^{t-36hr}_{RUSH}

5.3 Sum current flows at Abercrombie and Enloe, Q^t_{AE}*:*

$$Q^t_{ABER} + Q^t_{ENLOE} = Q^t_{AE}$$

5.4 Record the maximum combined Abercrombie and Enloe flow up to time *t:*

$$Q^t_{AE\_MAX} = Max(Q^t_{AE})$$

5.5 Compute flow reduction for tributary rivers*:*

- Sheyenne River

$$Q^{t}{}_{SHEY\_REDUC} = \begin{cases} 0 & when \quad Q_{SHEY}^{t-36hr} \le 2{,}000 cfs \\ Q_{SHEY}^{t-36hr} - 2{,}000 & when \quad 2{,}000 \le Q_{SHEY}^{t-36hr} \le 4{,}600 cfs \\ 0.5 \times (Q_{SHEY}^{t-36hr} - 4{,}600) + 2{,}600 & when \quad Q_{SHEY}^{t-36hr} > 4{,}600 cfs \end{cases}$$

- Maple River

$$Q^{t}{}_{MAPLE\_REDUC} = \begin{cases} 0 & when \quad Q_{MAPLE}^{t-36hr} \le 3{,}000 cfs \\ 0.8 \times (Q_{MAPLE}^{t-36hr} - 3{,}000) & when \quad Q_{MAPLE}^{t-36hr} > 3{,}000 cfs \end{cases}$$

- Rush River

$$Q^{t}{}_{RUSH\_REDUC} = Q_{RUSH}^{t-36hr}$$

5.6 Compute total flow reduction*:*

$$Q_{REDUCTION}^{t} = Q^{t}{}_{SHEY\_REDUC} + Q^{t}{}_{MAPLE\_REDUC} + Q^{t}{}_{RUSH\_REDUC}$$

5.7 Record maximum flow reduction up to time t*:*

$$Q_{REDUCTION\_MAX}^{t} = Max(Q^{t}{}_{REDUCTION})$$

5.8 Compute parameter ***c*** using Table 9*:*

$$c = Table\ 9(Q_{AE\_MAX}^{t}, Q_{REDUCTION\_MAX}^{t})$$

5.9 Compute the volume of water in the Staging Area using Table 3*:*

$$V_{STAGING\_AREA}^{t} = Table\ 3(Z_{STAGING\_AREA\_RR}^{t})$$

5.10 Compute $Q_{TRANSITION}$. It should be noted that in the first iteration of $Q_{TRANSITION}$ computation, Q_{RISING} is used*:*

$$Q_{\mathrm{TRANSITION}}^{t} = \begin{cases} c^{\Delta t} \times Q_{\mathrm{RISING}}^{t-1} - Q^{t}{}_{REDUCTION} & first \ \ iteration \\ c^{\Delta t} \times Q_{\mathrm{TRANSITION}}^{t-1} - Q^{t}{}_{REDUCTION} & sebsequent \ \ iterations \end{cases}$$

where Δt = number of hours for one operation iteration [hr].

5.11 Compute $Q_{FALLING}$*:*

$$Q_{\mathrm{FALLING}}^{t} = 0.00068 \times (V_{STAGING\_AREA}^{t} + 344{,}000)^{1.35} - Q^{t}{}_{REDUCTION}$$

5.12 Compare $Q_{TRANSITION}$ and $Q_{FALLING}$. *:*

- If $Q_{TRANSITION}$ is greater than $Q_{FALLING}$, begin “Operation Segment 6”.
- If the $Q_{FALLING}$ is greater than $Q_{TRANSITION}$, continue with the procedures in “Operation Segment 5”.

5.13 Compute design flow through town using Table 8*:*

$$Q_{FARGO}^{t} = Table\ 8(Q_{AE\_MAX}^{t})$$

5.14 Compare the $Q_{TRANSITION}$ with Q^{t}_{FARGO}.

5.15 If Q^{t}_{FARGO} is greater than $Q_{TRANSITION}$, compute the allowable flow to pass WRRCS and RRCS, Q^{t}_{WRRCS} *and* Q^{t}_{RRCS}. DIVCS is closed*:*

- Allowable flow to pass the WRRCS *(*Q^{t}_{WRRCS}*)*

$$Q_{WRRCS}^{t} = \tfrac{1}{3} Q_{\mathrm{TRANSITION}}^{t} \qquad when \quad Q_{\mathrm{TRANSITION}}^{t} \le Q_{FARGO}^{t}$$

- Allowable flow to pass the RRCS *(*Q^{t}_{RRCS}*)*

$$Q^t_{RRCS} = {}^{2}\!/_{3}\, Q^t_{\mathrm{TRANSITION}} \qquad when \quad Q^t_{\mathrm{TRANSITION}} \le Q^t_{FARGO}$$

- Allowable flow to pass the DIVCS *(Q^t_{DIVCS})*

$$Q^t_{DIVCS} = 0 \qquad when\ Q^t_{\mathrm{TRANSITION}} \le Q^t_{FARGO}$$

5.16 If $Q_{TRANSITION}$ is greater than Q^t_{FARGO}*,* compute the allowable flow to pass WRRCS and RRCS, Q^t_{WRRCS} *and* Q^t_{RRCS} and compute the DIVCS flow*:*

- Allowable flow to pass the *WRRCS (Q^t_{WRRCS})*

$$Q^t_{WRRCS} = {}^{1}\!/_{3}\, Q^t_{FARGO} \qquad when \quad Q^t_{\mathrm{TRANSITION}} > Q^t_{FARGO}$$

- Allowable flow to pass the *RRCS (Q^t_{RRCS})*

$$Q^t_{RRCS} = {}^{2}\!/_{3}\, Q^t_{FARGO} \qquad when \quad Q^t_{\mathrm{TRANSITION}} > Q^t_{FARGO}$$

- Allowable flow to pass the *DIVCS (Q^t_{DIVCS})*

$$Q^t_{DIVCS} = \begin{cases} Q^t_{\mathrm{TRANSITION}} - Q^t_{FARGO} & when \quad Q^t_{\mathrm{TRANSITION}} < Q^t_{FARGO} + 20{,}000cfs \\ 20{,}000 & when \quad Q^t_{\mathrm{TRANSITION}} - Q^t_{FARGO} \ge 20{,}000cf \end{cases}$$

5.17 Determine the gate opening for WRRCS, RRCS, and DIVCS using the computed allowable flow and the Staging Area water surface elevation using Tables 5-7*:*

- Gate height at Wild Rice River Control Structure

$$H^t_{\mathrm{WRRCS}} = Table\ 5(Q^t_{\mathrm{WRRCS}}, Z^t_{STAGING\_AREA\_WRR})$$

- Gate height at Red River Control Structure

$$H^t_{RRCS} = Table\ 6\ (Q^t_{RRCS}, Z^t_{STAGING\_AREA\_RR})$$

- Gate height at Diversion Control Structure

$$H^t_{DIVCS} = Table\ 7\ (Q^t_{DIVCS}, Z^t_{STAGING\_AREA\_RR})$$

5.18 Continue the iteration and repeat procedures for the gate operation in “Operation Segment 5”.

6 Operation Segment 6 – Falling

6.1 Record flows from USGS gages:

- 05053000, Wild Rice River at Abercrombie, Q^t_{ABER}
- 0505152130, Red River at Enloe, Q^t_{ENLOE}
- xxxxxxxxx, Maple River at Durbin, Q^{t-36hr}_{MAPLE}
- 05058980, Sheyenne River at Gol Road, Q^{t-36hr}_{SHEY}
- 05060500, Rush River at Amenia, Q^{t-36hr}_{RUSH}

6.2 Record the water surface elevations in Staging Area:

- Wild Rice River, $Z^t_{STAGING\_AREA\_WRR}$
- Red River, $Z^t_{STAGING\_AREA\_RR}$

6.3 Sum current flows at Abercrombie and Enloe, Q^t_{AE}*:*

$$Q^t_{ABER} + Q^t_{ENLOE} = Q^t_{AE}$$

6.4 Record the maximum combined Abercrombie and Enloe flow up to time *t:*

$$Q^{t}_{AE\_MAX} = Max(Q^{t}_{AE})$$

6.5 Compute design flow through town using Table 8*:*

$$Q^{t}_{FARGO} = Table\,8(Q^{t}_{AE\_MAX})$$

6.6 Compute flow reduction for tributary rivers*:*

- Sheyenne River

$$Q^{t}{}_{SHEY\_REDUC} = \begin{cases} 0 & when \quad Q^{t-36hr}_{SHEY} \leq 2{,}000 cfs \\ Q^{t-36hr}_{SHEY} - 2{,}000 & when \quad 2{,}000 \leq Q^{t-36hr}_{SHEY} \leq 4{,}600 cfs \\ 0.5 \times (Q^{t-36hr}_{SHEY} - 4{,}600) + 2{,}600 & when \quad Q^{t-36hr}_{SHEY} > 4{,}600 cfs \end{cases}$$

- Maple River

$$Q^{t}{}_{MAPLE\_REDUC} = \begin{cases} 0 & when \quad Q^{t-36hr}_{MAPLE} \leq 3{,}000 cfs \\ 0.8 \times (Q^{t-36hr}_{MAPLE} - 3{,}000) & when \quad Q^{t-36hr}_{MAPLE} > 3{,}000 cfs \end{cases}$$

- Rush River

$$Q^{t}{}_{RUSH\_REDUC} = Q^{t-36hr}_{RUSH}$$

6.7 Compute total flow reduction*:*

$$Q^{t}_{REDUCTION} = Q^{t}{}_{SHEY\_REDUC} + Q^{t}{}_{MAPLE\_REDUC} + Q^{t}{}_{RUSH\_REDUC}$$

6.8 Compute the volume of water in the Staging Area using Table 3*:*

$$V^{t}_{STAGING\_AREA} = Table\,3(Z^{t}_{STAGING\_AREA\_RR})$$

6.9 Compute $Q_{FALLING}$*:*

$$Q^{t}_{\mathrm{FALLING}} = 0.00068 \times (V^{t}_{STAGING\_AREA} + 344{,}000)^{1.35} - Q^{t}{}_{REDUCTION}$$

6.10 Compare the computed $Q_{FALLING}$ with Q^{t}_{FARGO}.

6.11 If $Q_{FALLING}$ is greater than Q^{t}_{FARGO}, compute the flow releasing through WRRCS and RRCS, Q^{t}_{WRRCS} *and* Q^{t}_{RRCS}, and compute the DIVCS flow*:*

- Allowable flow to pass the WRRCS *(*Q^{t}_{WRRCS}*)*

$$Q^{t}_{WRRCS} = \tfrac{1}{3} Q^{t}_{FARGO} \qquad when \quad Q^{t}_{\mathrm{FALLING}} > Q^{t}_{FARGO}$$

- Allowable flow to pass the RRCS *(*Q^{t}_{RRCS}*)*

$$Q^{t}_{RRCS} = \tfrac{2}{3} Q^{t}_{FARGO} \qquad when \quad Q^{t}_{\mathrm{FALLING}} > Q^{t}_{FARGO}$$

- Allowable flow to pass the DIVCS *(*Q^{t}_{DIVCS}*)*

$$Q^{t}_{DIVCS} = \begin{cases} Q^{t}_{\mathrm{FALLING}} - Q^{t}_{FARGO} & when \quad Q^{t}_{\mathrm{FALLING}} < Q^{t}_{FARGO} + 20{,}000 cfs \\ 20{,}000 & when \quad Q^{t}_{\mathrm{FALLING}} - Q^{t}_{FARGO} \geq 20{,}000 cfs \end{cases}$$

6.12 If Q^{t}_{FARGO} is greater than $Q_{FALLING}$, compute the allowable flow to pass WRRCS and RRCS, Q^{t}_{WRRCS} *and* Q^{t}_{RRCS}. DIVCS is closed*:*

- Allowable flow to pass the WRRCS *(*Q^{t}_{WRRCS}*)*

$$Q^{t}_{WRRCS} = \tfrac{1}{3} Q^{t}_{\mathrm{FALLING}} \qquad when \quad Q^{t}_{\mathrm{FALLING}} \leq Q^{t}_{FARGO}$$

- Allowable flow to pass the RRCS *(*Q^{t}_{RRCS}*)*

$Q^t_{RRCS} = \frac{2}{3} Q^t_{\text{FALLING}}$ $\quad$ *when* $Q^t_{\text{FALLING}} \leq Q^t_{FARGO}$

- Allowable flow to pass the DIVCS *(Q^t_{DIVCS})*

  $Q^t_{DIVCS} = 0$ $\quad$ *when* $Q^t_{\text{FALLING}} < Q^t_{FARGO}$

6.13 Determine the gate opening for WRRCS, RRCS, and DIVCS using the computed allowable flow and the Staging Area water surface elevation using Tables 5-7*:*

- Gate height at Wild Rice River Control Structure

  $H^t_{WRRCS} = Table\ 5(Q^t_{WRRCS}, Z^t_{STAGING\_AREA\_WRR})$

- Gate height at Red River Control Structure

  $H^t_{RRCS} = Table\ 6\ (Q^t_{RRCS}, Z^t_{STAGING\_AREA\_RR})$

- Gate height at Diversion Control Structure

  $H^t_{DIVCS} = Table\ \ 7\ (Q^t_{DIVCS}, Z^t_{STAGING\_AREA\_RR})$

6.14 Continue the iteration and repeat the procedures in “Operation Segment 5” until the computed gate height + gate invert > Staging Area WSE.

Abbreviations and Notations:

a: coefficient for the Two-step Nonlinear Reservoir Model

c: coefficient for the Two-step Nonlinear Reservoir Model

H^t_{DIVCS} : Gate height at Diversion Control Structure

H^t_{RRCS} : Gate height at Red River Control Structure

H^t_{WRRCS} : Gate height at Wild Rice River Control Structure

Q^t_{ABER} : Wild Rice River at Abercrombie flow

Q^t_{AE} : The combined flow at the Wild Rice River, Abercrombie, and Red River, Enloe

$Q^t_{AE\_MAX}$: The maximum of the combined flow at Abercrombie and Enloe at time *t*

$Q^t_{\text{ALLOWABLE\_}SF}$: Calculated allowable flow for small flood events

Q^t_{ENLOE} : Red River at Enloe flow

Q^t_{FALLING} : Calculated allowable flow to be sent downstream for Operation segment 6

Q^t_{FARGO} : The allowable flow through town

Q^{t-36hr}_{MAPLE} : Maple River at Durbin flow, 36 hours ago

$Q^t{}_{MAPLE\_REDUC}$: Flow reduction calculation for Maple River

$Q^t_{REDUCTION}$: Total flow reduction from all tributary rivers

$Q_{REDUCTION\_MAX}^{t}$: Maximum flow reduction at the time *t*

Q_{RISING}^{t} : Calculated allowable flow to be sent downstream for Operation segment 4

Q_{RRCS}^{t} : Flow at Red River Control Structure

$Q^{t}{}_{RUSH\_REDUC}$: Flow reduction calculation for Rush River

Q_{RUSH}^{t-36hr} : Rush River at Amenia flow, 36 hours ago

Q_{SHEY}^{t-36hr} : Sheyenne River at Gol Road flow, 36 hours ago

$Q^{t}{}_{SHEY\_REDUC}$: Flow reduction calculation for Sheyenne River

$V_{STAGING\_AREA}^{t}$: The volume of water stored in the staging area

$Z_{STAGING\_AREA\_WRR}^{t}$: Elevation in staging area at the Wild Rice River

$Z_{STAGING\_AREA\_RR}^{t}$: Elevation in staging area at the Red River

$Q_{\mathrm{TRANSITION}}^{t}$: Calculated allowable flow to be sent downstream for Operation segment 5

Q_{WRRCS}^{t} : Flow at Wild Rice River Control Structure

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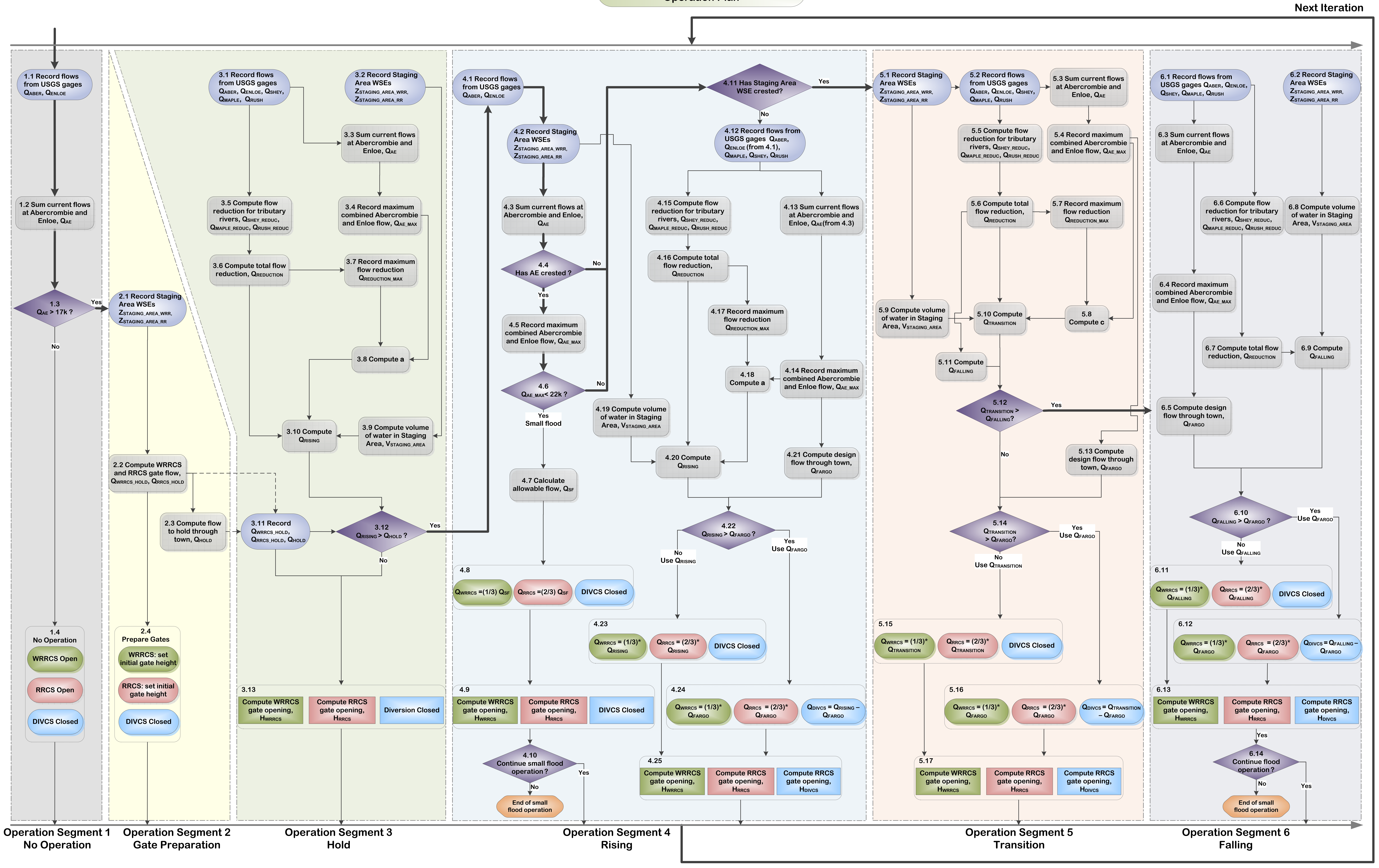
Appendix B

Fargo-Moorhead Diversion Project
Operation Plan



Fargo-Moorhead Diversion Project
Operation Plan