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St. Paul District

Hydraulics and Hydrology
Appendix D

Fargo Moorhead Metropolitan Area
Flood Risk Management Project

EA Document

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Hydraulics and Hydrology
Appendix D

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1 OVERVIEW OF CHANGES SINCE FEASIBILITY

Following completion of the Final Feasibility Report and Environmental Impact Statement (FEIS) for the Fargo-Moorhead Metropolitan (FMM) Area Flood Risk Management Project (Project), a Value Engineering (VE) study was conducted which identified potential cost savings if the tie-back embankment was moved north (Value Engineering Proposal Number 13 (VE13)). In addition to this VE study, the Corps, the non-Federal sponsors, and local technical consultants met in a series of workshops with the Local Sponsor, Local Consultant Technical Team (LSLCTT). The intent of these workshops was to continue to improve the Project. While the basic project features have not changed since the FEIS, there have been a number of important changes that affect the hydraulic performance of the Project. The important changes are:

- Increasing flow through the flood risk management area for events up through the 1-percent chance event
- Realignment of the tieback embankment
- Adding gates to the diversion inlet control structure
- Adjustments to the diversion channel alignment
- Modifications to the diversion channel cross-section

1.1 Flow through Flood Risk Management Area

The 1-percent chance event target stage at the Fargo gage was 30.8 feet in the FEIS. To achieve this target, the Project would begin operating once the combined flow of the Red River and the Wild Rice River exceeded 9600 cfs, which is about the 28-percent chance (3.6-year) event at Fargo. For a number of reasons, including the desire to reduce flood risk sooner and to reduce the need for fish passage at the Red River and Wild Rice River control structures, the concept of allowing more flow through the risk management area was investigated. Ultimately this investigation recommended targeting a stage of 35 instead of 30.8 for the 1-percent chance event. Some levees would be required within the risk management area to achieve this target, but this higher target stage reduces the frequency of project operation and reduces the duration of staging area flooding caused by the Project.

The frequency of project operation is reduced with a target stage of 35 since this allows the combined flow of the Red River and the Wild Rice River to be 17,000 cfs before project operation is required. With 17,000 cfs being the 10-percent chance (10-year) event at Fargo, the need for fish passage mitigation features at the Red River and Wild Rice River control structures is eliminated. This also reduces the risk of project operation during the late spring and summer, thereby reducing the risk of crop damage.

While allowing 17,000 cfs instead of 9600 cfs through the flood risk management area does little to reduce the peak stage for infrequent flooding, it does reduce the duration of staging area flooding because the staging area can be emptied somewhat faster. At Oxbow, the duration of flooding for the 2-percent (50-year), 1-percent (100-year), and 0.2-percent (500-year) chance events is reduced by approximately 4 days, 7 days, and 3 days, respectively with 17,000 cfs instead of 9600 cfs allowed through the flood risk management area. The change from 9600 cfs to 17,000 cfs has the greatest effect on the 1-percent chance event, not the 0.2-percent chance event, since the target stage is 40 feet for both the LPP as described in the FEIS and the proposed plan.

1.2 Tieback Embankment Alignment

Figure 1 shows the project features. The tieback embankment defining the northern limit of the staging area at the upstream end of the Project has been adjusted from the northern boundary of the gray line to the green line. During the feasibility phase there appeared to be some benefit in having a storage area (Storage Area 1) separate from the rest of the staging area, but since the feasibility phase, modeling has shown that it would be very difficult and relatively expensive to realize the benefit of a separate storage area for the wide variety of potential flood scenarios that could threaten the Fargo-Moorhead metropolitan area. The revised tieback embankment follows a more direct east-west path which trades storage volume lost from Storage Area 1 with storage volume gained by crossing the Wild Rice River and Red River north of the FEIS alignment. The shift north at the Red River eliminates the need for a separate control structure for Wolverton Creek. The tieback embankment would be constructed to meet Corps of Engineers dam safety standards.

The revised tieback embankment alignment in conjunction with the addition of gates to the diversion inlet, discussed in the next section, results in changes to the extent of the staging area, the expected staging area elevations, and the required additional storage to mitigate for downstream stage impacts. The red line on Figure 1 delineates the revised staging area. Table 1 presents a comparison of the model results for the FEIS plan and the current proposed alternative, which is known is the “VE13A-Bundled” alternative (“VE13” is defined above; “A” comes from the proposed alignment, option A; “Bundled” means it includes the diversion inlet gates).

Table 1 Upstream Staging Area Elevation Comparison

Event	FEIS (ft)	VE13A-Bundled (ft)	Difference (ft)
10-percent chance	916.29	908.83	-7.46
2-percent chance	920.86	921.52	0.66
1-percent chance	922.88	922.22	-0.66
0.2-percent chance	922.44	922.24	-0.20
103 kcfs	925.40	923.70	-1.70
PMF	926.11	924.90	-1.21

The increase for the 2-percent chance event is due to model updates in addition to the tieback embankment alignment modification that has affected how water fills the staging area, especially for events in the 10-percent chance to 2-percent change range. The additional storage required to mitigate downstream stage impacts has been reduced to approximately 150,000 acre-feet.

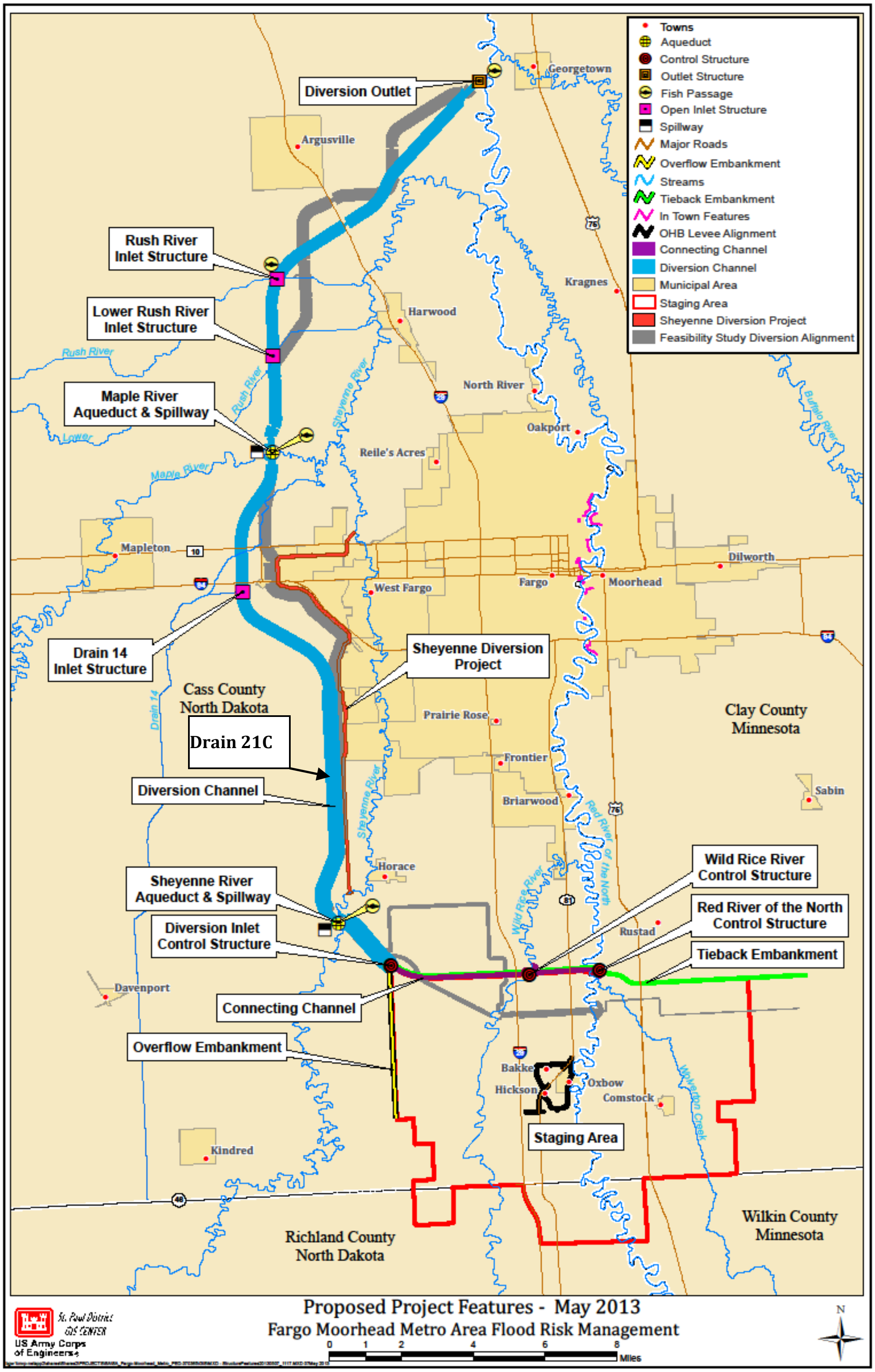

Figure 1 Proposed Project Features

1.3 Diversion Inlet Control Structure

Without gates at the diversion inlet control structure, the amount of flow allowed into the diversion channel is simply determined by the width of the inlet weir and the water surface elevation upstream of the weir. Without any ability to prevent large diversion inflow from combining with the peak flow on the Maple River at the Maple River diversion channel junction, modeling conducted during the feasibility phase showed that the hydrograph on the Red River at the diversion outlet shifts earlier in time with the diversion channel compared to the existing condition. When this slightly earlier peak combines with tributary peaks downstream, it tends to increase downstream stages. To counteract this effect and minimize downstream impacts, it is necessary to achieve a slight stage reduction on the Red River at the diversion outlet, which in the FEIS was achieved by storing more water in the upstream staging area. In other words, staging can be reduced slightly if flow into the diversion channel is reduced when the Maple River is reaching its peak at its junction with the diversion channel. Gates at the diversion inlet control structure provide the necessary control. The results of a detailed investigation of the diversion inlet gates is documented in a Fargo-Moorhead Flood Diversion Authority Technical Memorandum (TM) titled Diversion Inlet Gate Analysis, dated January 10, 2013. The effect of having gates at the diversion inlet is demonstrated in Figures 2 – 4, which show existing-condition, with-project-diversion-inlet-weir, and with-project-diversion-inlet-gate discharge hydrographs on the Red River just downstream of the diversion outlet at Georgetown, at Halstad, and at Grand Forks. Flow control at the diversion inlet results in a with-project hydrograph that better matches the existing-condition hydrograph just downstream of the Project. With just an uncontrolled weir at the diversion inlet, the with-project hydrograph just downstream of the project needs to have a lower peak to prevent stage increases further downstream.

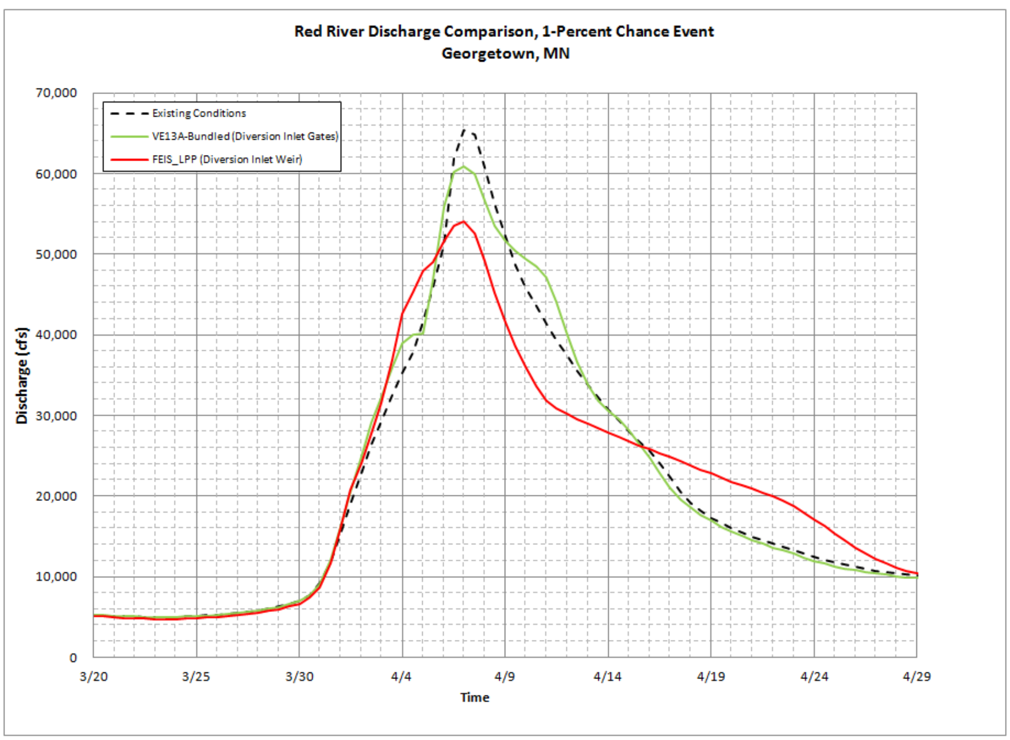

Figure 2 Effect of Diversion Inlet Gates on Hydrographs at Downstream End of Diversion Channel

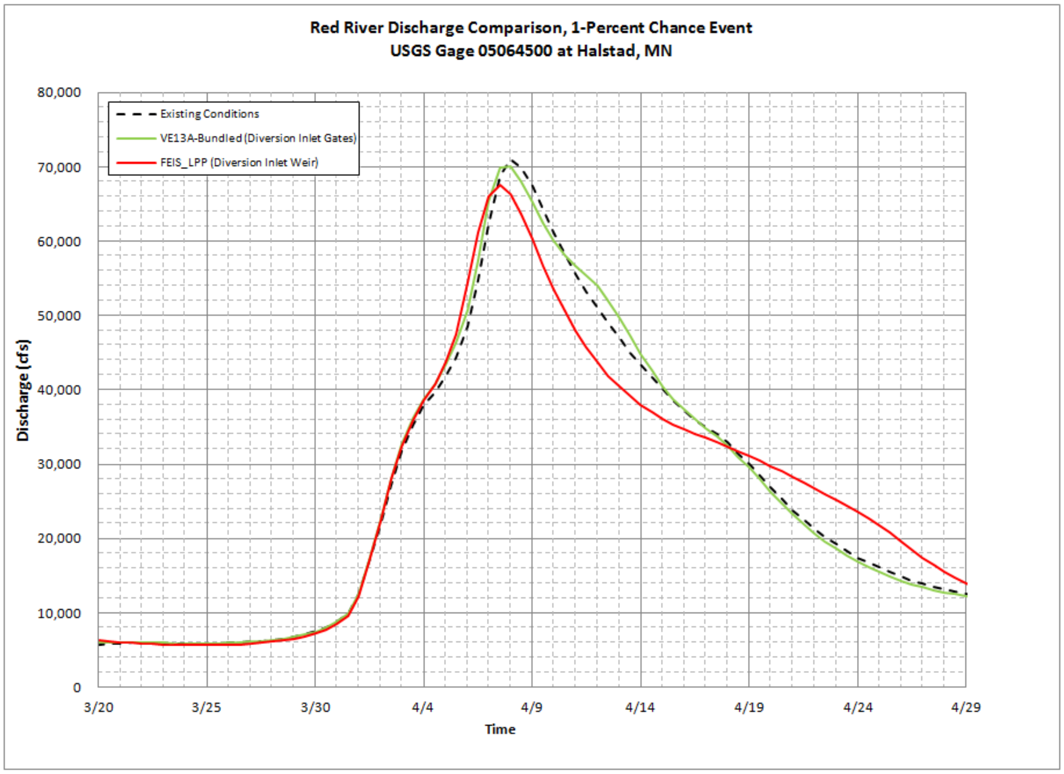

Figure 3 Effect of Diversion Inlet Gates on Hydrographs at Halstad, MN

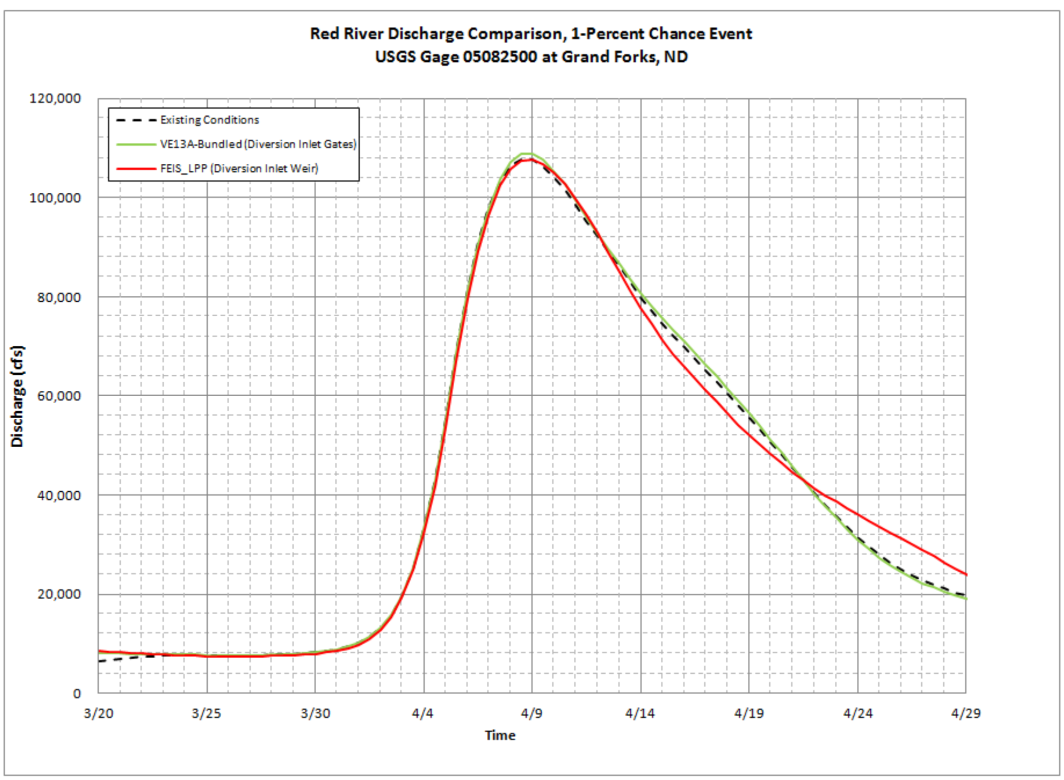

Figure 4 Effect of Diversion Inlet Gates on Hydrographs at Grand Forks, ND

1.4 Diversion Channel Alignment

The FEIS and proposed diversion channel alignments are shown on Figure 1. The modifications downstream of the Lower Rush River were made to reduce the impact to existing structures and reduce the number and degree of channel bends. While the diversion channel bends of the FEIS alignment are gradual, any bend increases the potential for erosion so unnecessary bends were eliminated. The alignment was also modified in the vicinity of the I-94 crossing after it was determined that it would be very difficult to fit the diversion channel alongside the existing West Fargo diversion channel and reconstruct the I-94 bridges in a safe and efficient manner. This alignment shift also reduces the likelihood of encountering sand lenses, which would increase erosion concerns, since the alignment is now mostly west of instead of over the Drain 14 meander belt. With this adjustment Drain 14 would be directed into the diversion channel just upstream of I-94. Further upstream, the diversion channel alignment has been shifted slightly west so that the existing Horace to West Fargo diversion channel would remain relatively unchanged with construction of the FMM diversion channel. This alignment modification also addresses constructability issues.

1.5 Diversion Channel Cross-Section

In the FEIS the diversion channel generally consisted of a 250 ft wide channel bottom with 1V:7H side slopes. The depth of the main channel ranged from 15 to 30 ft deep and the channel was set at a longitudinal slope of 0.8 ft/mile. The side slopes included geotechnical “benches” of 15 to 40 ft wide, as needed, to provide additional stability to meet the required factors of safety. At the center of the flat 250 ft wide channel bottom was a small low-flow channel that was included to convey the runoff from small drains and streams, such as the Rush and Lower Rush Rivers. This low-flow channel for the entire diversion was sized to be 3 ft deep with a 10 ft bottom width and 1V:4H side slopes, giving a low-flow cross-sectional area of 66 sq ft.

Even in early stages of the feasibility phase, it was recognized that further analysis would need to be completed to fully design the low-flow channel. Other factors, such as the sinuosity of the low-flow channel across the main channel bottom width and the need for slope across the main channel bottom to allow for drainage, would also need to be considered.

Surfaces such as the bottom width and the geotechnical stability benches would now include a 1V:50H, or 2%, cross-slope towards the center of the channel to provide adequate drainage within the Project. As a result of the addition of the cross-slope to the bottom of the diversion channel, the overall bottom width would be increased to 300 ft to retain approximately the same diversion channel top width and conveyance as in the FEIS. Figure 5 and Table 2 compare FEIS vs. the proposed modified diversion channel features.

The original design of the low-flow channel assumed one size would be effective for all reaches of the diversion channel. It has been determined that the 3 ft deep low-flow channel was undersized for the majority of the project reaches to handle the existing drainage. The low-flow has been redesigned to accommodate drainage inflows all the way along the diversion channel. As a result, the low-flow channel would increase in size and capacity as the diversion channel moves downstream. For constructability and design purposes, this gradually increasing low-flow channel was designated into four separate reaches. Details of the geometric configuration of these four low-flow channel sizes can be seen in Figure 6 and Table 3.

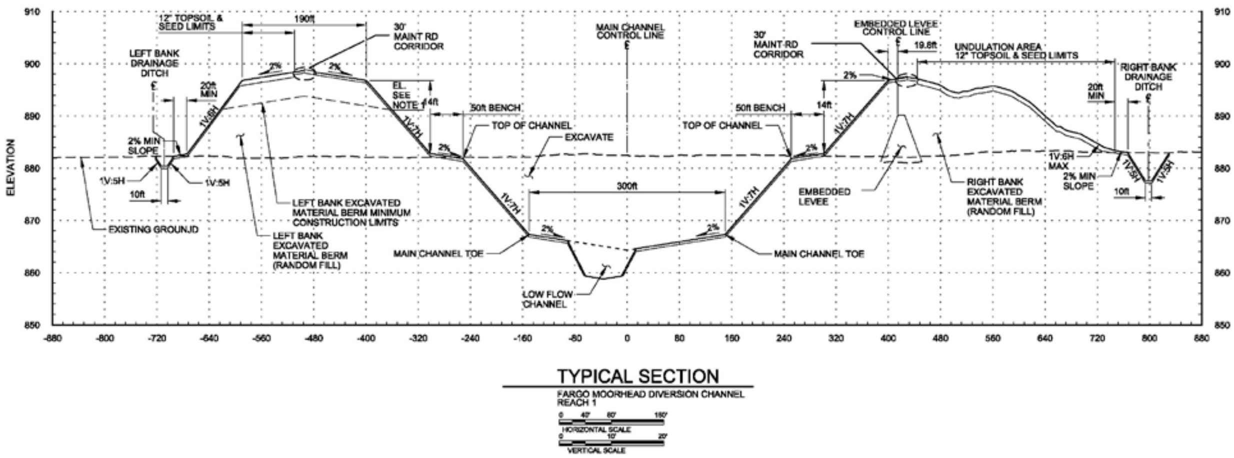

Figure 5 Diversion Cross-Section Changes

Table 2 Diversion Channel Geometry

Diversion Channel Feature	FEIS	Proposed
Bottom width	250 ft	300 ft
Cross-slope	0%	2%
Top width	450-750 ft	450-700 ft
Side slopes	1V:7H	1V:7H
Geotech stability benches	0-40 ft	0-30 ft
Excavation Material Berm Slope	1V:7H	1V:7H
Excavation Material Berm Offset	50 ft	50 ft

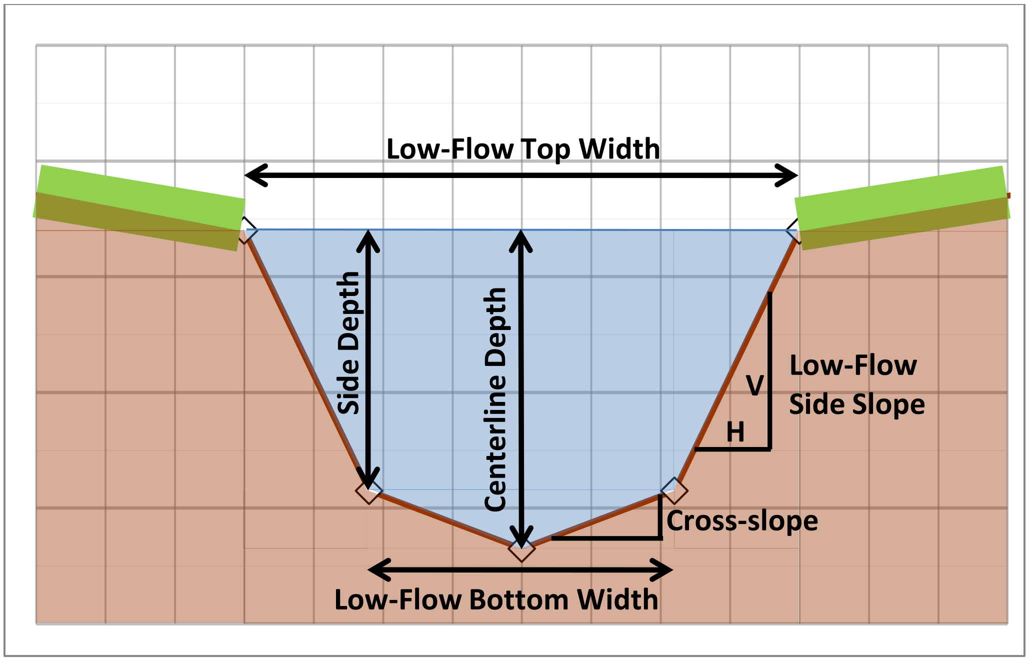

Figure 6 Low-Flow Channel Terminology

Table 3 Low-Flow Channel Geometry Comparison

	FEIS	*Proposed*			
	Inlet to Outlet	Inlet to Drain 21c	Drain 21c to Drain 14	Drain 14 to Rush River	Rush River to Outlet
Centerline Depth	3 ft	2.5 ft	4 ft	6 ft	6.5 ft
Side Depth	3 ft	2.4 ft	3.7 ft	5.6 ft	6.0 ft
Bottom Width	10 ft	10 ft	30 ft	45 ft	52 ft
Cross-slope	0%	2%	2%	2%	2%
Top Width	34 ft	30 ft	60 ft	90 ft	100 ft
Side Slopes	1V:4H	1V:4H	1V:4H	1V:4H	1V:4H
Area	66 sq ft	48 sq ft	170 sq ft	386 sq ft	469 sq ft

2 PROJECT IMPACTS

A summary of discharge and stage information at the USGS Gage at Fargo, ND is provided in Table 4. The USACE Expert Opinion Elicitation (EOE) Wet and USACE Period of Record (POR) discharges are the same as presented in the FEIS. The USACE EOE (Wet) existing condition without-protection stages (column 3 of Table 4) have changed somewhat from the FEIS (see Appendix B, Table B-1) due to model updates. The effective FEMA discharge and stage information, existing condition with-project stage information, historic discharge and stage information, and with-project stage information are also presented for comparison purposes. As footnoted below the table, all the historic events have had at least some degree of emergency protection employed. This is why the 2009 flood had a stage approximately equal to the USACE EOE (Wet) without-protection stage even though the discharge was over 5,000 cfs less than USACE EOE (Wet) discharge.

Table 4 Discharges and Stages, USGS Gage at Fargo, ND

Event	Discharge (cfs)	Existing Condition Without-Protection Stage (ft)	Existing Condition With-Protection[1] Stage (ft)	Projected RRN Stage (ft) with Project in Place
10% FEMA	10,300	29.5[2]	N/A[2]	29.5[3]
10% USACE EOE (Wet)	17,000	34.9[4]	35.0[4]	34.8[3,4]
10% USACE POR	13,865	32.5[5]	N/A[6]	32.5[3]
2% FEMA	22,300	36.6[2]	N/A[2]	35.0[7]
2% USACE EOE (Wet)	29,300	40.1[4]	40.4[4]	35.0[4]
2% USACE POR	26,000	39.4[5]	N/A[6]	35.0[7]
1% FEMA	29,300	39.3[2]	N/A[2]	35.0[7]
1% USACE EOE (Wet)	34,700	40.9[4]	42.1[4]	35.0[4]
1% USACE POR	33,000	40.7[5]	N/A[6]	35.0[7]
0.2% FEMA	50,000	43.5[2]	N/A[2]	39.9[7]
0.2% USACE EOE (Wet)	61,700	42.5[4]	46.3[4]	39.9[4]
0.2% USACE POR	66,000	42.6[5]	N/A[6]	39.9[7]
1997 Historic	28,000	N/A[8]	39.7[8]	35.0[7]
2006 Historic	19,900	N/A[8]	37.1[8]	35.0[7]
2009 Historic	29,500	N/A[8]	40.8[8]	35.0[7]
2010 Historic	21,200	N/A[8]	37.0[8]	35.0[7]
2011 Historic	27,200	N/A[8]	38.8[8]	35.0[7]

(1) With-Protection means with permanent and emergency levees and floodwalls implemented.
(2) Only accredited levees are given credit in a FEMA study. Stages are from the Clay County, Minnesota Flood Insurance Study, effective April 17, 2012.
(3) Based on proposed Project Operation Plan - project would not be in operation
(4) Phase 7 unsteady HEC-RAS modeling result, 28 Mar 2013
(5) Not modeled, but estimated from unsteady HEC-RAS model rating curve.
(6) Not modeled and, at this time, not estimated from unsteady HEC-RAS rating curve.
(7) Based on Phase 7 unsteady HEC-RAS modeling results and Project Operation Plan
(8) All historic events have had at least some degree of emergency protection measures employed to prevent flooding. Stage is from USGS.

Definitions:

EOE – Expert Opinion Elicitation. A panel of hydrology experts was convened to elicit opinions regarding historic flooding trends on the Red River.
FEMA – Federal Emergency Management Agency
POR – Period of Record
RRN – Red River of the North
USGS – United States Geological Survey
USACE – United States Army Corps of Engineers

The following figures (Figures 7-10), which are a combination of a table and a chart, show project impacts in terms of water surface elevations along the Red River for the 10-percent, 2-percent, 1-percent, and 0.2-percent chance events. All of the changes described in Section 1 play a part in why the with-project water surface elevations and impacts have changed since the FEIS, but allowing more flow through the risk management area by constructing in-town levees is the main reason for the changes. There is no longer any in-town stage reduction and upstream staging for the 10-percent chance event since more flow through the risk management area means the project no longer operates for this event. Also, more flow through the risk management area means that the in-town stage reduction is now less for the 2-percent and 1-percent chance events.

As stated in Section 1.3, a stage decrease at the diversion outlet is no longer necessary to minimize downstream impacts since the gated diversion inlet control structure allows with-project hydrographs to better match existing-condition hydrographs just downstream of the diversion outlet. By better matching the existing-condition hydrographs, stage impacts would be more consistently near zero as you move downstream away from the Project. In general the downstream impacts would be essentially zero and no worse than what was reported in the FEIS, except that the slight stage reduction necessary to get to essentially zero impacts downstream of Grand Forks in the FEIS is no longer necessary due to the addition of gates at the diversion inlet control structure (see Section 1.3). The HEC-RAS model does report water surface elevations to the nearest 0.01 foot, and with a less complicated model a modeler might be able to claim that project impacts can be determined to the hundredth of a foot level. However, it has become increasingly clear that the complex flow conditions in combination with the complex model connections results in model accuracy that is on the order of 0.1 to 0.2 feet. Therefore a reported stage increase within 0.1 to 0.2 feet of what was reported in the FEIS is essentially the same as what was reported in the FEIS.

VE13A-Bundled, 10% Chance (10-yr) Event						
Location	Station	Existing Conditions (March 2013)	VE13A-Bundled	Difference Project vs. Existing Conditions	FEIS Impacts (April 2011)	Change in Impacts Relative to FEIS
		Elevation (ft)	Elevation (ft)	(ft)	(ft)	(ft)
Drayton Gage	1062362	798.75	798.76	0.01	0.01	0.00
ND SH#17/ MN SH317	1223286	801.77	801.78	0.01	0.02	-0.01
Co. Hwy 15	1315673	803.49	803.51	0.02	0.01	0.01
Oslo Gage	1416287	810.40	810.40	0.00	0.04	-0.04
Minimum DS Impact Location	1416530	810.62	810.62	0.00	N/A	N/A
DS Grand Forks Levees	1533523	822.64	822.68	0.04	0.08	-0.04
Grand Forks Gage	1558518	825.41	825.45	0.04	0.11	-0.07
32nd Ave, Grand Forks	1580152	827.55	827.61	0.06	0.11	-0.05
Thompson Gage	1667877	837.90	838.01	0.11	0.04	0.07
Co. Hwy 25/ Co. Rd 221	1726274	843.11	843.24	0.13	0.04	0.09
DS Sandhill River/ Climax	1763746	845.74	845.88	0.14	0.03	0.11
Nielsville	1829877	850.24	850.38	0.14	0.03	0.11
DS Marsh River	1864960	853.20	853.36	0.16	0.04	0.12
US Goose River/ Shelly	1891054	855.92	856.08	0.16	0.03	0.13
Maximum DS Impact Location	1961282	863.05	863.22	0.17	N/A	N/A
Halstad Gage	1981580	864.54	864.69	0.15	-0.12	0.27
Hendrum	2038409	868.50	868.62	0.12	-0.25	0.37
Perley	2129181	874.85	874.92	0.07	-0.54	0.61
Georgetown	2194021	879.89	879.97	0.08	-0.43	0.51
North River/ Clay Co. Hwy 93	2305647	890.13	889.80	-0.33	-5.49	5.16
19th Ave N Fargo/ 28th Ave N Moorhead	2360321	893.92	893.68	-0.24	-5.36	5.12
Fargo Gage (13th Ave S, 12th Ave S)	2388223	897.67 (34.93*)	897.49 (34.75*)	-0.18	-5.47	5.29
52nd Ave S Fargo/ 60th Ave S Moorhead	2438085	902.29	902.13	-0.16	-5.49	5.33
US ND Wild Rice River	2484618	906.17	906.03	-0.14	-5.15	5.01
US Diversion	2531315	908.71	908.83	0.12	8.23	-8.11
Oxbow	2552977	909.96	910.05	0.09	7.13	-7.04
Hickson Gage	2563754	910.76	910.71	-0.05	6.59	-6.64
Cass/Richland County Line	2582760	912.26	912.22	-0.04	5.64	-5.68
Abercrombie	2764908	927.87	927.86	-0.01	0.11	-0.12

* Flood stage at USGS Gaging Station 05054000, Fargo, ND

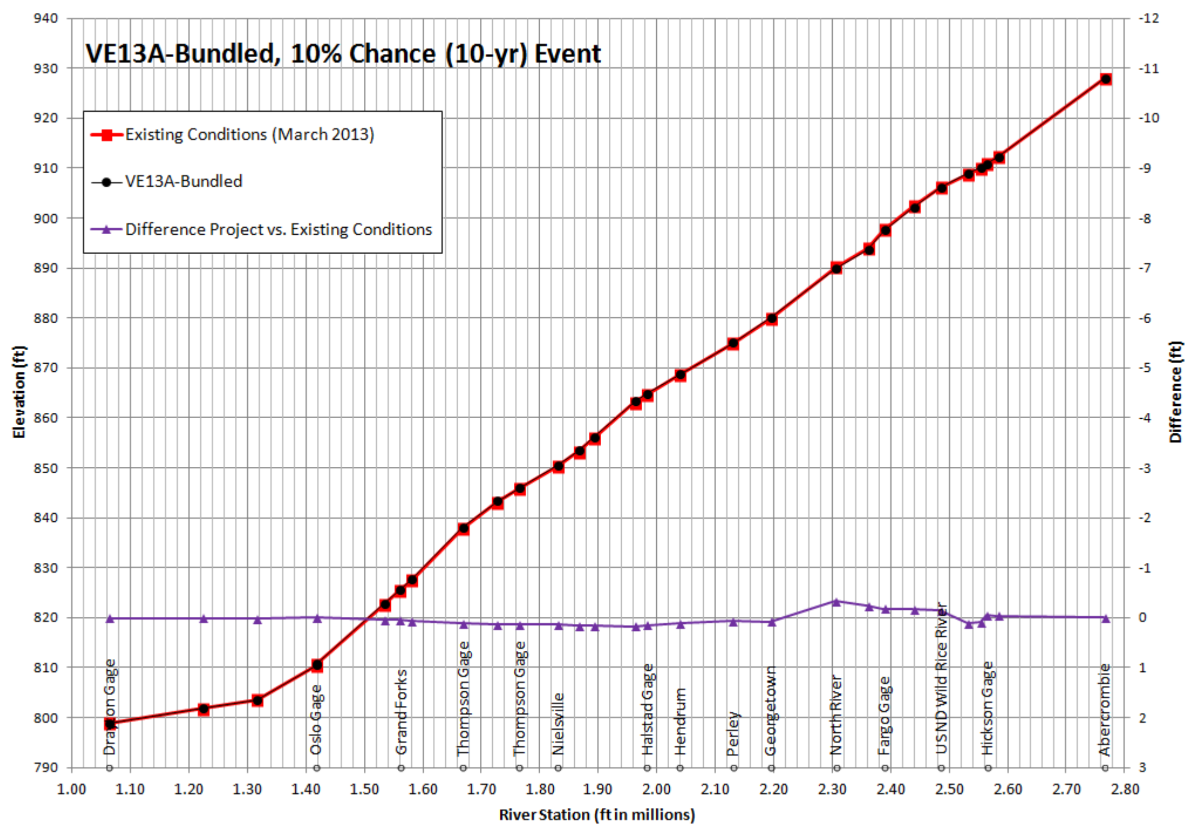

Figure 7 Red River Profiles, Existing vs. With-Project for 10-Percent Chance Event

VE13A-Bundled, 2% Chance (50-yr) Event						
Location	Station	Existing Conditions (March 2013)	VE13A-Bundled	Difference Project vs. Existing Conditions	FEIS Impacts (April 2011)	Change in Impacts Relative to FEIS
		Elevation (ft)	Elevation (ft)	(ft)	(ft)	(ft)
Drayton Gage	1062362	800.49	800.53	0.04	0.08	-0.04
ND SH#17/ MN SH317	1223286	803.94	803.98	0.04	0.07	-0.03
Co. Hwy 15	1315673	805.33	805.37	0.04	0.05	-0.01
Oslo Gage	1416287	812.51	812.53	0.02	0.04	-0.02
DS Grand Forks Levees	1533523	827.01	827.07	0.06	0.11	-0.05
Grand Forks Gage	1558518	831.15	831.24	0.09	0.18	-0.09
32nd Ave, Grand Forks	1580152	834.13	834.24	0.11	0.28	-0.17
Thompson Gage	1667877	845.60	845.71	0.11	0.24	-0.13
Co. Hwy 25/ Co. Rd 221	1726274	851.65	851.80	0.15	0.21	-0.06
DS Sandhill River/ Climax	1763746	854.41	854.57	0.16	0.21	-0.05
Nielsville	1829877	858.65	858.84	0.19	0.18	0.01
Maximum DS Impact Location	1832761	858.77	858.96	0.19	N/A	N/A
DS Marsh River	1864960	861.16	861.33	0.17	0.16	0.01
US Goose River/ Shelly	1891054	863.19	863.34	0.15	0.12	0.03
Halstad Gage	1981580	868.19	868.19	0.00	0	0.00
Hendrum	2038409	872.68	872.65	-0.03	-0.12	0.09
Perley	2129181	877.52	877.49	-0.03	-0.32	0.29
Minimum DS Impact Location	2155582	879.09	879.05	-0.04	N/A	N/A
Georgetown	2194021	881.90	882.00	0.10	-0.23	0.33
North River/ Clay Co. Hwy 93	2305647	893.80	890.29	-3.51	-6.75	3.24
19th Ave N Fargo/ 28th Ave N Moorhead	2360321	898.37	894.03	-4.34	-8.35	4.01
Fargo Gage (13th Ave S, 12th Ave S)	2388223	902.82 (40.08*)	897.77 (35.03*)	-5.05	-9.88	4.83
52nd Ave S Fargo/ 60th Ave S Moorhead	2438085	906.73	902.33	-4.40	-10.21	5.81
US ND Wild Rice River	2484618	910.42	906.32	-4.10	-9.41	5.31
US Diversion	2531315	914.04	921.52	7.48	7.10	0.38
Oxbow	2552977	915.54	921.60	6.06	5.40	0.66
Hickson Gage	2563754	916.49	921.68	5.19	4.58	0.61
Cass/Richland County Line	2582760	918.36	922.06	3.70	3.52	0.18
Abercrombie	2764908	934.04	934.17	0.13	0.14	-0.01

* Flood stage at USGS Gaging Station 05054000, Fargo, ND

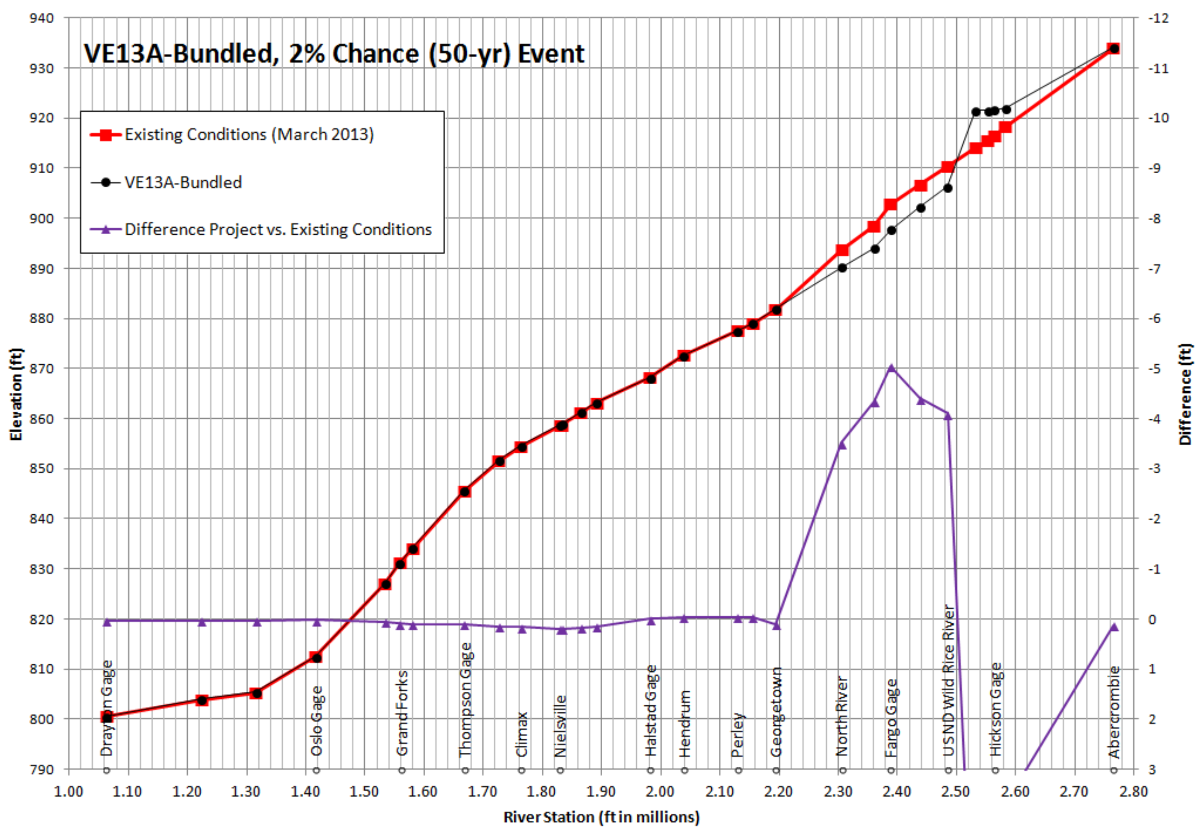

Figure 8 Red River Profiles, Existing vs. With-Project for 2-Percent Chance Event

VE13A-Bundled, 1% Chance (100-yr) Event						
Location	Station	Existing Conditions (March 2013)	VE13A-Bundled	Difference Project vs. Existing Conditions	FEIS Impacts (April 2011)	Change in Impacts Relative to FEIS
		Elevation (ft)	Elevation (ft)	(ft)	(ft)	(ft)
Drayton Gage	1062362	803.11	803.14	0.03	0.08	-0.05
ND SH#17/ MN SH317	1223286	806.17	806.20	0.03	0.07	-0.04
Co. Hwy 15	1315673	807.05	807.08	0.03	0.05	-0.02
Oslo Gage	1416287	813.24	813.26	0.02	0.06	-0.04
DS Grand Forks Levees	1533523	828.43	828.51	0.08	0.15	-0.07
Grand Forks Gage	1558518	833.27	833.40	0.13	0.24	-0.11
32nd Ave, Grand Forks	1580152	836.44	836.60	0.16	0.28	-0.12
Maximum DS Impact Location	1624976	841.93	842.21	0.28	N/A	N/A
Thompson Gage	1667877	847.41	847.58	0.17	0.04	0.13
Co. Hwy 25/ Co. Rd 221	1726274	854.55	854.72	0.17	-0.02	0.19
DS Sandhill River/ Climax	1763746	857.58	857.75	0.17	-0.04	0.21
Nielsville	1829877	861.85	861.98	0.13	-0.04	0.17
DS Marsh River	1864960	864.12	864.23	0.11	-0.03	0.14
US Goose River/ Shelly	1891054	865.80	865.89	0.09	-0.04	0.13
Halstad Gage	1981580	869.13	869.09	-0.04	-0.06	0.02
Hendrum	2038409	873.63	873.55	-0.08	-0.06	-0.02
Perley	2129181	877.93	877.85	-0.08	-0.28	0.20
Minimum DS Impact Location	2165445	880.08	879.99	-0.09	N/A	N/A
Georgetown	2194021	882.27	882.34	0.07	-0.25	0.32
North River/ Clay Co. Hwy 93	2305647	894.28	890.28	-4.00	-7.25	3.25
19th Ave N Fargo/ 28th Ave N Moorhead	2360321	898.89	894.02	-4.87	-8.58	3.71
Fargo Gage (13th Ave S, 12th Ave S)	2388223	903.59 (40.85*)	897.77 (35.03*)	-5.82	-10.32	4.50
52nd Ave S Fargo/ 60th Ave S Moorhead	2438085	907.13	902.34	-4.79	-10.05	5.26
US ND Wild Rice River	2484618	910.82	906.31	-4.51	-8.99	4.48
US Diversion	2531315	914.75	922.22	7.47	8.23	-0.76
Oxbow	2552977	916.45	922.29	5.84	6.30	-0.46
Hickson Gage	2563754	917.51	922.35	4.84	5.38	-0.54
Cass/Richland County Line	2582760	919.68	922.67	2.99	4.02	-1.03
Abercrombie	2764908	936.51	936.55	0.04	0.11	-0.07

* Flood stage at USGS Gaging Station 05054000, Fargo, ND

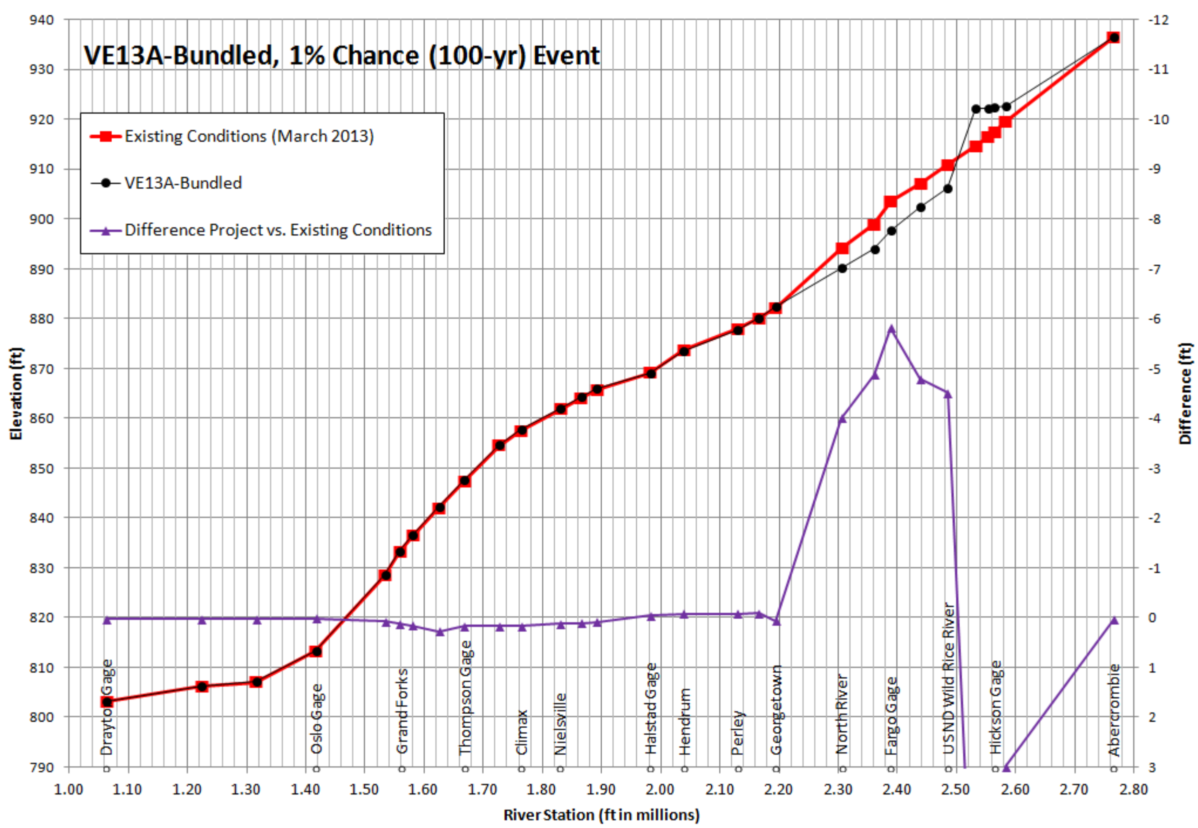

Figure 9 Red River Profiles, Existing vs. With-Project for 1-Percent Chance Event

VE13A-Bundled, 0.2% Chance (500-yr) Event						
Location	Station	Existing Conditions (March 2013)	VE13A-Bundled	Difference Project vs. Existing Conditions	FEIS Impacts (April 2011)	Change in Impacts Relative to FEIS
		Elevation (ft)	Elevation (ft)	(ft)	(ft)	(ft)
Drayton Gage	1062362	803.55	803.63	0.08	0.08	0.00
ND SH#17/ MN SH317	1223286	806.71	806.77	0.06	0.07	-0.01
Co. Hwy 15	1315673	807.93	807.98	0.05	0.05	0.00
Oslo Gage	1416287	814.16	814.19	0.03	0.06	-0.03
DS Grand Forks Levees	1533523	830.69	830.77	0.08	0.15	-0.07
Grand Forks Gage	1558518	837.07	837.23	0.16	0.22	-0.06
32nd Ave, Grand Forks	1580152	840.81	840.99	0.18	0.27	-0.09
Thompson Gage	1667877	850.88	850.95	0.07	-0.05	0.12
Co. Hwy 25/ Co. Rd 221	1726274	859.78	859.84	0.06	-0.12	0.18
DS Sandhill River/ Climax	1763746	863.23	863.29	0.06	-0.15	0.21
Nielsville	1829877	867.33	867.37	0.04	-0.16	0.20
DS Marsh River	1864960	868.49	868.51	0.02	-0.14	0.16
US Goose River/ Shelly	1891054	869.65	869.66	0.01	-0.13	0.14
Halstad Gage	1981580	871.48	871.45	-0.03	-0.22	0.19
Minimum DS Impact Location	2021924	873.51	873.41	-0.10	N/A	N/A
Hendrum	2038409	875.16	875.10	-0.06	-0.30	0.24
Perley	2129181	878.38	878.33	-0.05	-0.36	0.31
Georgetown	2194021	882.76	882.98	0.22	-0.33	0.55
Maximum DS Impact Location	2203356	883.29	883.59	0.30	N/A	N/A
North River/ Clay Co. Hwy 93	2305647	894.75	893.50	-1.25	-2.39	1.14
19th Ave N Fargo/ 28th Ave N Moorhead	2360321	899.81	898.19	-1.62	-1.99	0.37
Fargo Gage (13th Ave S, 12th Ave S)	2388223	905.24 (42.5*)	902.67 (39.93*)	-2.57	-3.03	0.46
52nd Ave S Fargo/ 60th Ave S Moorhead	2438085	908.00	906.67	-1.33	-2.05	0.72
US ND Wild Rice River	2484618	911.47	910.37	-1.10	-1.31	0.21
US Diversion	2531315	915.95	922.24	6.29	6.50	-0.21
Oxbow	2552977	918.26	922.41	4.15	3.98	0.17
Hickson Gage	2563754	919.70	922.61	2.91	2.85	0.06
Cass/Richland County Line	2582760	923.13	923.68	0.55	1.13	-0.58
Abercrombie	2764908	939.55	939.55	0.00	0.01	-0.01

* Flood stage at USGS Gaging Station 05054000, Fargo, ND

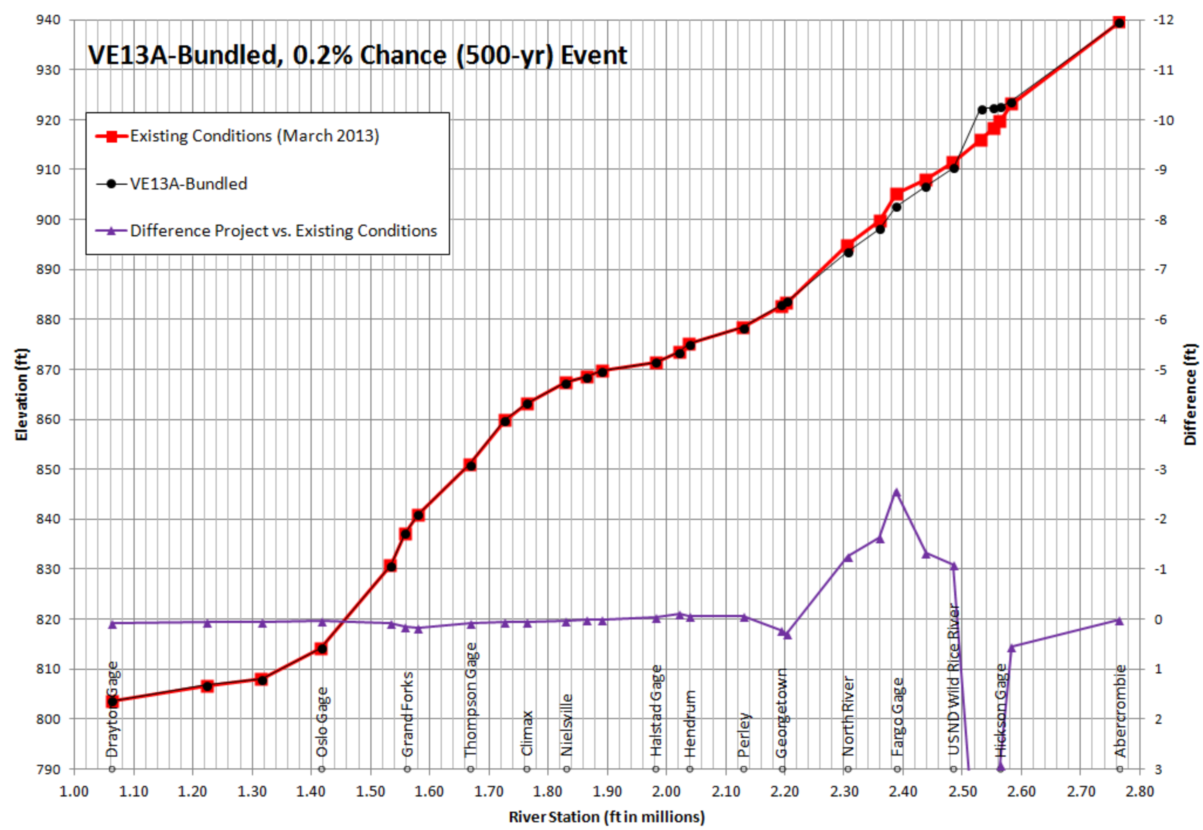

Figure 10 Red River Profiles, Existing vs. With-Project for 0.2-Percent Chance Event

In addition to the tributary sensitivity analyses presented in the FEIS, the timing of the Red Lake River hydrographs was varied to determine the effect on downstream stage impacts . The Red Lake River coincident hydrograph for the 1-percent chance event on the Red River of the North was introduced one- and two-days earlier and one- and two-days later than the baseline for both existing and with-project conditions. The results for all five scenarios are nearly identical (i.e. the timing of the Red Lake River has essentially no effect on the downstream impacts). The results of this sensitivity analysis are presented in Table 5.

Table 5 Red Lake River Timing Sensitivity for 1-Pecent Chance Event

Location	Station	Red Lake -2 Days From Baseline	Red Lake -1 Day From Baseline	Red Lake at VE13A Baseline	Red Lake +1 Day From Baseline	Red Lake +2 Days From Baseline
		Benefits/Impacts in Feet	Benefits/Impacts in Feet	Benefits/Impacts in Feet	Benefits/Impacts in Feet	Benefits/Impacts in Feet
Grand Forks Gage	1558518	0.09	0.08	0.09	0.10	0.10
32nd Ave, Grand Forks	1580152	0.11	0.14	0.15	0.15	0.14
Thompson Gage	1667877	0.09	0.09	0.08	0.07	0.06
Co. Hwy 25/ Co. Rd 221	1726274	0.10	0.10	0.10	0.10	0.10
DS Sandhill River/ Climax	1763746	0.11	0.11	0.11	0.10	0.10
Nielsville	1829877	0.10	0.09	0.09	0.09	0.10
DS Marsh River	1864960	0.08	0.07	0.07	0.08	0.08
US Goose River/ Shelly	1891054	0.06	0.06	0.06	0.06	0.06
Halstad Gage	1981580	-0.05	-0.04	-0.04	-0.05	-0.05
Hendrum	2038409	-0.08	-0.08	-0.08	-0.08	-0.08
Perley	2129181	-0.08	-0.08	-0.08	-0.08	-0.08
Georgetown	2194021	0.07	0.07	0.07	0.07	0.07
North River/ Clay Co. Hwy 93	2305647	-4.00	-4.00	-4.00	-4.00	-4.00
19th Ave N Fargo/ 28th Ave N Moorhead	2360321	-4.87	-4.87	-4.87	-4.87	-4.87
Fargo Gage (13th Ave S, 12th Ave S)	2388223	-5.82	-5.82	-5.82 (35.03*)	-5.82	-5.82
52nd Ave S Fargo/ 60th Ave S Moorhead	2438085	-4.79	-4.79	-4.79	-4.79	-4.79
US ND Wild Rice River	2484618	-4.51	-4.51	-4.51	-4.51	-4.51
US Diversion	2531315	7.47	7.47	7.47 (922.22)	7.47	7.47
Oxbow	2552977	5.84	5.84	5.84	5.84	5.84
Hickson Gage	2563754	4.84	4.84	4.84	4.84	4.84
Cass/Richland County Line	2582760	2.99	2.99	2.99	2.99	2.99
Abercrombie	2764908	0.04	0.04	0.04	0.04	0.04

* Flood stage at USGS Gaging Station 05054000, Fargo, ND

Stage and flow hydrographs for the 10-percent, 2-percent, 1-percent, and 0.2-percent chance events are provided as Figures 11-20, 21-30, 31-40, and 41-50, respectively. These hydrographs are updates to the hydrographs found in Attachment 5 (the Consultant's report), Appendix C of the Final Feasibility Report and Environmental Impact Statement (FEIS). Again, as explained in Section 1.3, the control provided by having gates at the diversion inlet allows with-project hydrographs to be more similar to the existing-condition hydrographs. The similarity to existing-condition hydrographs minimizes changes in ice impacts and flow conditions where tributaries and ditches enter the Red River of the North.

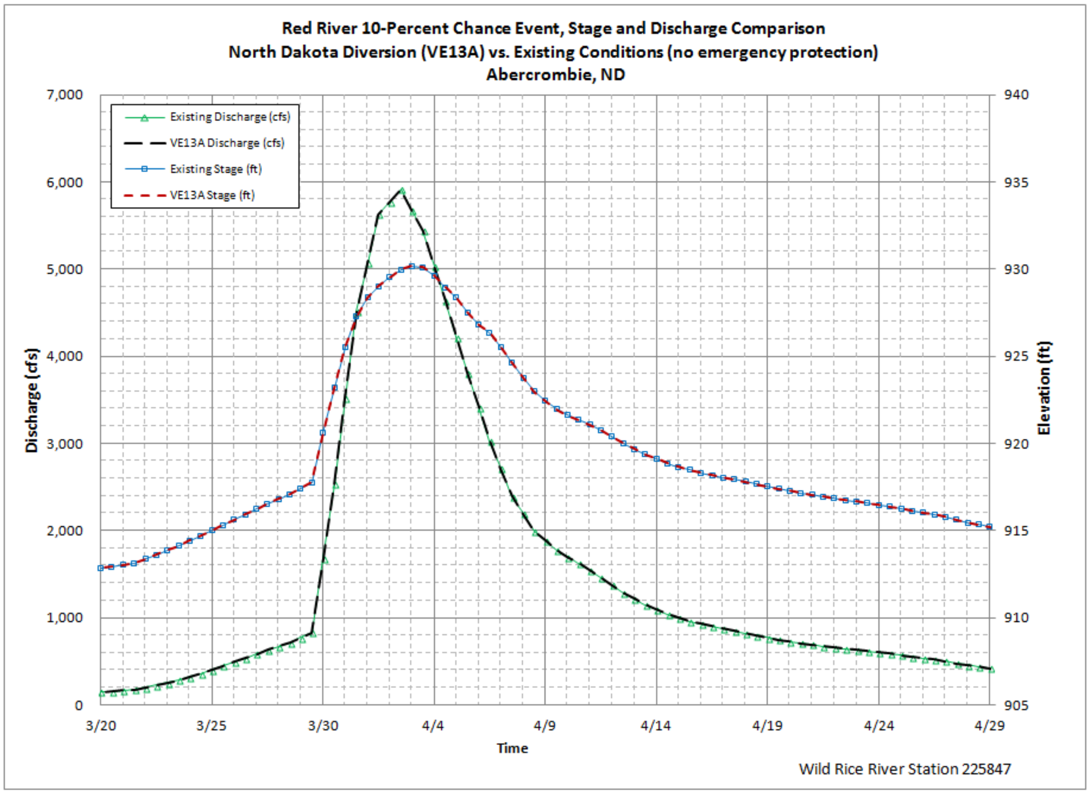

Figure 11 Stage and Flow Hydrographs Wild Rice River at Abercrombie, Existing vs. With-Project for 10-Percent Chance Event

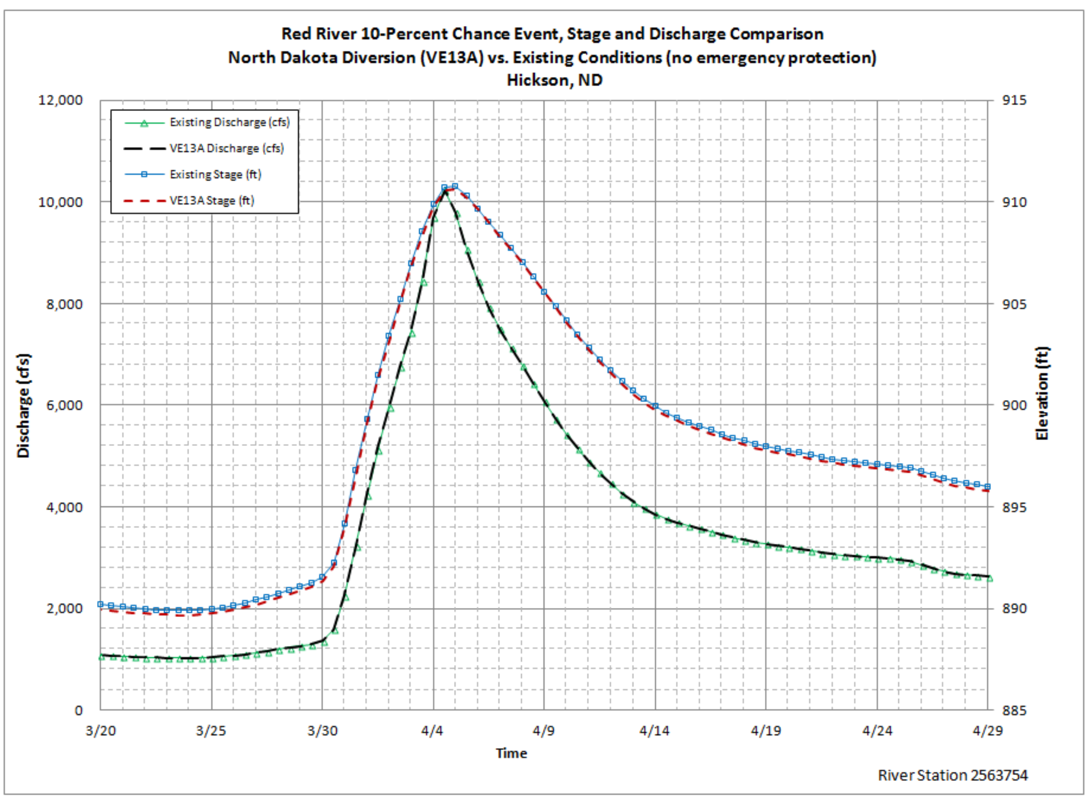

Figure 12 Stage and Flow Hydrographs on Red River at Hickson, Existing vs. With-Project for 10-Percent Chance Event

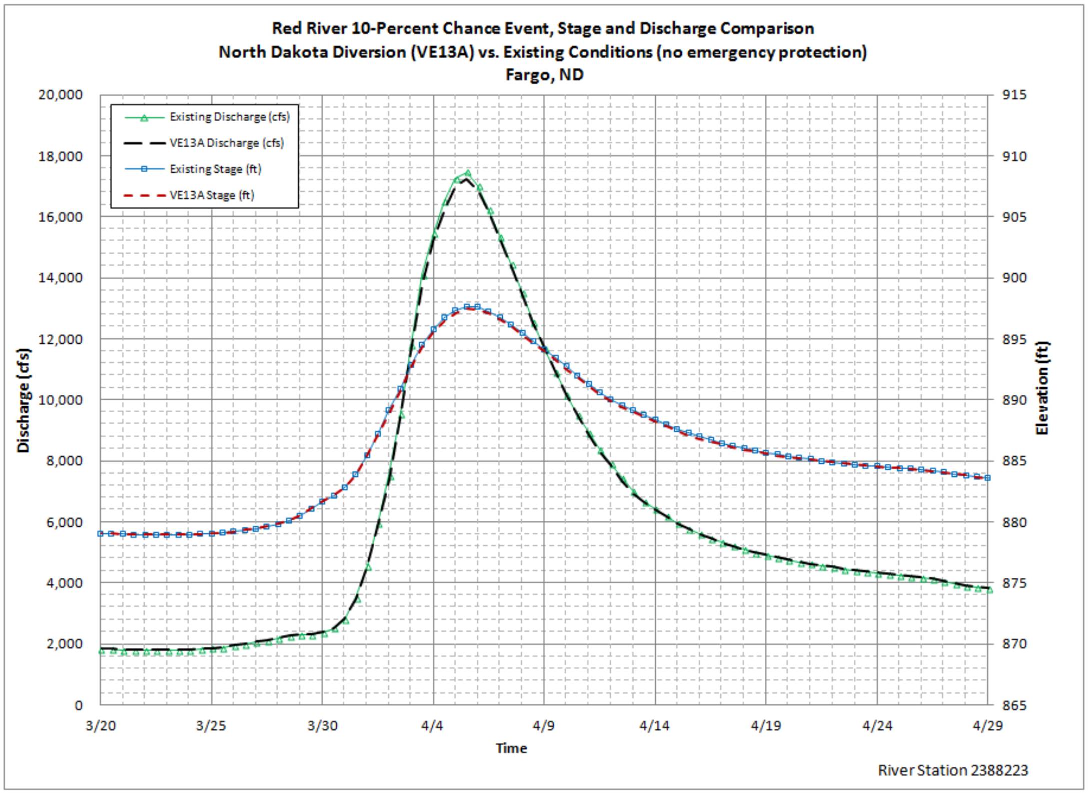

Figure 13 Stage and Flow Hydrographs on Red River at Fargo, Existing vs. With-Project for 10-Percent Chance Event

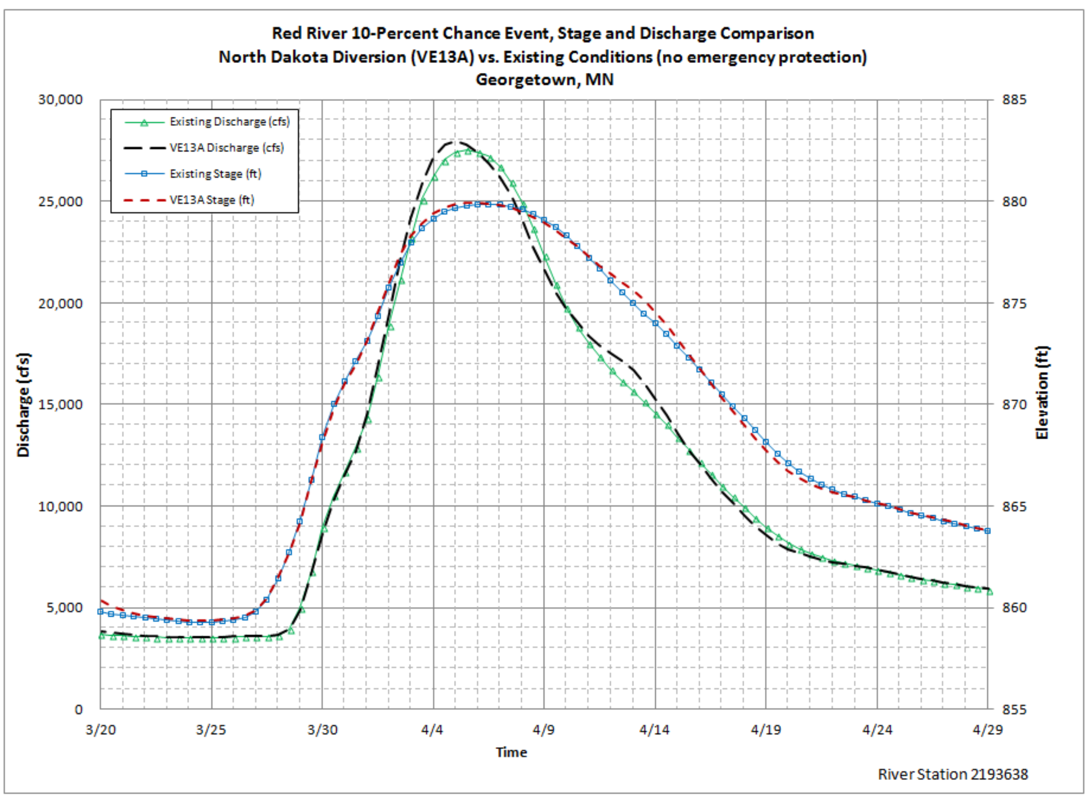

Figure 14 Stage and Flow Hydrographs on Red River at Georgetown, Existing vs. With-Project for 10-Percent Chance Event

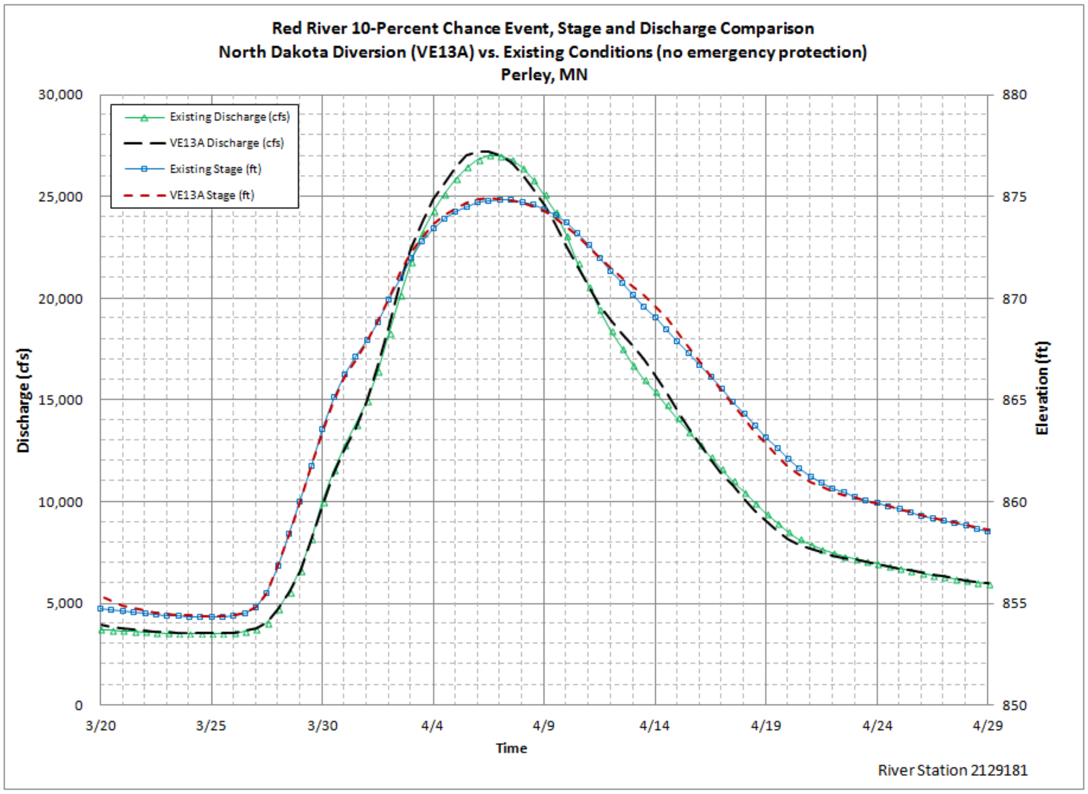

Figure 15 Stage and Flow Hydrographs on Red River at Perley, Existing vs. With-Project for 10-Percent Chance Event

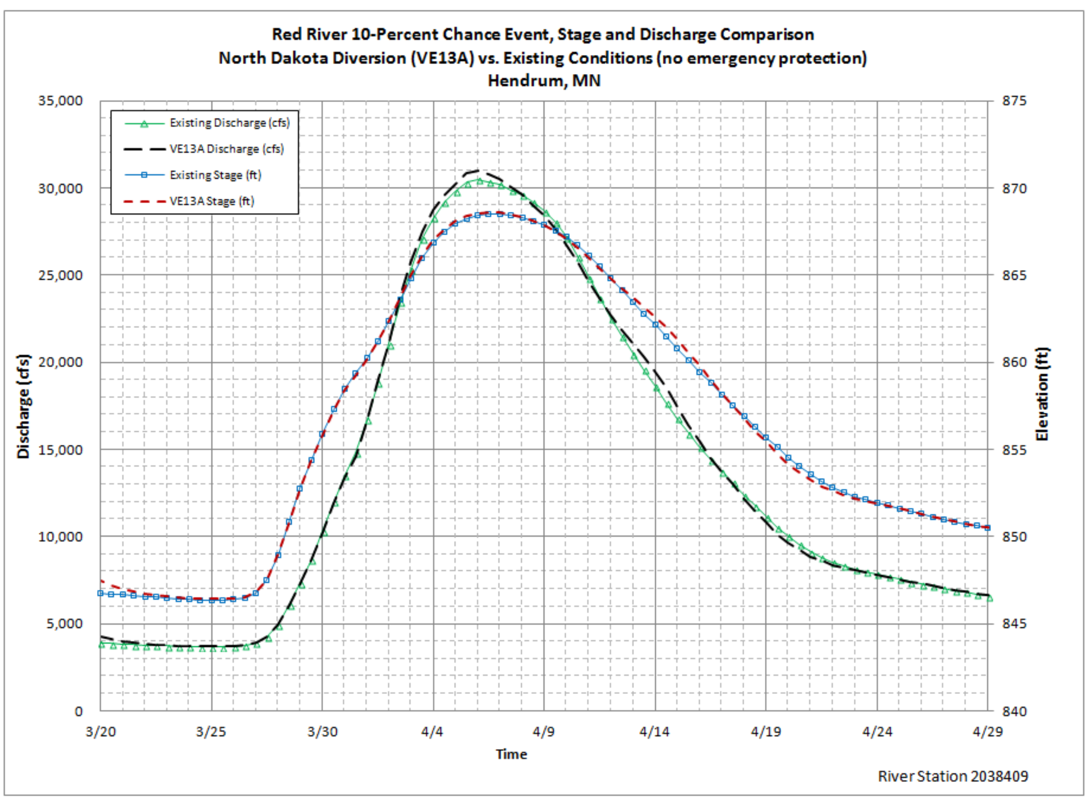

Figure 16 Stage and Flow Hydrographs on Red River at Hendrum, Existing vs. With-Project for 10-Percent Chance Event

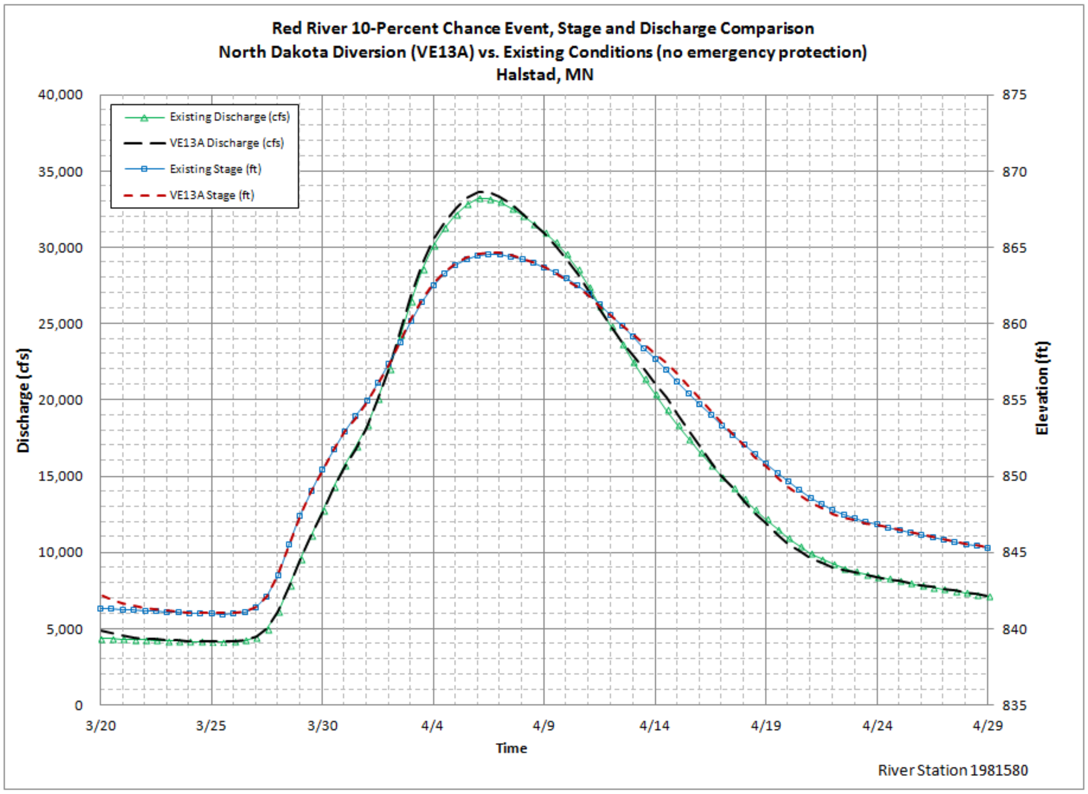

Figure 17 Stage and Flow Hydrographs on Red River at Halstad, Existing vs. With-Project for 10-Percent Chance Event

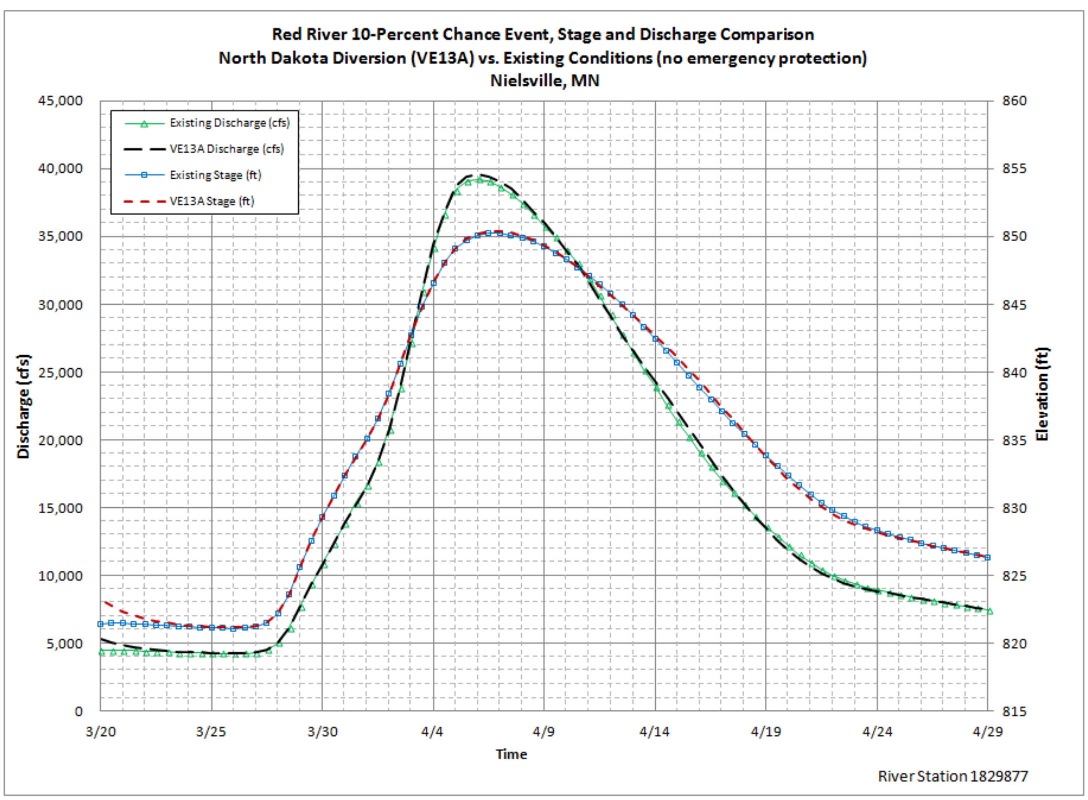

Figure 18 Stage and Flow Hydrographs on Red River at Nielsville, Existing vs. With-Project for 10-Percent Chance Event

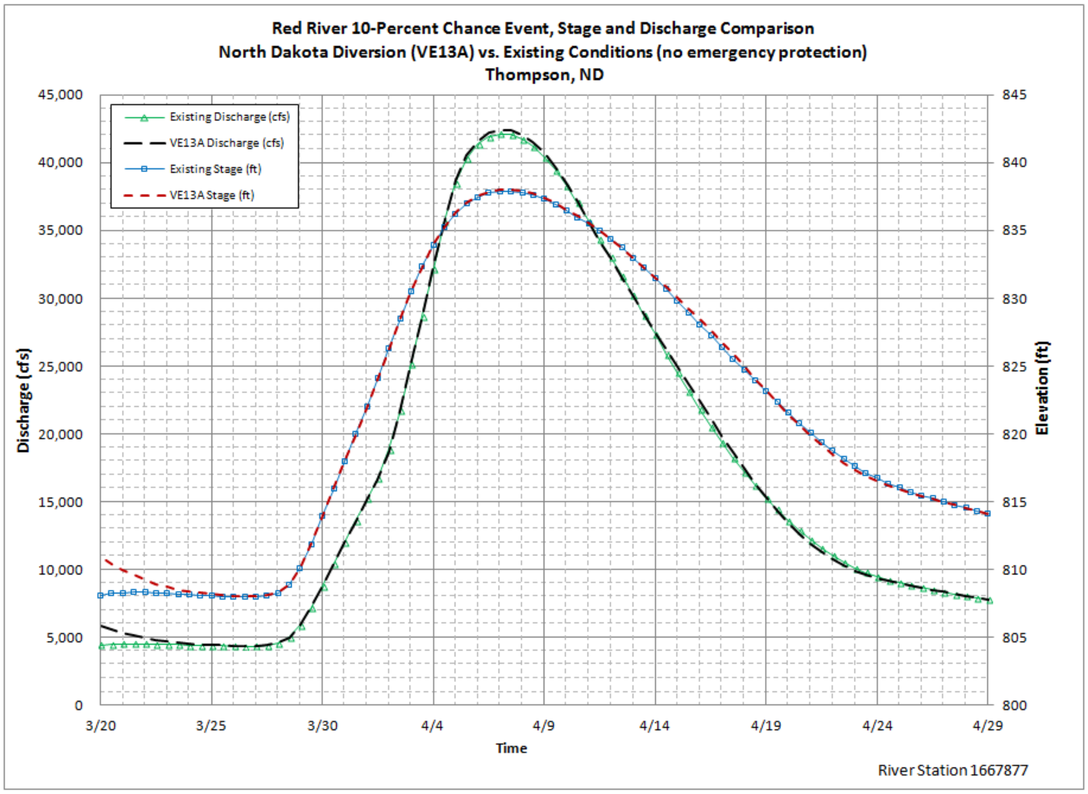

Figure 19 Stage and Flow Hydrographs on Red River at Thompson, Existing vs. With-Project for 10-Percent Chance Event

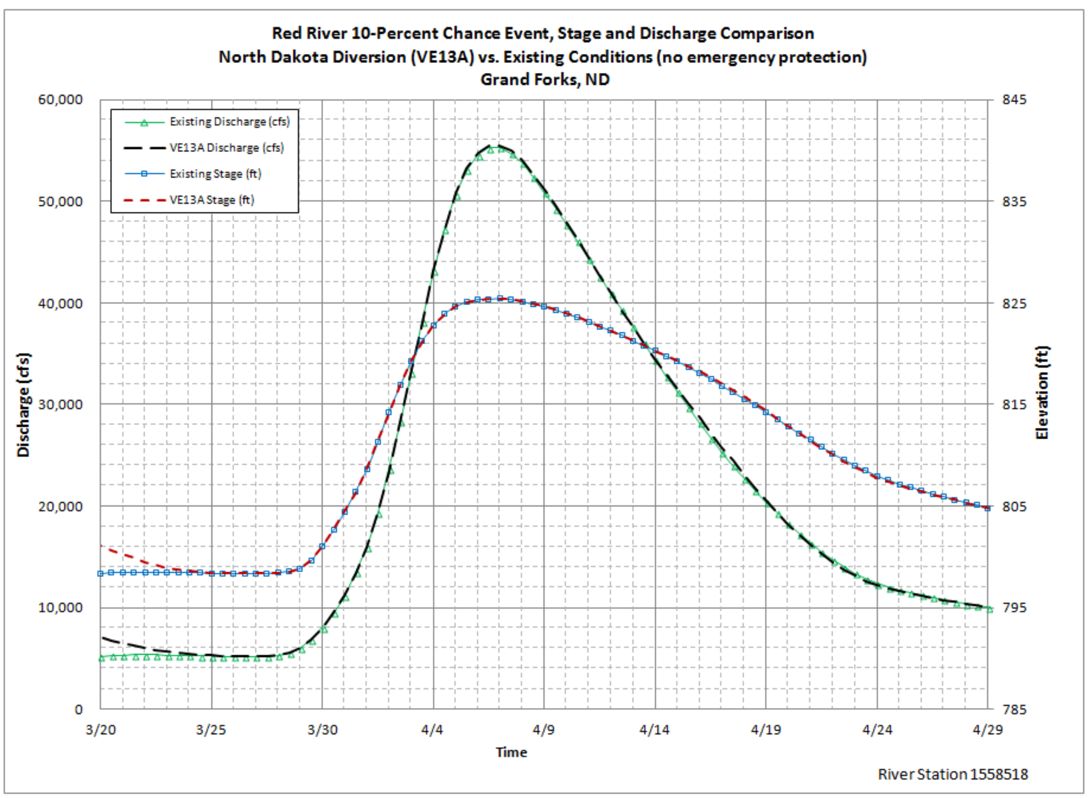

Figure 20 Stage and Flow Hydrographs on Red River at Grand Forks, Existing vs. With-Project for 10-Percent Chance Event

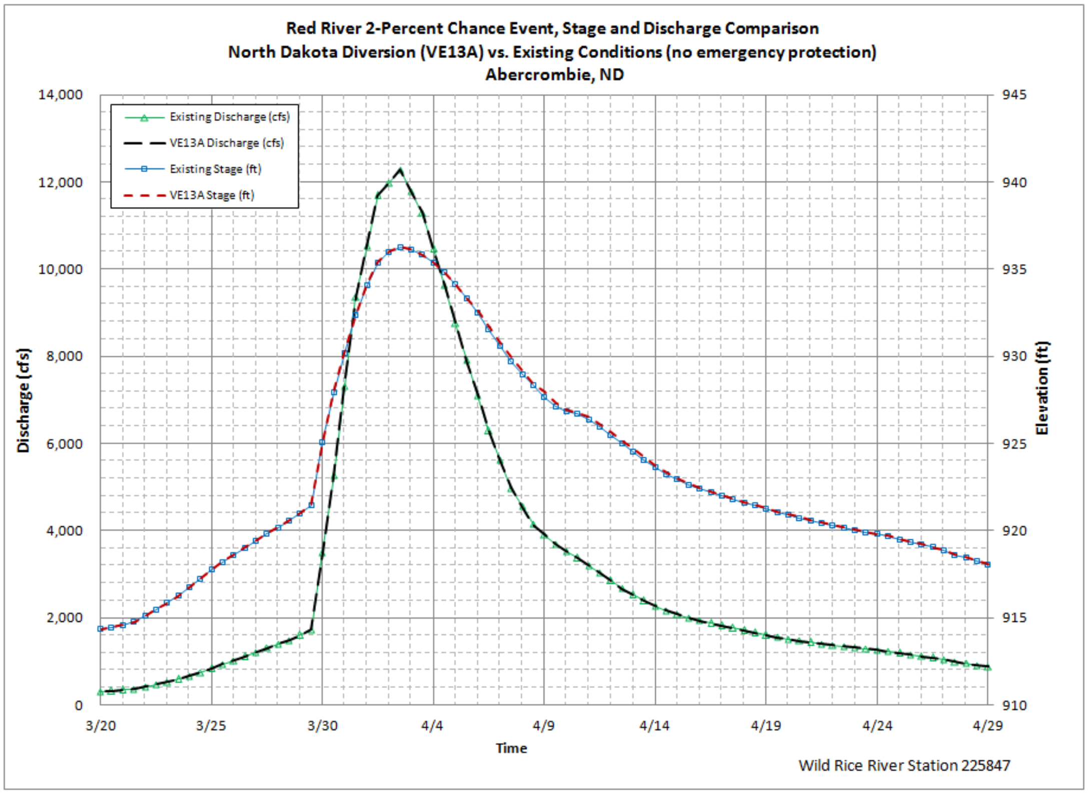

Figure 21 Stage & Flow Hydrographs Wild Rice River at Abercrombie, Existing vs. With-Project for 2-Percent Chance Event

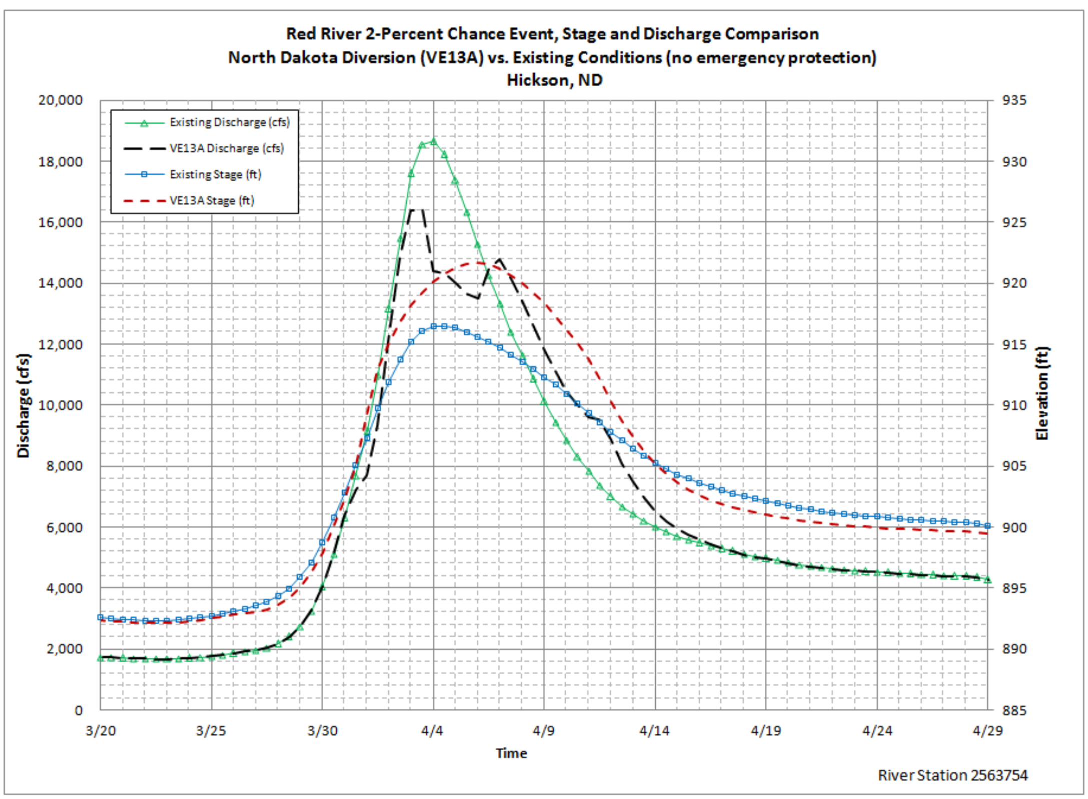

Figure 22 Stage and Flow Hydrographs on Red River at Hickson, Existing vs. With-Project for 2-Percent Chance Event

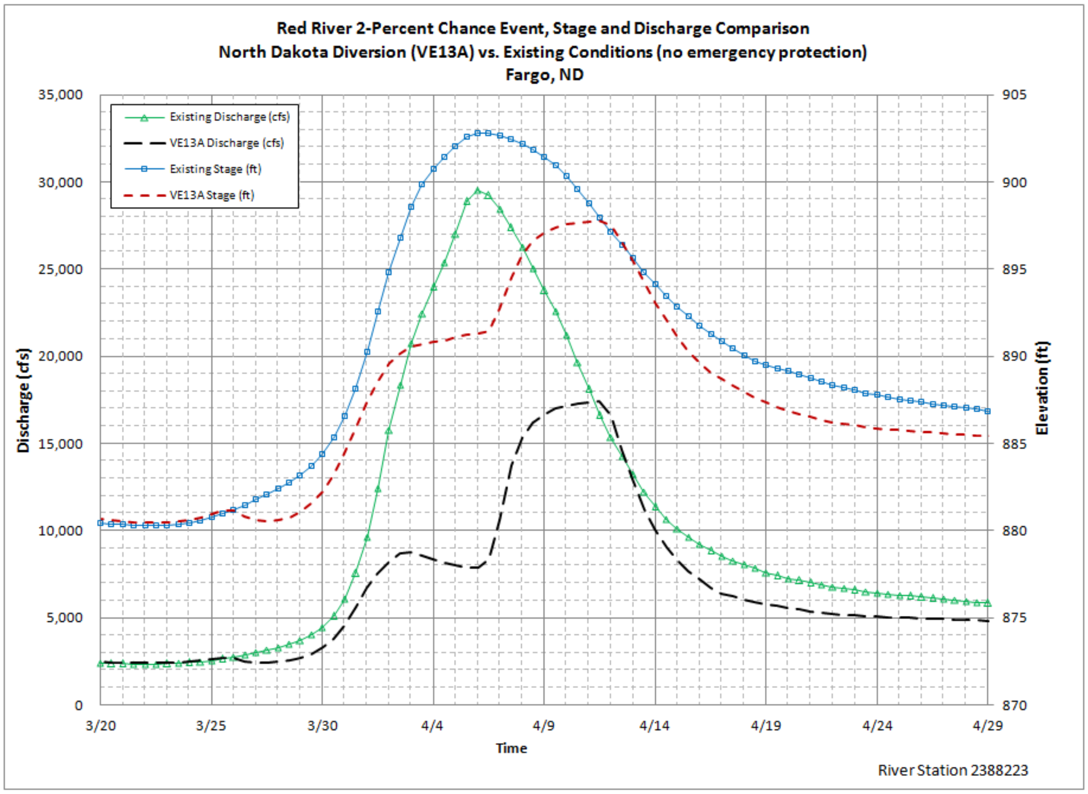

Figure 23 Stage and Flow Hydrographs on Red River at Fargo, Existing vs. With-Project for 2-Percent Chance Event

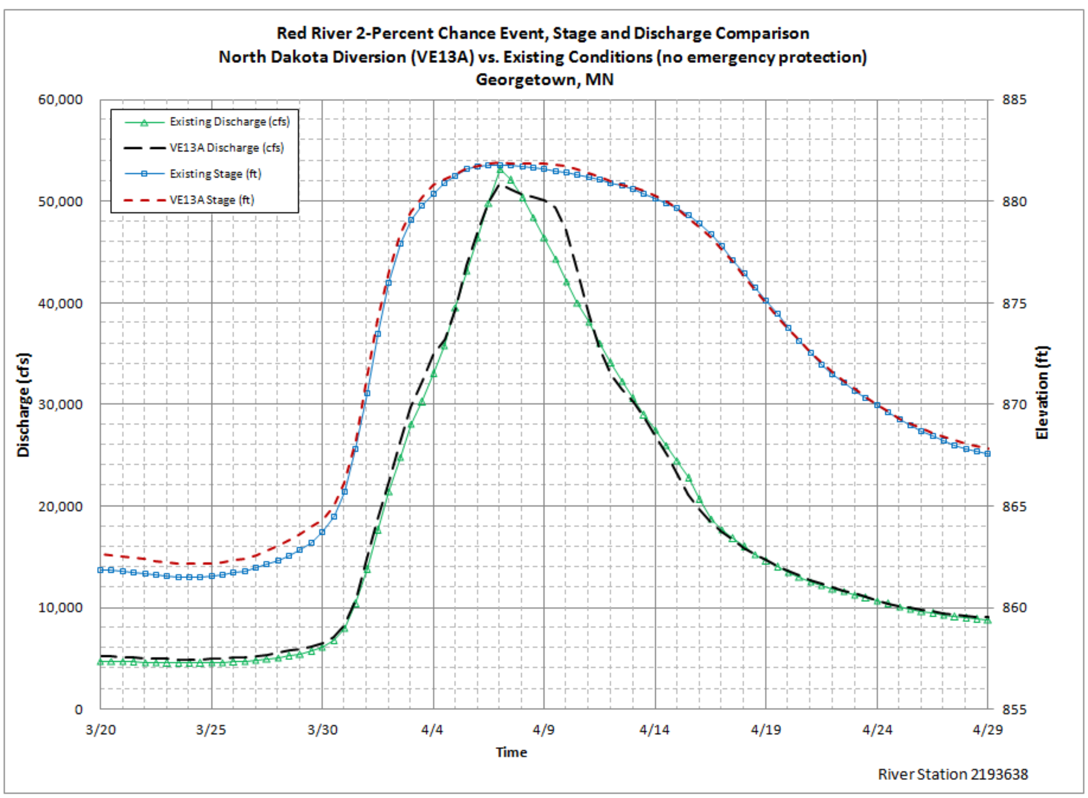

Figure 24 Stage and Flow Hydrographs on Red River at Georgetown, Existing vs. With-Project for 2-Percent Chance Event

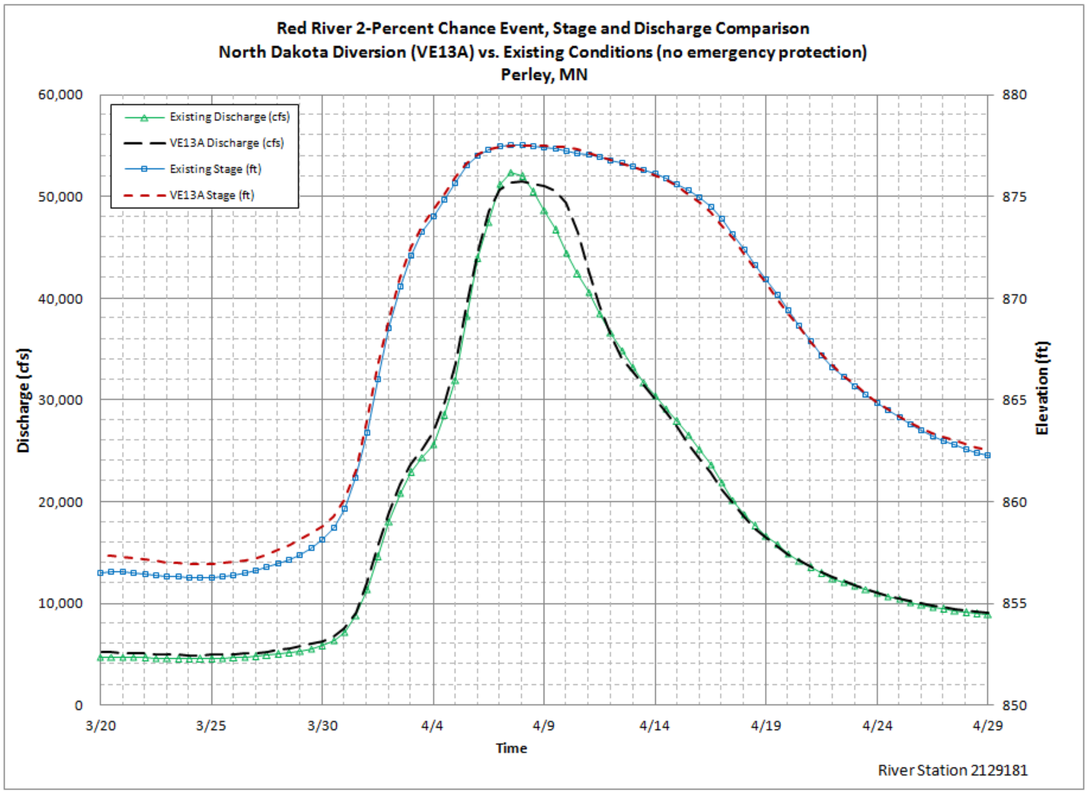

Figure 25 Stage and Flow Hydrographs on Red River at Perley, Existing vs. With-Project for 2-Percent Chance Event

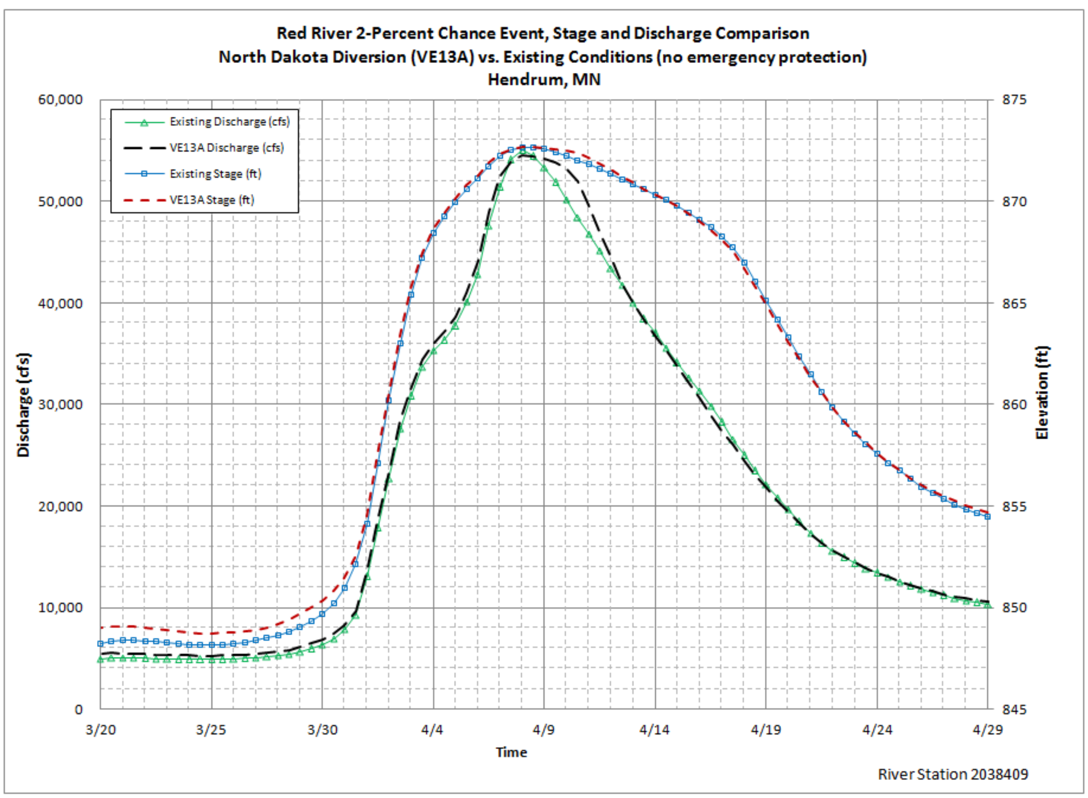

Figure 26 Stage and Flow Hydrographs on Red River at Hendrum, Existing vs. With-Project for 2-Percent Chance Event

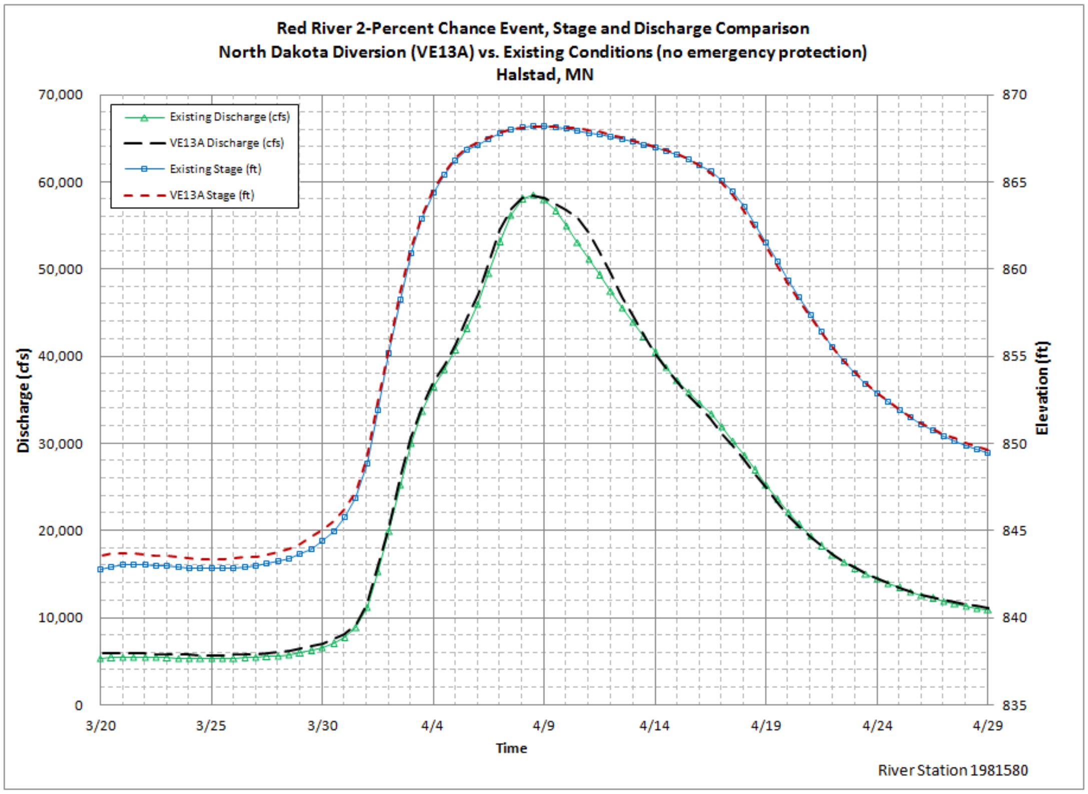

Figure 27 Stage and Flow Hydrographs on Red River at Halstad, Existing vs. With-Project for 2-Percent Chance Event

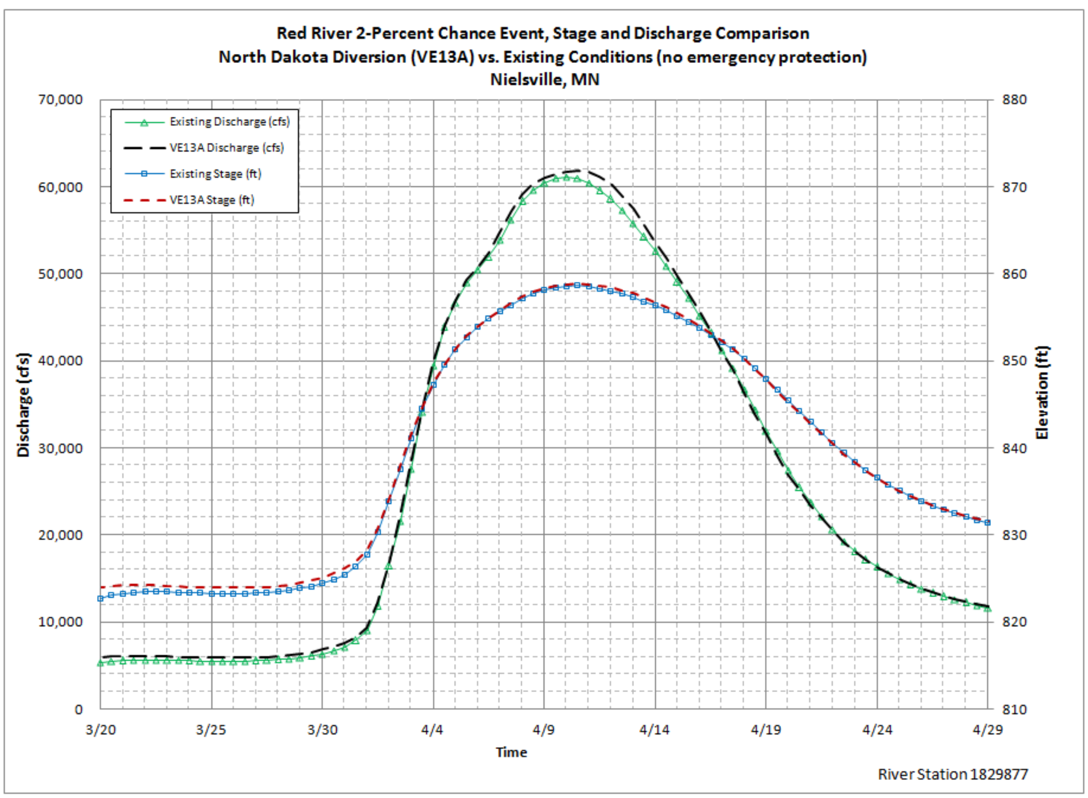

Figure 28 Stage and Flow Hydrographs on Red River at Nielsville, Existing vs. With-Project for 2-Percent Chance Event

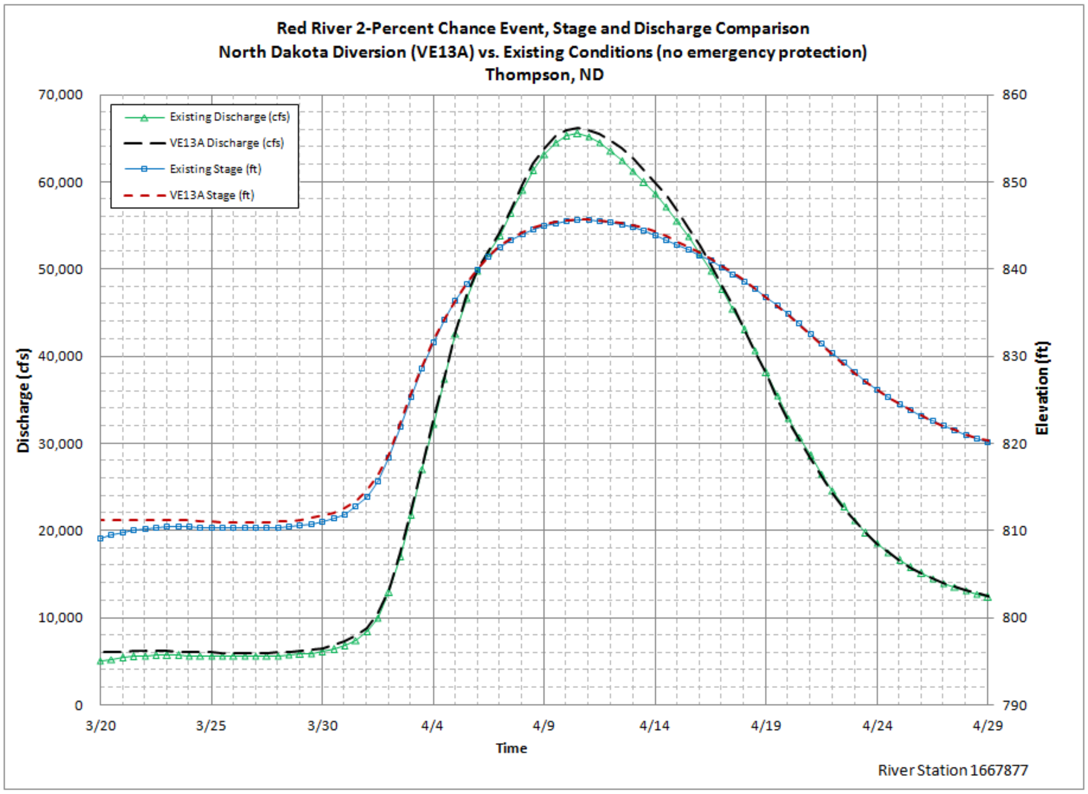

Figure 29 Stage and Flow Hydrographs on Red River at Thompson, Existing vs. With-Project for 2-Percent Chance Event

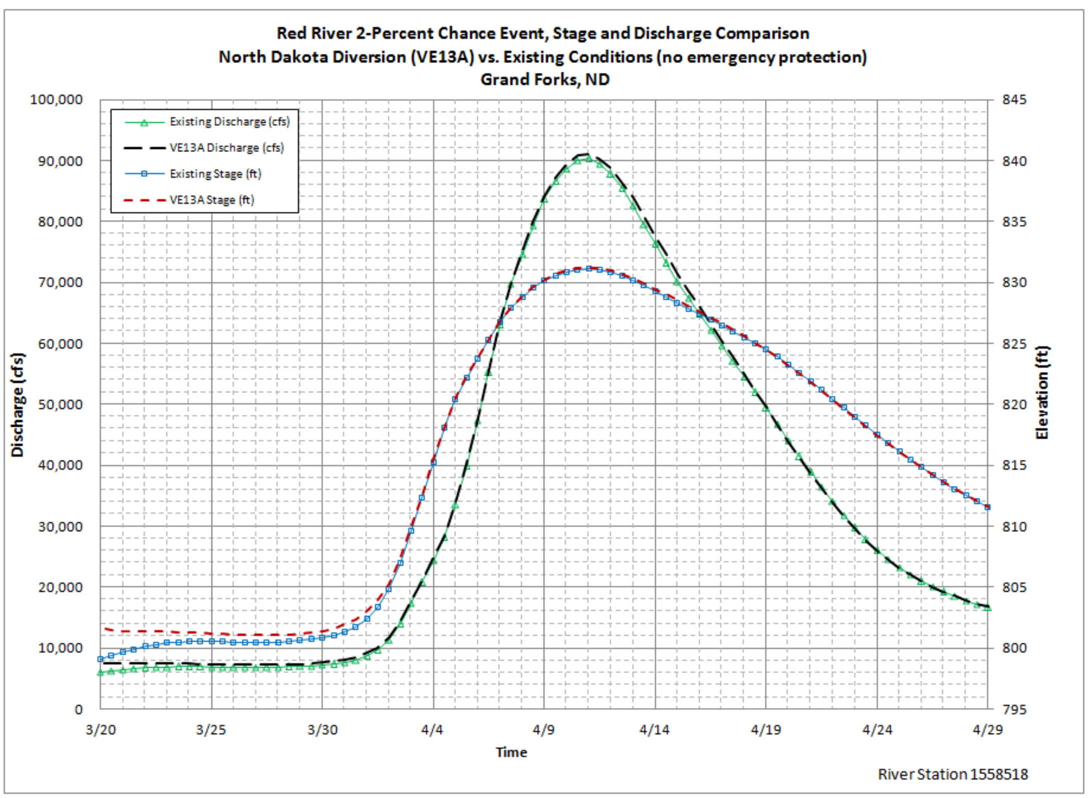

Figure 30 Stage and Flow Hydrographs on Red River at Grand Forks, Existing vs. With-Project for 2-Percent Chance Event

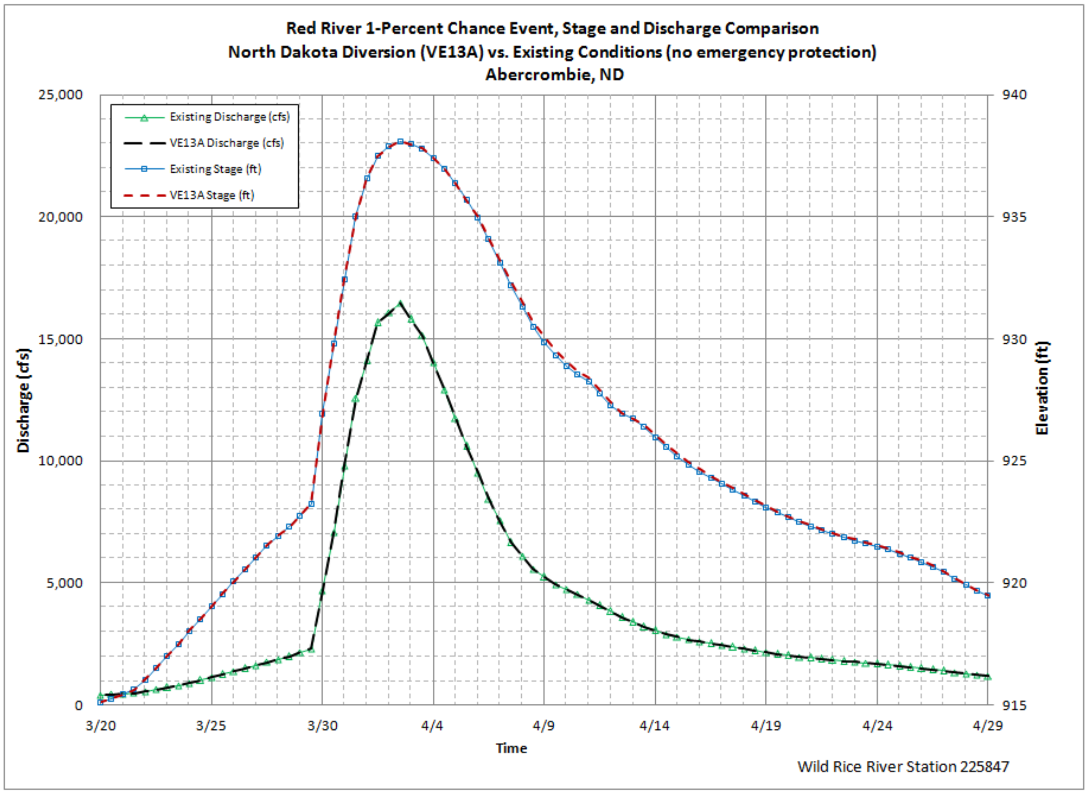

Figure 31 Stage and Flow Hydrographs Wild Rice River at Abercrombie, Existing vs. With-Project for 1-Percent Chance Event

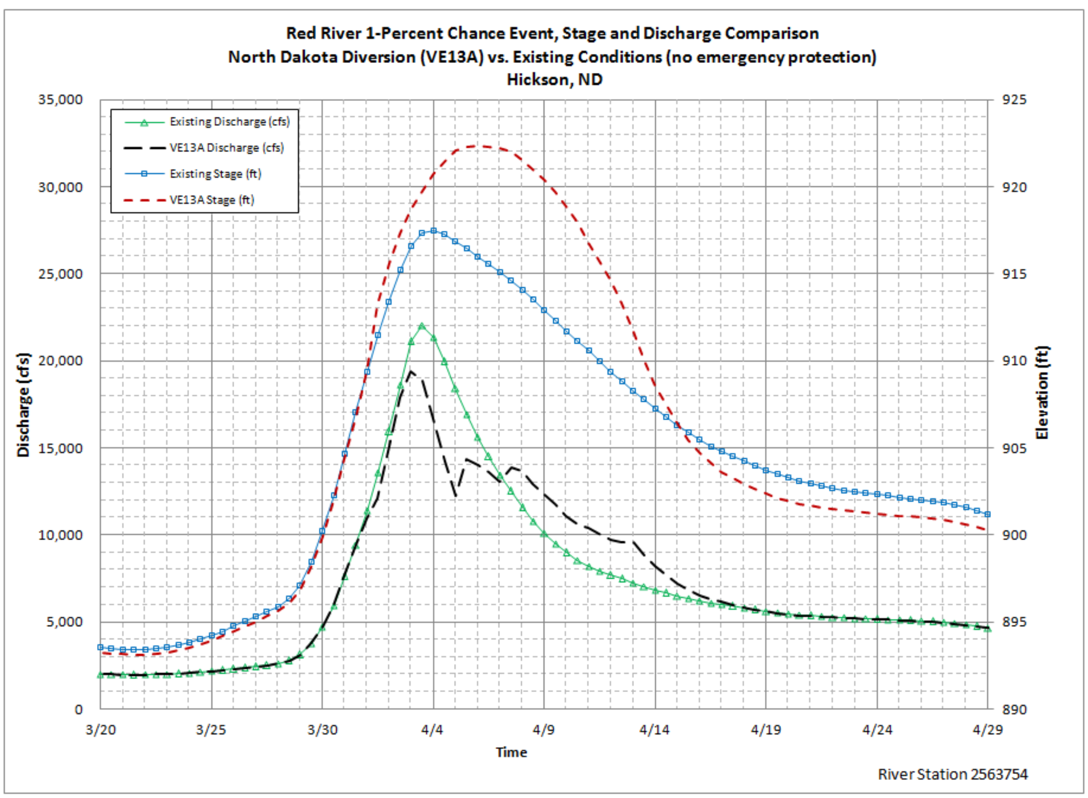

Figure 32 Stage and Flow Hydrographs on Red River at Hickson, Existing vs. With-Project for 1-Percent Chance Event

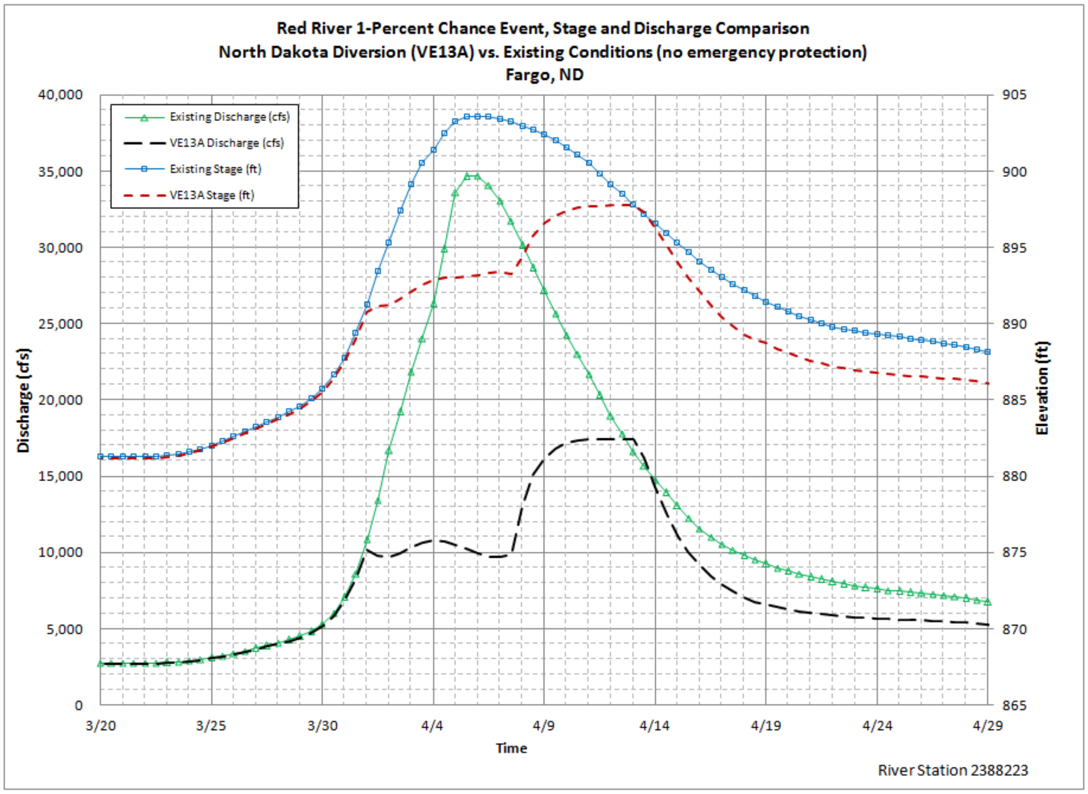

Figure 33 Stage and Flow Hydrographs on Red River at Fargo, Existing vs. With-Project for 1-Percent Chance Event

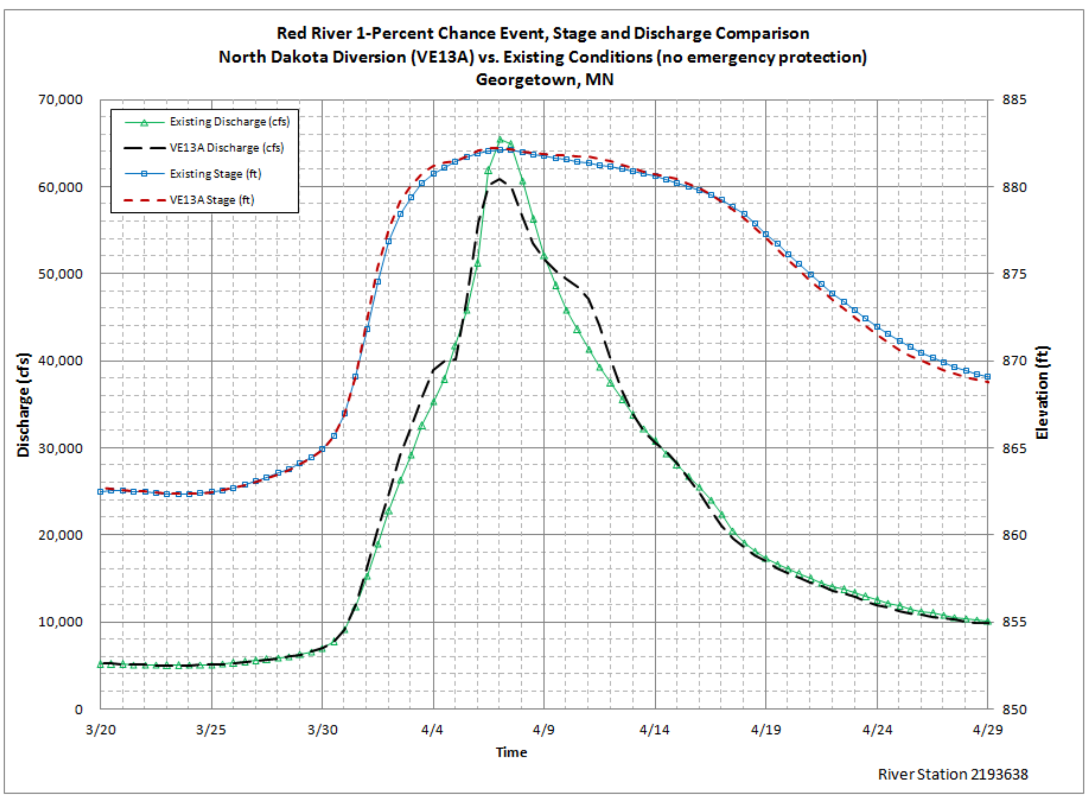

Figure 34 Stage and Flow Hydrographs on Red River at Georgetown, Existing vs. With-Project for 1-Percent Chance Event

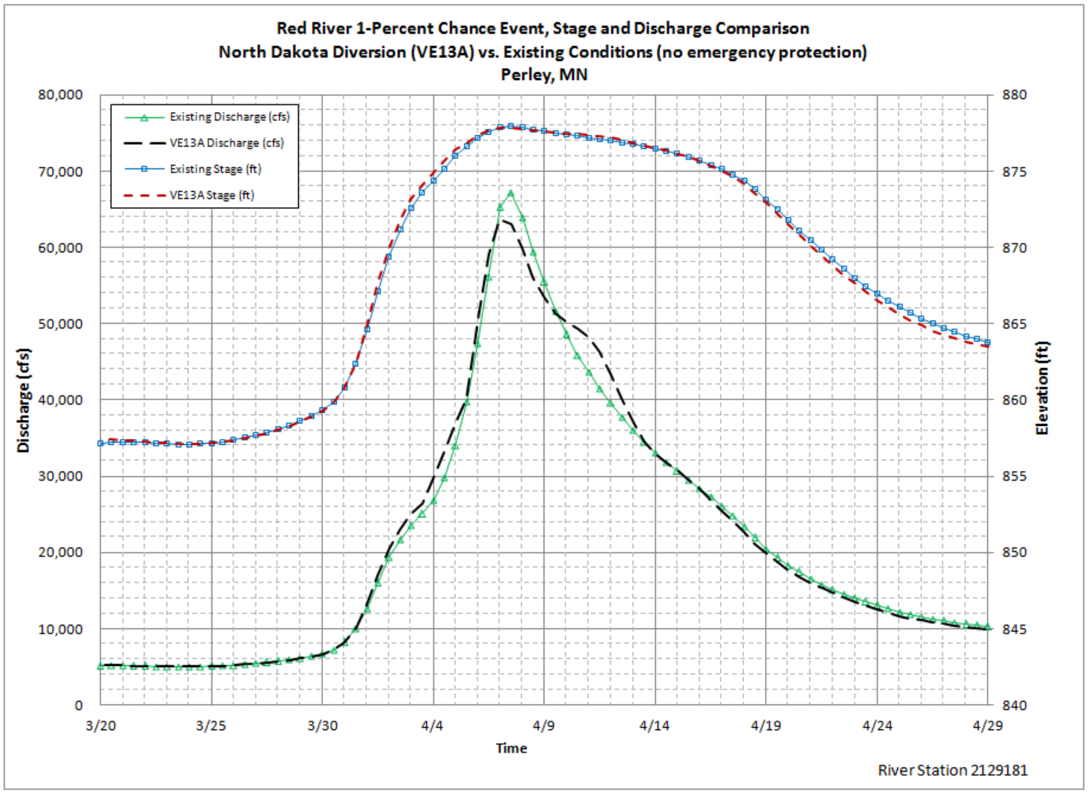

Figure 35 Stage and Flow Hydrographs on Red River at Perley, Existing vs. With-Project for 1-Percent Chance Event

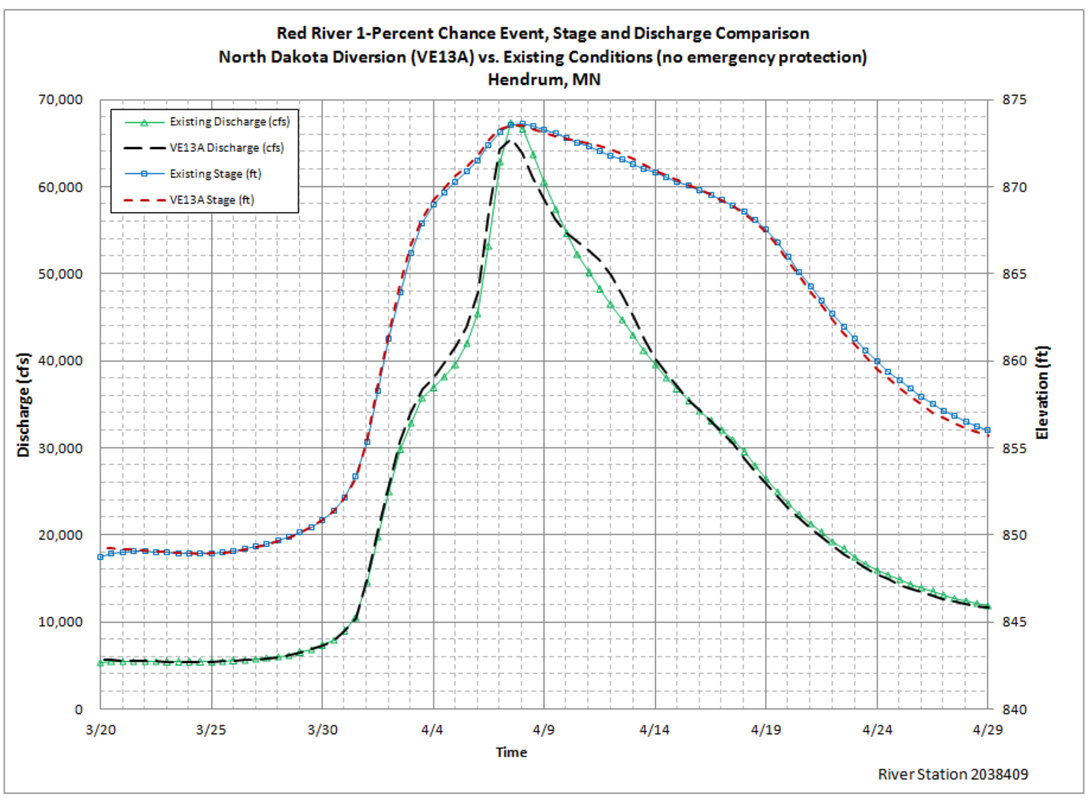

Figure 36 Stage and Flow Hydrographs on Red River at Hendrum, Existing vs. With-Project for 1-Percent Chance Event

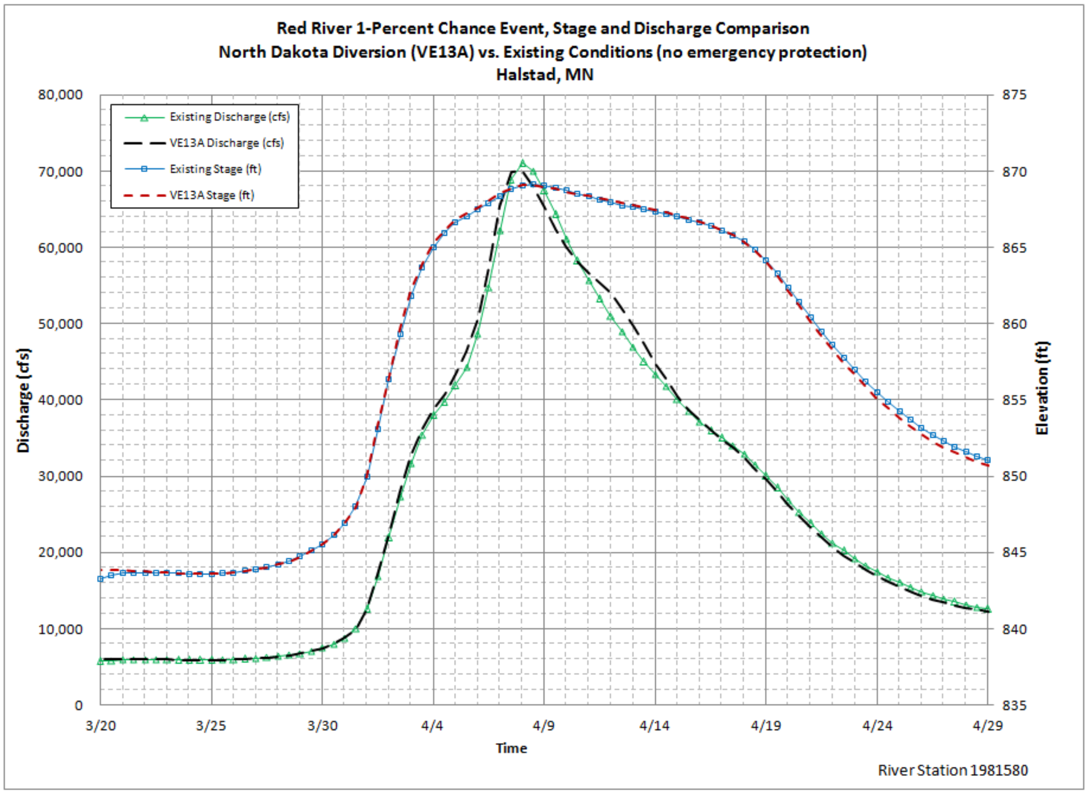

Figure 37 Stage and Flow Hydrographs on Red River at Halstad, Existing vs. With-Project for 1-Percent Chance Event

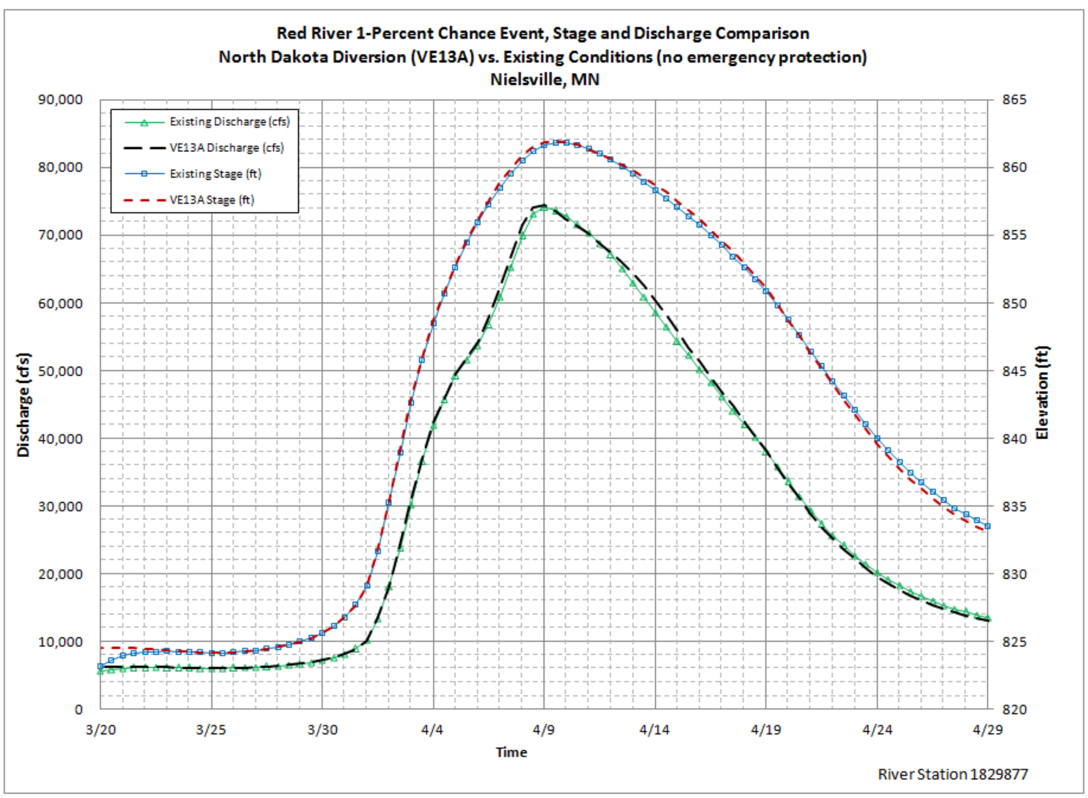

Figure 38 Stage and Flow Hydrographs on Red River at Nielsville, Existing vs. With-Project for 1-Percent Chance Event

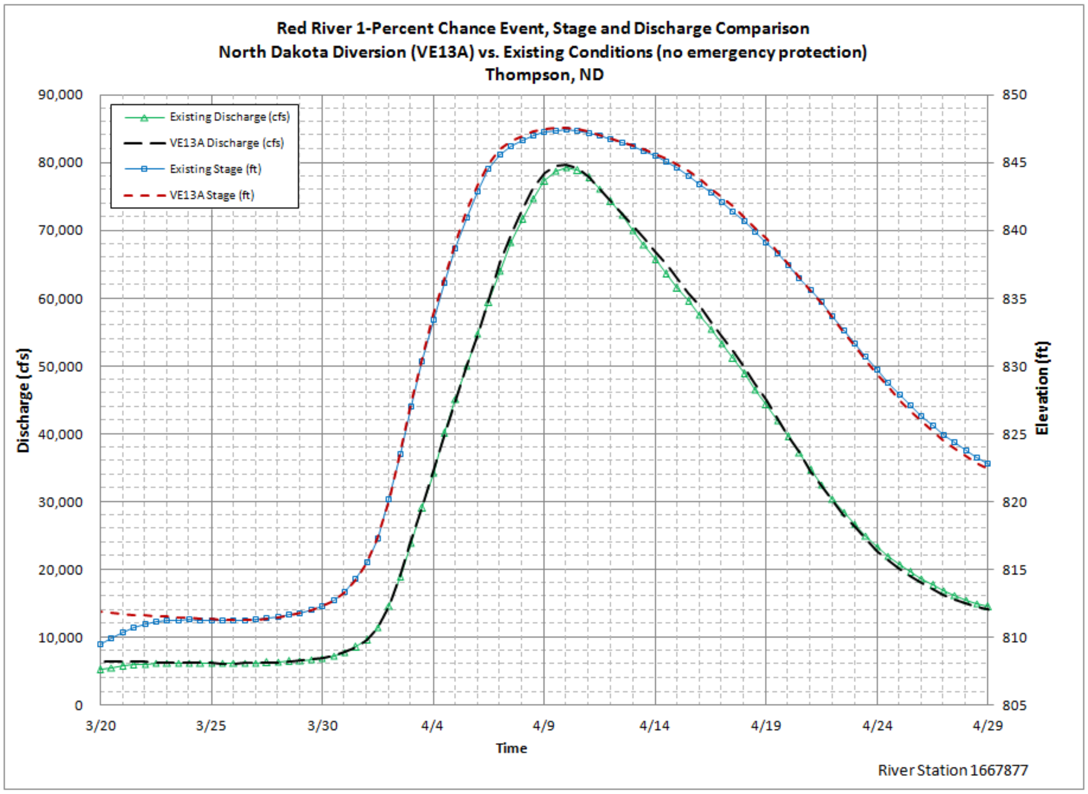

Figure 39 Stage and Flow Hydrographs on Red River at Thompson, Existing vs. With-Project for 1-Percent Chance Event

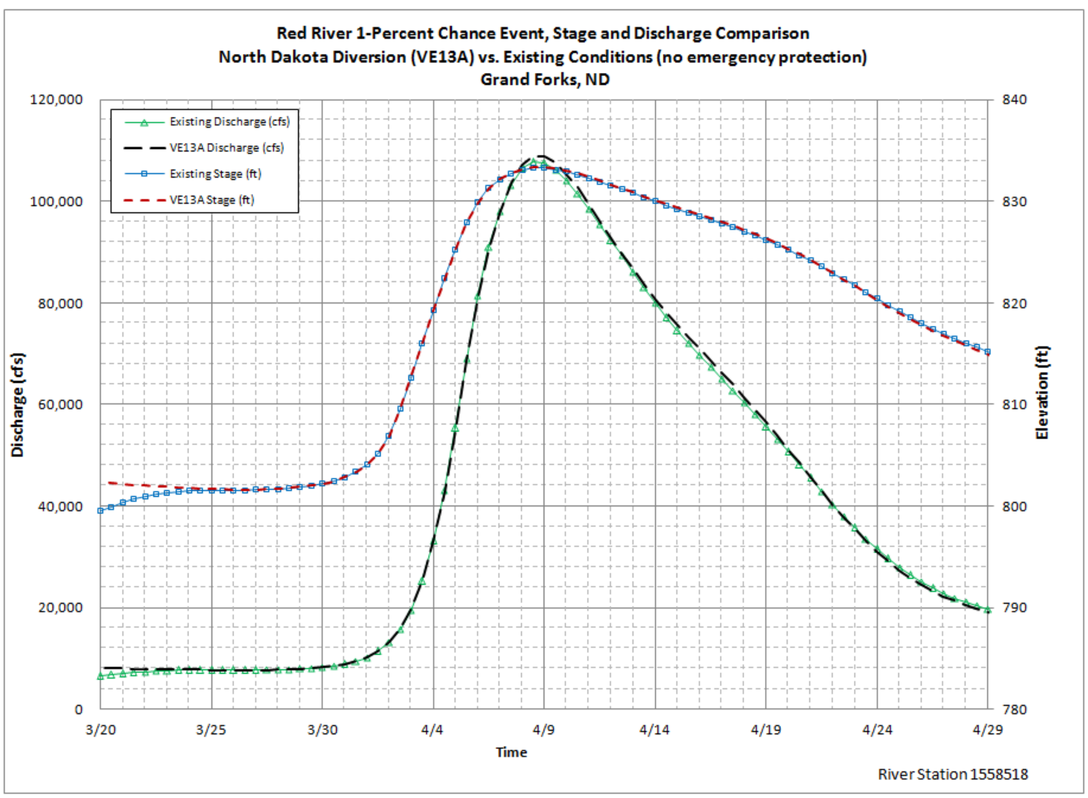

Figure 40 Stage and Flow Hydrographs on Red River at Grand Forks, Existing vs. With-Project for 1-Percent Chance Event

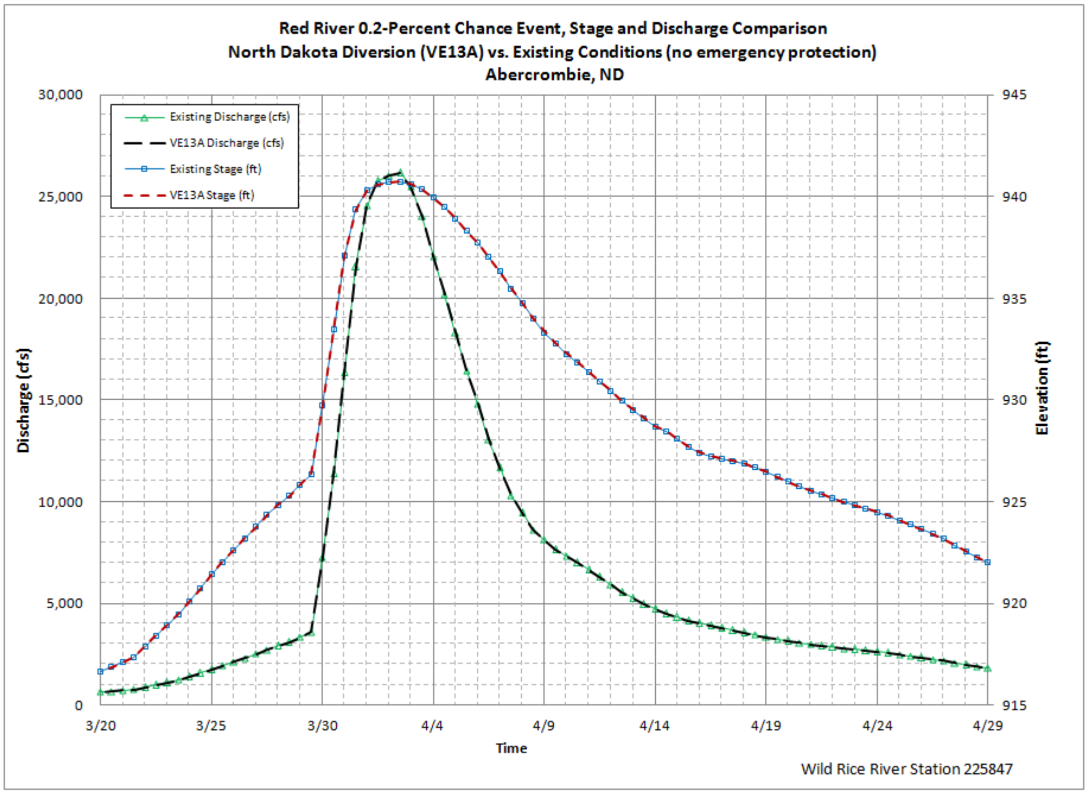

Figure 41 Stage and Flow Hydrographs Wild Rice River at Abercrombie, Existing vs. With-Project for 0.2-Percent Chance Event

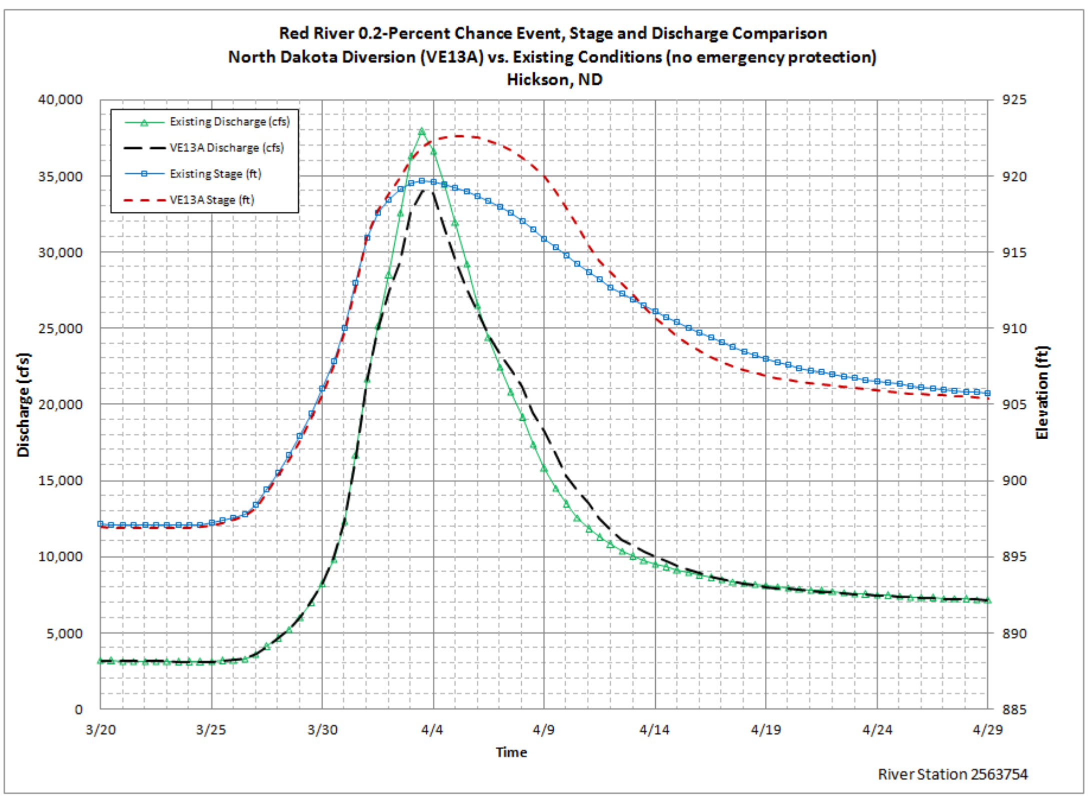

Figure 42 Stage and Flow Hydrographs on Red River at Hickson, Existing vs. With-Project for 0.2-Percent Chance Event

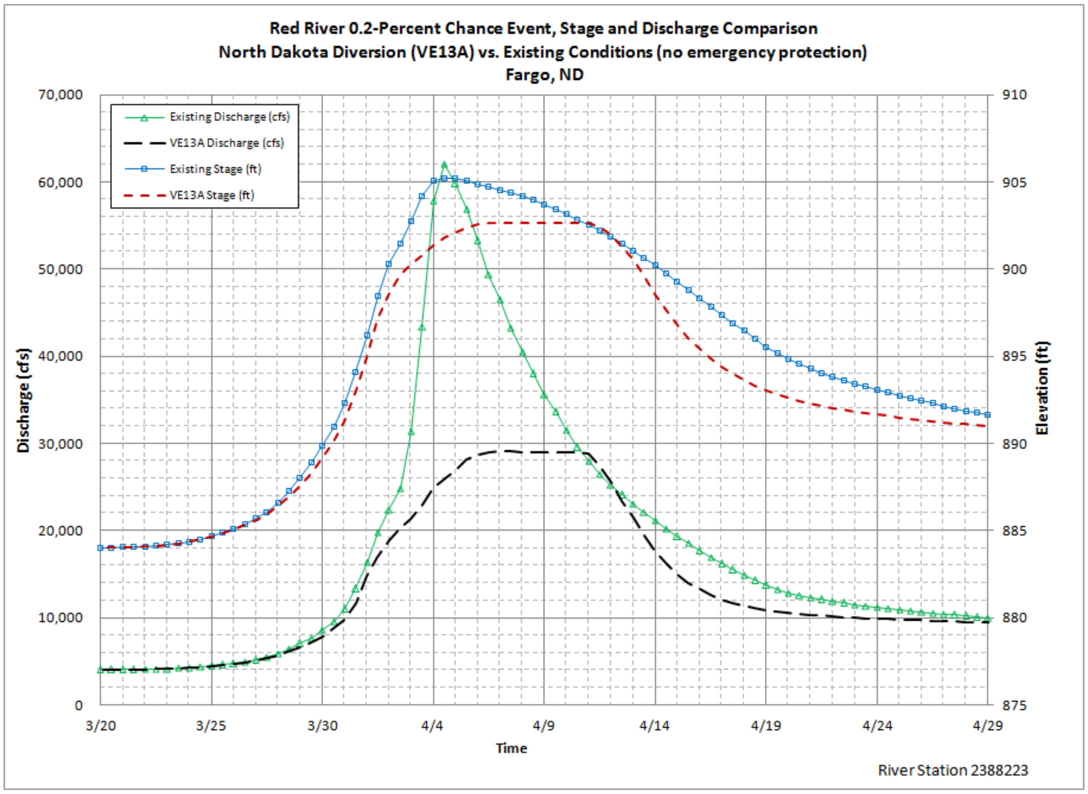

Figure 43 Stage and Flow Hydrographs on Red River at Fargo, Existing vs. With-Project for 0.2-Percent Chance Event

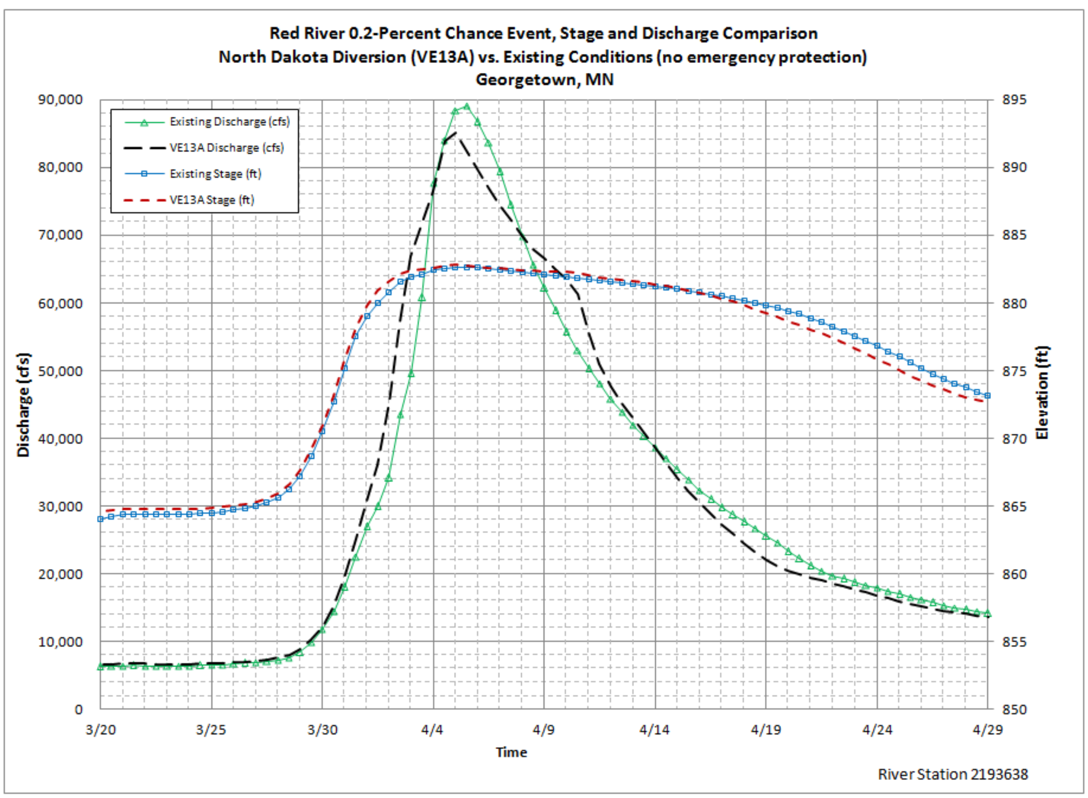

Figure 44 Stage and Flow Hydrographs on Red River at Georgetown, Existing vs. With-Project for 0.2-Percent Chance Event

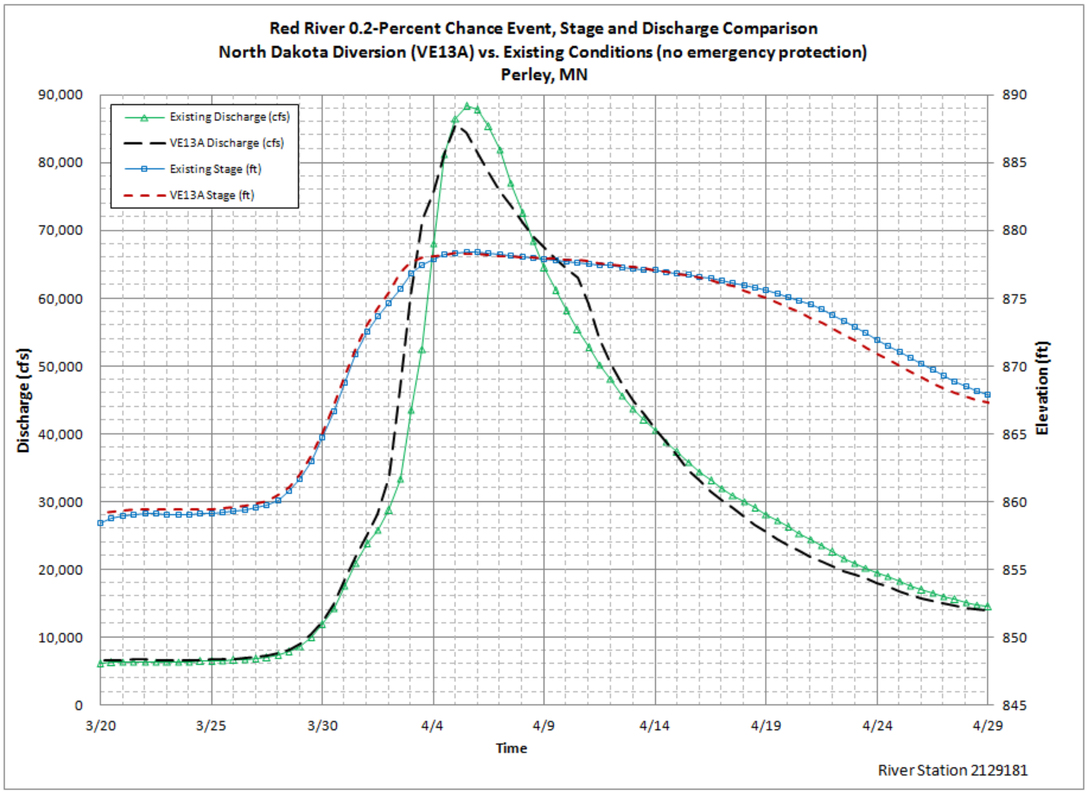

Figure 45 Stage and Flow Hydrographs on Red River at Perley, Existing vs. With-Project for 0.2-Percent Chance Event

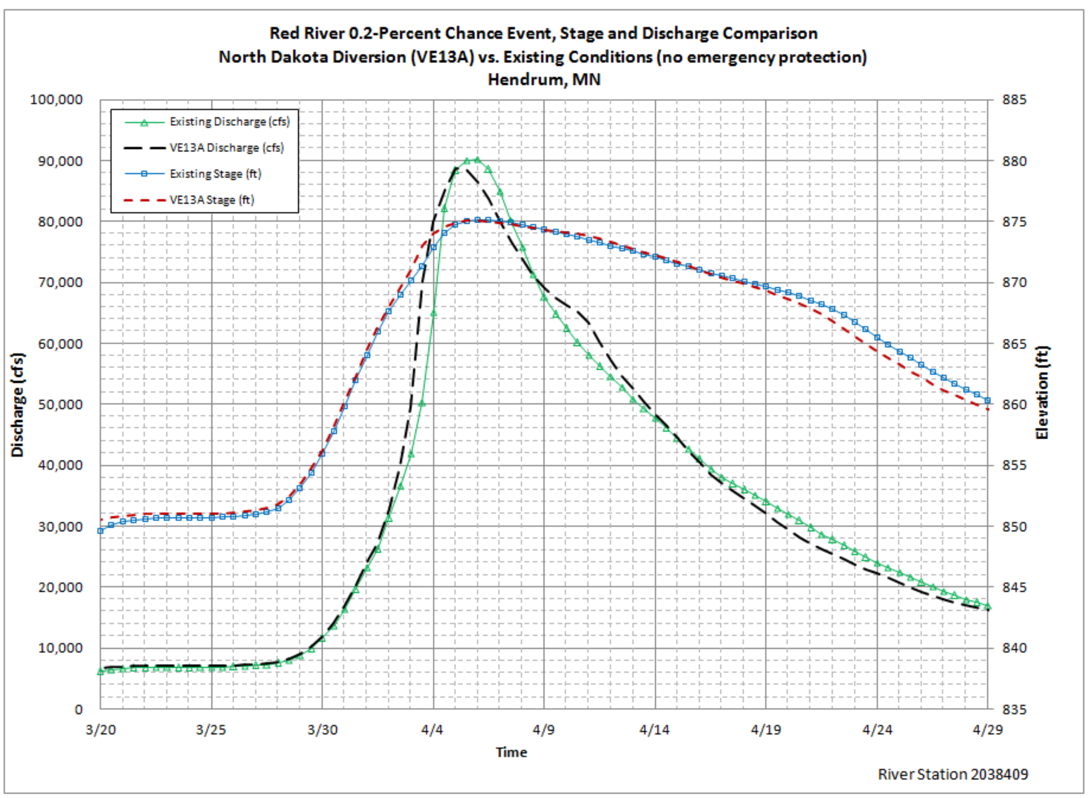

Figure 46 Stage and Flow Hydrographs on Red River at Hendrum, Existing vs. With-Project for 0.2-Percent Chance Event

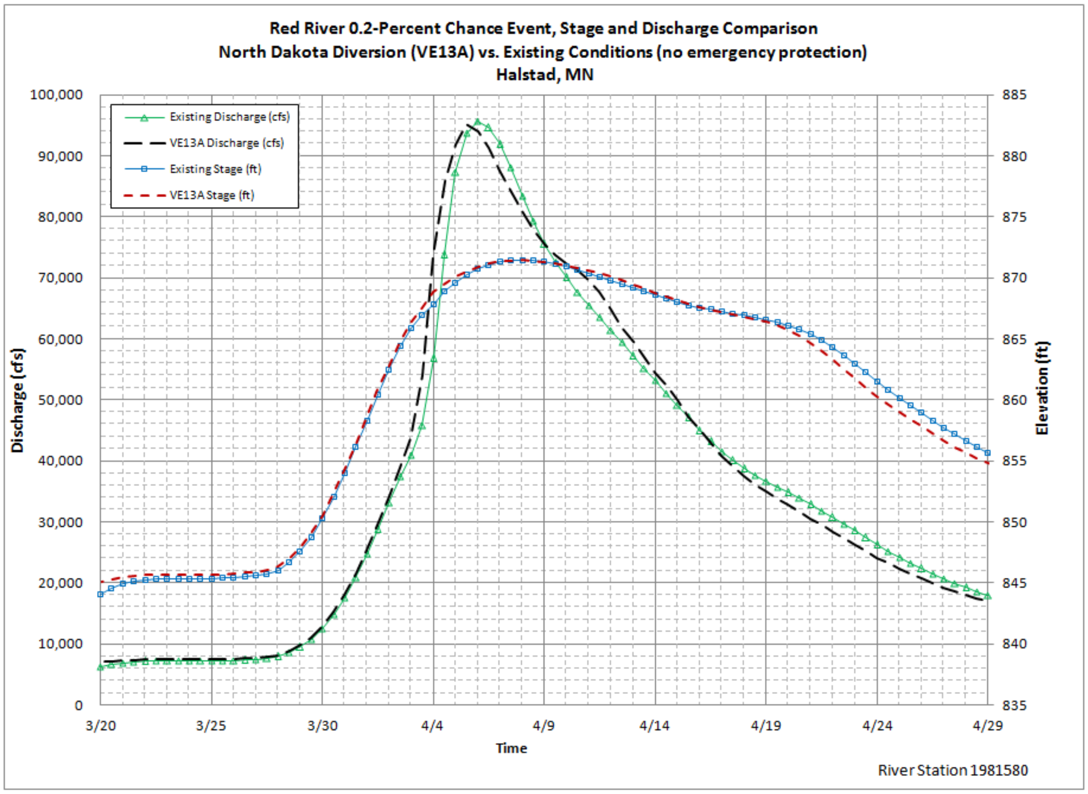

Figure 47 Stage and Flow Hydrographs on Red River at Halstad, Existing vs. With-Project for 0.2-Percent Chance Event

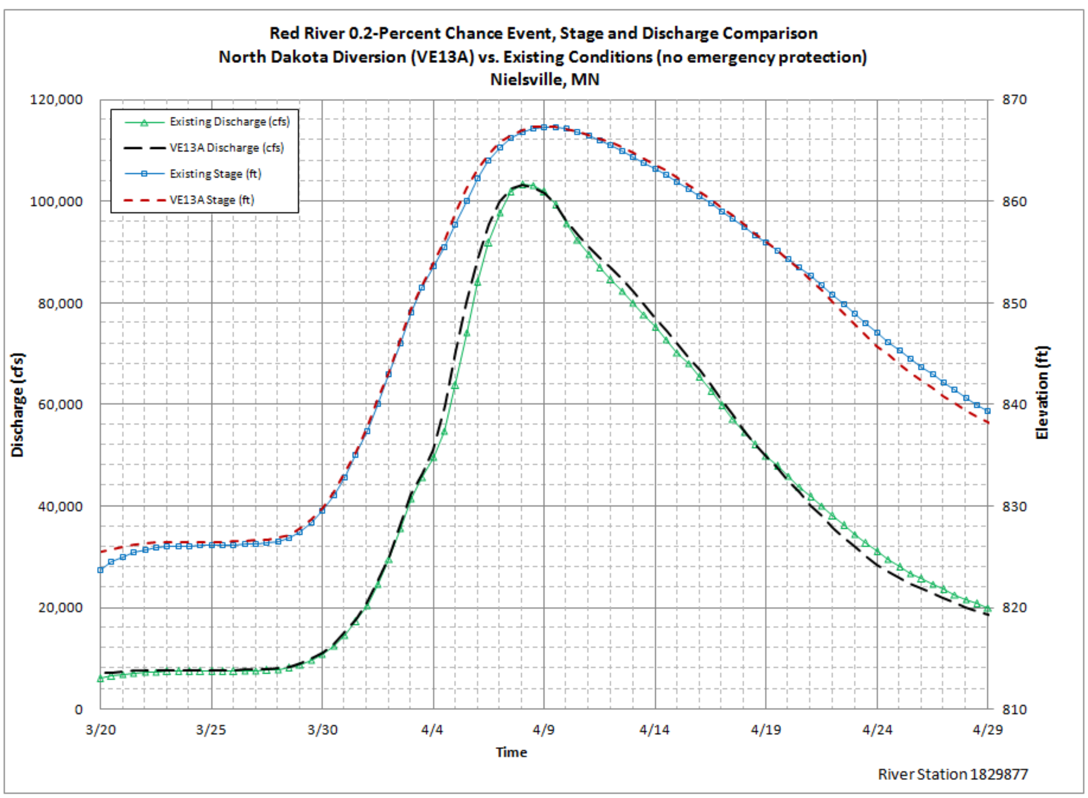

Figure 48 Stage and Flow Hydrographs on Red River at Nielsville, Existing vs. With-Project for 0.2-Percent Chance Event

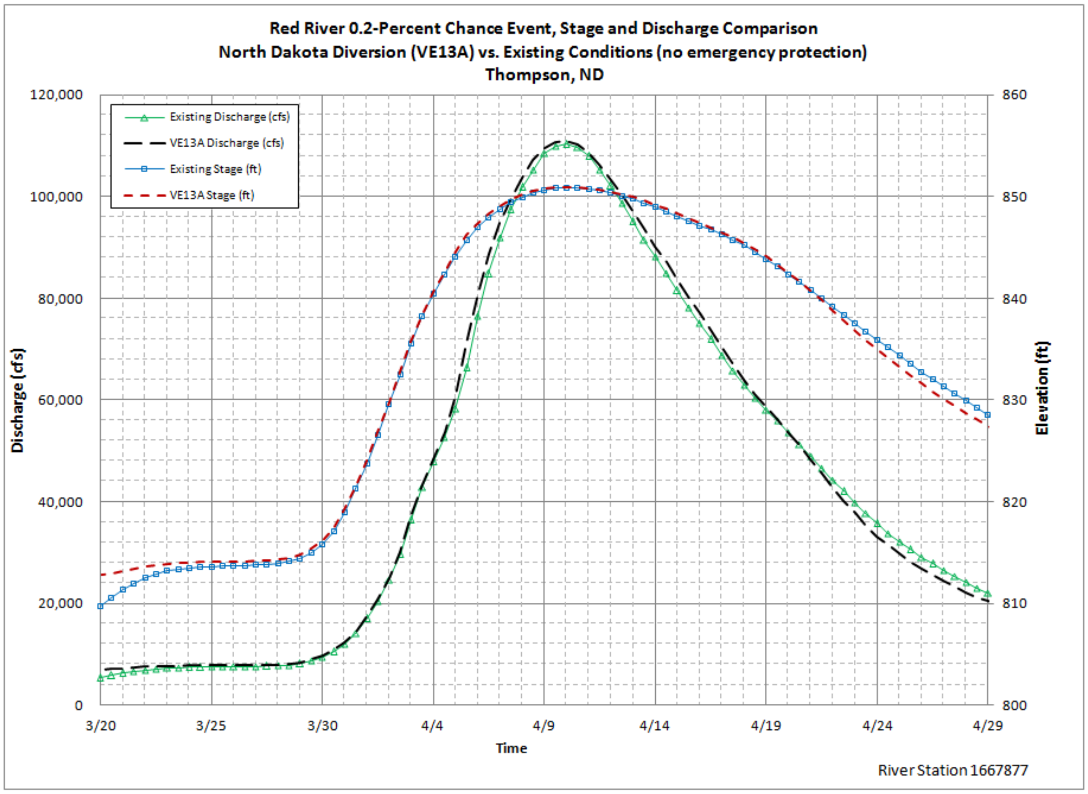

Figure 49 Stage and Flow Hydrographs on Red River at Thompson, Existing vs. With-Project for 0.2-Percent Chance Event

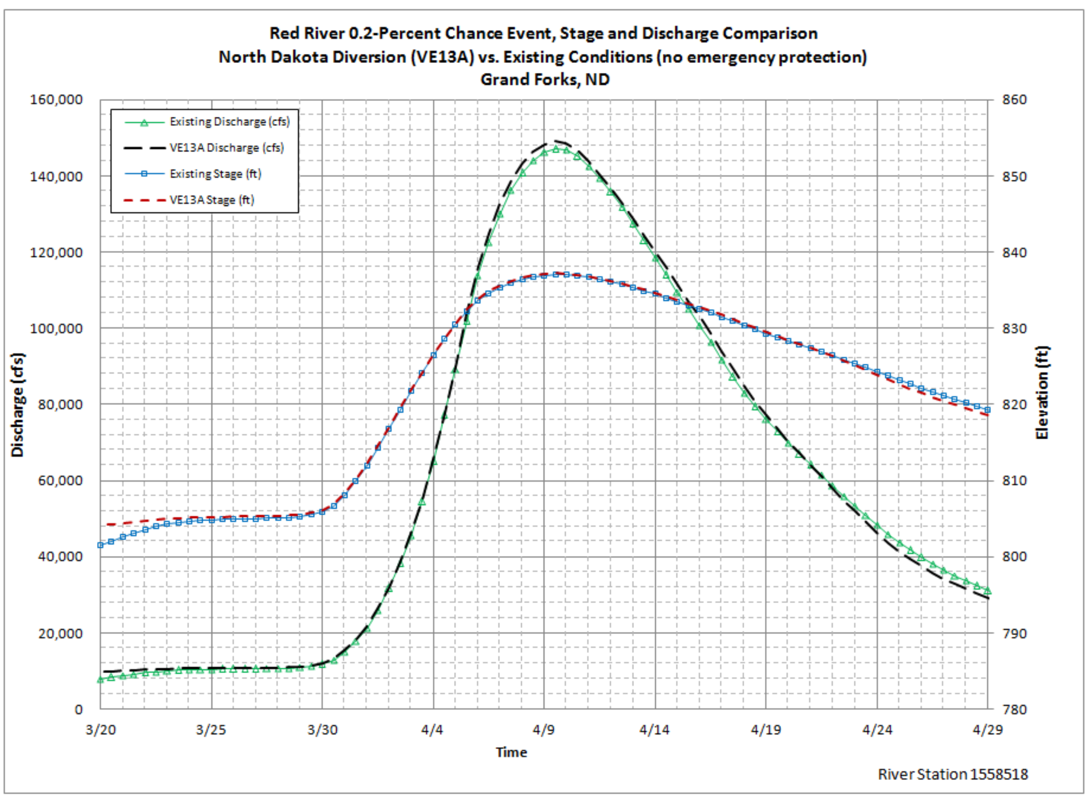

Figure 50 Stage and Flow Hydrographs on Red River at Grand Forks, Existing vs. With-Project for 0.2-Percent Chance Event