US Army Corps
of Engineers®

Papillion Creek and Tributaries Lakes, Nebraska

General Reevaluation Report

Appendix A. Hydrology

June 2021

Omaha District
Northwestern Division
Hydrologic Engineering Branch
Engineering Division

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Executive Summary

The purpose of this general reevaluation report (GRR) study was to model flood risk management alternatives in the Papillion Creek watershed. This main hydrology appendix documents hydrologic analyses completed for these evaluations. Existing hydrologic models were used to analyze steady-state conditions with existing conditions for the Tentatively Selected Plan (TSP) alternative screening and then to provide inputs for both existing and future conditions for modeling after TSP.

This appendix focuses on the feasibility level of design used to determine Federal interest. See Appendices A-1 and A-2 for the later National Economic Development (NED) plan modeling for Dam Sites 10 and 19 which refine the TSP designs.

This main hydrology appendix provides the following:

1. Peak flows for existing and future conditions. Flows included the 50-percent annual exceedance probability (AEP) to the 0.2-percent AEP for the existing and build-out future conditions land use. Build-out conditions are for the year 2040.
2. Peak flows for several proposed dam site alternatives for TSP screening to determine Federal interest. Proposed dams were modeled separately and as a system with existing conditions land use. Two dam sites (DS10 and DS19) were carried forward after economic analysis and modeled with future conditions for later unsteady hydraulic modeling.
3. TSP level dry dam versus "wet" dam top-of-dam comparisons. This analysis estimated the change in dam height with conversion of a wet dam to a dry dam. Wet dams have a permanent pool for storage and recreation while dry dams do not.
4. Check of channel modification alternative flows. This check ensured that the peak flows provided to the Hydraulics section for the channel modification alternative did not change significantly with channel modifications in the hydraulic modeling.
5. Update of two dam sites (DS10 and DS19) to current USACE standards for TSP. Modeling included both wet dam and dry dam designs. Existing information was used for TSP screening design as recommended by SMART planning. Additional modeling was completed for ADM and beyond with analysis specific to the dam sites.
6. Real estate pool estimates for land acquisitions for both wet dam and dry dam scenarios up to TSP. Pools considered were the probable maximum flood (PMF) pool and the normal pool for wet dams and the PMF max pool for dry dams. See Appendices A-1 and A-2 for updated values after TSP.
7. List of risks accepted in this screening-level analysis to meet SMART planning study budget and deadlines.
8. A climate change analysis completed in accordance with ECB 2018-14. Future Without Project Conditions could be significantly impacted by changes in climate at some indeterminate point in the future. However, at present there is no evidence within stream flow records observed at the project-site scale indicating climate change is causing flood peaks to increase.
9. Runoff hydrographs for input into the unsteady hydraulics model. Refer to Appendix B Hydraulics for additional information on this modeling.

Note that the flows for the existing, future, and dam scenarios in this report were provided to the Omaha District Hydraulics Section for the simulation of alternatives. However, changes were made to some peak flows by the Hydraulics Section based on engineering judgment. Therefore, the peak flows in this report may not accurately represent all the peak flows used in the hydraulic models. Refer to the Hydraulics appendix for details.

Full hydrographs were provided for the unsteady hydraulics modeling after TSP. These were produced by the same model used to provide peak flows leading up to TSP. Hydrologic modeling after TSP focused on providing runoff hydrographs for hydraulic modeling and refining the design of DS10 and DS19. These designs are addressed in detail in Appendices A-1 and A-2.

The project sponsor was the Papio-Missouri River Natural Resources District (NRD).

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1 Purpose

The purpose of this general reevaluation report (GRR) study was to model flood risk management alternatives in the Papillion Creek watershed to determine Federal interest. This Hydrology Appendix, and the additional appendices listed below, document hydrologic analyses completed for these evaluations. This main appendix (Appendix A) focuses on work, assumptions, and risks leading up to the determination of a Tentatively Selected Plan (TSP). A small section discusses the hydrology used for hydraulic unsteady flow modeling but work following the TSP milestone was mainly on the two dams documented in the appendices listed below.

- Appendix A-1. Dam Site 10 Hydrology
- Appendix A-2. Dam Site 19 Hydrology

The project sponsor was the Papio-Missouri River Natural Resources District (NRD).

2 Project Site

The project site is the 400 square mile Papillion Creek watershed in Douglas, Sarpy, and Washington Counties in Nebraska. The watershed includes four U.S. Army Corps of Engineers dams (Cunningham Lake, Standing Bear Lake, Zorinsky Lake, and Wehrspann Lake) and additional dams constructed by other government and private entities.

A Comprehensive Plan to reduce flood risks for the Papillion Creek Basin (Papillion Creek and Tributaries Lakes, Nebraska) was authorized in the Flood Control Act of 1968, which consisted of 21 dams for flood control, recreation, and water quality. After several delays, cost increases, and design criteria changes, only four of the original twenty-one dams were constructed as part of the Federal project, and the plan was updated in the 1980s to substitute some channel improvements and levees to address localized risks in specific reaches. The four dams and six levee systems that comprise the Federal project are operated by local sponsors, and the sponsors have subsequently continued to implement additional flood risk management through constructing four additional dams, several detention basins, and nine additional non-Federal levee systems.

Figure 1 shows the Papillion Creek watershed with existing dams, NRD proposed dams, and NRD dams under construction. Existing dams are indicated by call-outs while proposed dams are shown with point markers.

3 Vertical Datums

The vertical datums in this report vary due to the variety of sources from which elevations are referenced. Conversions from project datum (PD), National Geodetic Vertical Datum 1929 (NGVD29), and North American Vertical Datum 1988 (NAVD88) are also not consistent between all the sites. The Omaha Dam Safety section noted that PD does not equal NGVD29 for these sites.

To avoid confusion, elevations are kept in the vertical datums of their original sources and noted after the elevation (e.g., 1189 ft-PD, etc.). The following conversions were obtained from the Omaha Dam Safety section for the existing four USACE dams in the watershed. When elevations are considered at proposed sites, the vertical datum of the closest existing site is referenced from conversions.

Table 1. Vertical Datum Conversions

Site	Papio No.	Conversion
Cunningham Lake	11	NAVD88 = PD + 0.243 ft
Standing Bear Lake	16	NAVD88 = PD - 0.371 ft
Zorinsky Dam	18	NAVD88 = PD + 0.487 ft
Wehrspann Lake	20	NAVD88 = PD + 0.525 ft
Cunningham Lake	11	NGVD29 = NAVD88 - 0.404 ft
Standing Bear Lake	16	NGVD29 = NAVD88 - 0.404 ft
Zorinsky Dam	18	NGVD29 = NAVD88 - 0.358 ft
Wehrspann Lake	20	NGVD29 = NAVD88 - 0.344 ft

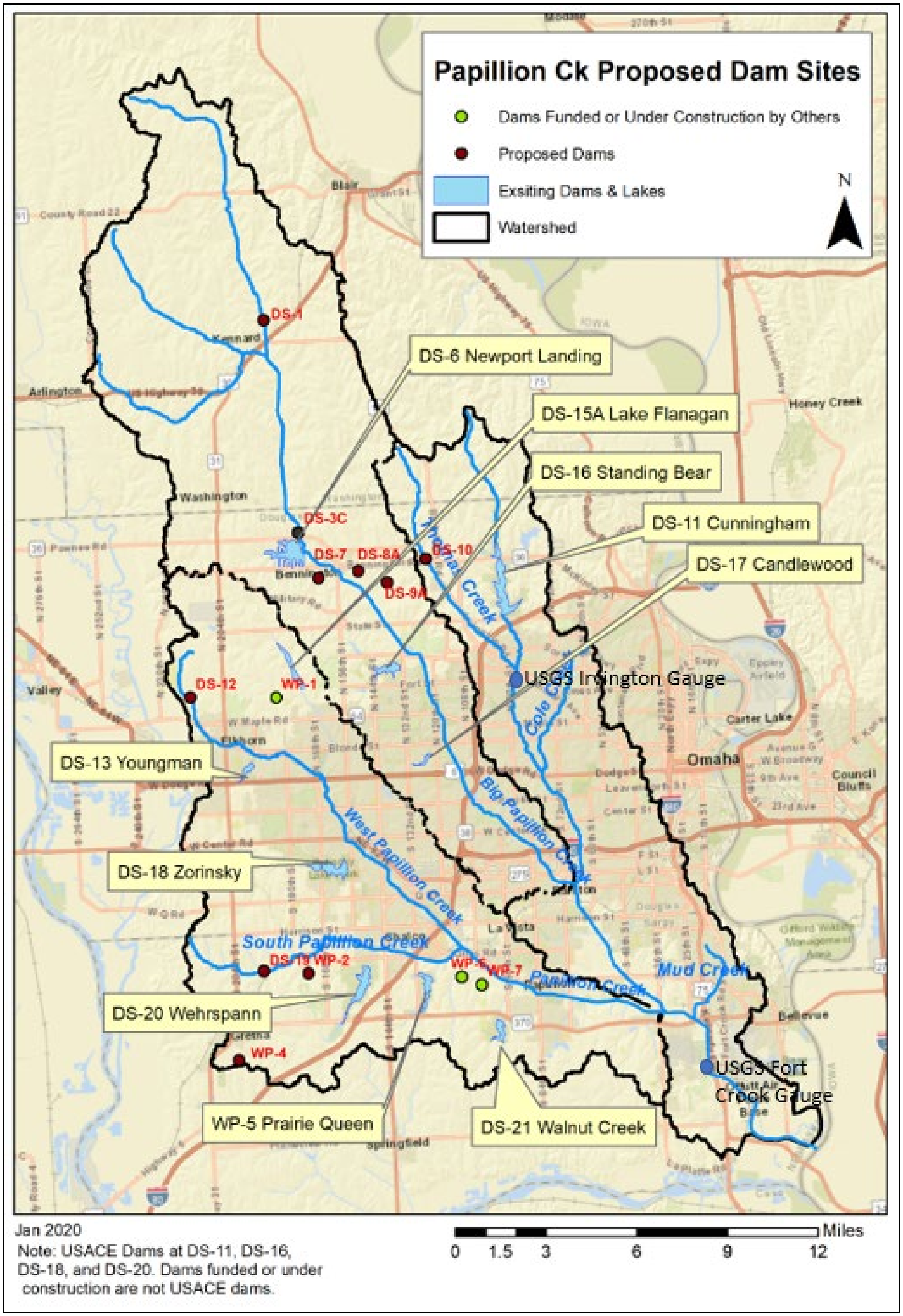


Figure 1. Papillion Creek Watershed

4 Past Studies

The following are a list of the most applicable past studies referenced for hydrologic modeling. Other studies were referenced as well but not all are listed.

- USACE 1975. Original design memorandum for Dam Site 10 (DS10). This was one of the dam sites identified in screening as having possible Federal interest. Existing information in the form of elevation-storage-discharge curves and design pool elevations for the Tentatively Selected Plan (TSP) analysis were referenced from this source. Note that these were later updated for the final NED plan designs which are discussed as part of Appendices A-1 and A-2.
- HDR 2004. This study screened potential combinations of dam sites in Washington County to determine their feasibility for flood protection in Omaha, NE. This was the reference used to help determine which dam site(s) in Washington County should be added to the screening analysis.
- USACE 2010. This study provided updated flows for the 10 percent through 0.2 percent annual exceedance probability (AEP) events to be used to update pervious floodplain mapping to reflect current land use, development, and stream characteristics. It was the main source of comparison between the pervious USACE studies and the updated 2018 FYRA. The ALERT gauge system was used for calibration, the percent imperviousness was used to reflect current conditions, and Clark unit hydrograph transforms were updated for three subbasins in the West Papillion reach to reflect more urbanized conditions.
- FYRA 2018. This study updated flows from the 10 percent through 0.2 percent AEP events for a floodplain mapping update. This study recalibrated the USACE 2010 model using radar rainfall data opposed to the ALERT gauge network data. This model was developed by the consultant FYRA. The model in the FYRA 2018 study was used in this Papillion GRR study.

5 Flood History

The following is a summary of the flood history in the Papillion Creek Basin. Significant events since the dams were constructed (in the last 1970s to early 1980s) were 1993 to the present. Note that while the June 1999 event is credited as the worst event since the 1964 flood, impacts were mainly localized to West Papillion Basin due to the location of the heaviest rainfall. The South and West Papillion Basins have measures included in the NED plan. These basins have not been heavily impacted by flooding since the construction of the four USACE dams, but they have the potential of being impacted, based on study results, in future events.

June 1943: During the night of June 2, 1943, approximately 9 to 10 inches of rain fell in the vicinity of Irvington, which is just outside the city limits of Omaha near the current site of Cunningham Reservoir. Flooding began in the upper reaches of the Little Papillion Creek about 12:45 a.m. and by morning the stream was back in its banks. Flooding occurred throughout the length of the creek with a maximum width of approximately 3,600 ft at the junction of the Big and Little Papillion Creeks. Water averaged about 3 to 4 feet deep on the floodplain. The estimated peak discharge on the Little Papillion Creek at Irvington was 12,500 cubic feet per second (cfs) and at the mouth was 9,000 cfs. Total damages within the basin were estimated at $200,000 and were mostly agricultural.

August 1959: Thunderstorms that caused the flood of August 2-3, 1959 stalled in Eastern Nebraska producing torrential rains that measured 12 inches in some places. In the Papillion Creek basin, 6.4 inches was reported at Bennington. Omaha Eppley Airfield reported 3.35 inches. Parts of the western sections of Omaha received more than six inches. Flooding began at Irvington around 9:00 a.m. when water flowed over a bridge. A one-square mile area located near the junction of the Little and Big Papillion Creeks and the area around Fort Crook (east of HWY 75 in Bellevue) were hit the hardest. Water flowed five feet deep on 66th Street for two blocks south of "Q" Street. Six business establishments were flooded Sunday morning in the town of Papillion. A motel area west of the Big Papillion Creek on Dodge Street was also hit hard. At Fort Crook, a recently constructed levee broke, flooding a farm area. Some peak discharges during this flood were 5,900 cfs at Irvington on the Little Papillion Creek, 22,500 cfs on the West Papillion Creek near Papillion, 10,900 cfs at 80th and "F" Streets on the Big Papillion, and 14,600 cfs at Fort Crook on the Papillion Creek. On Big Papillion Creek on August 3 at Irvington, discharges were noted as three-foot above flood stage and at Fort Crook, six foot above flood stage. West Papillion Creek had a 35-year flood with a discharge of 22,500 (NDNR, 2013). Total damages within the basin were estimated at $1,090,000.

June 1960: Local heavy rains fell in the vicinity of Omaha on June 20, 1960. The North Omaha Weather Station reported 4.32 inches, of which 3.70 inches fell between the hours of 3:00 a.m. and 5:00 a.m. Omaha Eppley Airfield reported 2.42 inches. The Little Papillion Creek crested at "L" Street at 9:00 a.m. and was back in its banks by 2:30 p.m. Some peak discharges during this flood were 15,300 cfs at Irvington on the Little Papillion Creek, 12,000 cfs near Papillion on the West Papillion Creek, 9,500 cfs at 80th and "F" Streets on the Big Papillion Creek, and 9,200 cfs at Fort Crook on Papillion Creek. Total damages within the basin were estimated at $671,000.

June 1964: On June 16th and 17th, 1964, seven people lost their lives and millions of dollars in personal property losses occurred. Ninety-five trailer homes were swept more than a half mile downstream by torrential flooding in the Millard area. During that storm, eight inches of rain falling for three hours on Hell Creek flowing down from Boys Town into the West Branch Papillion Creek created a roaring torrent of water 50 feet wide with waves five feet high. Approximately 4,500 acres of farmland were flooded near Big Papillion Creek and south of Dodge Street on the Big Papillion Creek, 108 homes and 34 businesses were flooded and an estimated $6M in damages occurred (Papio-NRD, 2019). Figure 2 shows the rainfall map (isohyetal map) for the June 1964 event.

September 1965: One of the worst and most damaging floods in the Papillion Creek watershed. During the late evening of September 6, 1965 and the early morning of the 7th, intense rain fell over the Papillion Creek basin. Bennington reported six inches of rain in a little over two hours, with a storm total of 8.90 inches. The North Omaha Weather Station reported 7.84 inches. Eppley Airfield reported 6.45 inches of which 3.13 inches fell in one hour and 5.18 inches fell in three hours. Waterloo reported 6.71 inches. The Little Papillion Creek crested between 5:00 a.m. and 7:00 a.m. and dropped below flood stage at "L" Street by noon. Some peak discharges were 6,500 cfs at Irvington on the Little Papillion Creek, 20,400 cfs near Papillion on the West Papillion Creek, 15,500 cfs at 80th and "F" Streets on the Big Papillion Creek, and 15,600 cfs at Fort Crook on the Papillion Creek. Total damages within the basin were estimated at $529,000. Almost the entire business district of Papillion was covered by water (Omaha World-Herald, 2017).

As a result of the serious flooding in 1964 and 1965, the USACE completed a study in 1967 calling for comprehensive flood risk management for the Metropolitan area that included the construction of reservoirs throughout the Papillion Creek Watershed.

Major floods and damages that occurred after the four main flood control reservoirs were constructed are not reported in the USACE Water Control Manual. Standing Bear Reservoir on the Big Papillion Creek was completed in 1974; Cunningham Reservoir on the Little Papillion Creek was completed in 1976; Wehrspann Reservoir on the South Papillion Creek in the West Papillion watershed was completed in 1982; and Zorinsky Reservoir on the West Papillion Creek was completed in 1989. After the four reservoirs were constructed, the largest stream flows occurred in 1993, 1997, 1999, and 2008.

July 1993: Credited as the worst flood since the 1964 event (Omaha World-Herald, 2017). A two-system thunderstorm produced 5.5 inches of rainfall in a 2-hour period near Papillion, NE. Wettest June since 1967. Rainfall was focused on the West Papillion watershed and resulted in out of bank flows in places along West Papillion. A channel that typically had a 3-foot stage crested around 20 feet (Omaha World-Herald, 2017). At the time this was assigned a 0.4 percent annual change exceedance (on average a 25-year event). Some peak discharges from July 22, 1993 were 800 cfs at Irvington on Little Papillion Creek, 4,100 cfs at 125th & Fort Streets on Big Papillion Creek, and 10,800 cfs at Fort Crook on Papillion Creek. Flood damages were recorded in the Big Papillion Creek watershed from consistent, heavy downpours, with many homeowners reporting bowing and collapsed foundations (City of Omaha, n.d.). Most damage was to the south bank of the West Papillion Creek. Flood waters spilled across 84th and 72nd Streets and were closed by officials (Omaha World-Herald, 2017).

September 1997: Some peak discharges from September 2, 1997 were 1,500 cfs at Irvington on Little Papillion Creek, 7,300 cfs at 125th & Fort Streets on Big Papillion Creek, and 13,000 cfs at Fort Crook on Papillion Creek.

August 1999: Ten and a half inches of rain fell within less than 24 hours August 6-7, 1999, causing flash flooding along Big Papillion Creek resulting in one fatality and overburdening of sewers. Some peak discharges from August 6, 1999 were 8,400 cfs at Irvington on Little Papillion Creek, 17,700 cfs at 125th & Fort Streets on Big Papillion Creek, and 23,200 cfs at Fort Crook on Papillion Creek. Some basements filled with chest-deep water and flooding damaged more than 1,000 homes (Omaha World-Herald, 2014). Flooding from this event was estimated to result in approximately $11 million in property damages (flood damage source: https://planning.cityofomaha.org/images/stories/floodplain%20documents/5_Douglas_County_Appendix_Feb_2016.pdf p.64).

June 2008: Some peak discharges from June 11th and 12th 2008 were 3,600 cfs at Irvington on Little Papillion Creek, 4,300 cfs at 125th & Fort Streets on Big Papillion Creek, and 24,800 cfs at Fort Crook on Papillion Creek. According to the USACE annual flood damage prevented estimate, there were an estimated $238,000 in flood damages. (USACE annual flood damages prevented provides a damage estimate based on best available USACE data and has not been verified with actual damages reported.)

June 2014: A torrential downpour resulted in flooding on the Big Papillion Creek, causing one fatality in Bellevue when rushing water swept away a 29-year-old man who left his vehicle after it went into a drainage ditch (Omaha World-Herald, 2014). Channels in parts of the basin were at capacity. Up to 5-feet of flooding was reported at Fun-Plex amusement park near 70th and Q Streets. Millard Airport near 132nd and Q Street recorded 6.83 inches in 24 hours and Offutt Airforce Base recorded 3.95 inches (Omaha World-Herald, 2014). According to the USACE annual flood damage prevented estimate, there were an estimated $320,000 in flood damages. (USACE annual flood damages prevented provides a damage estimate based on best available USACE data and has not been verified with actual damages reported.)

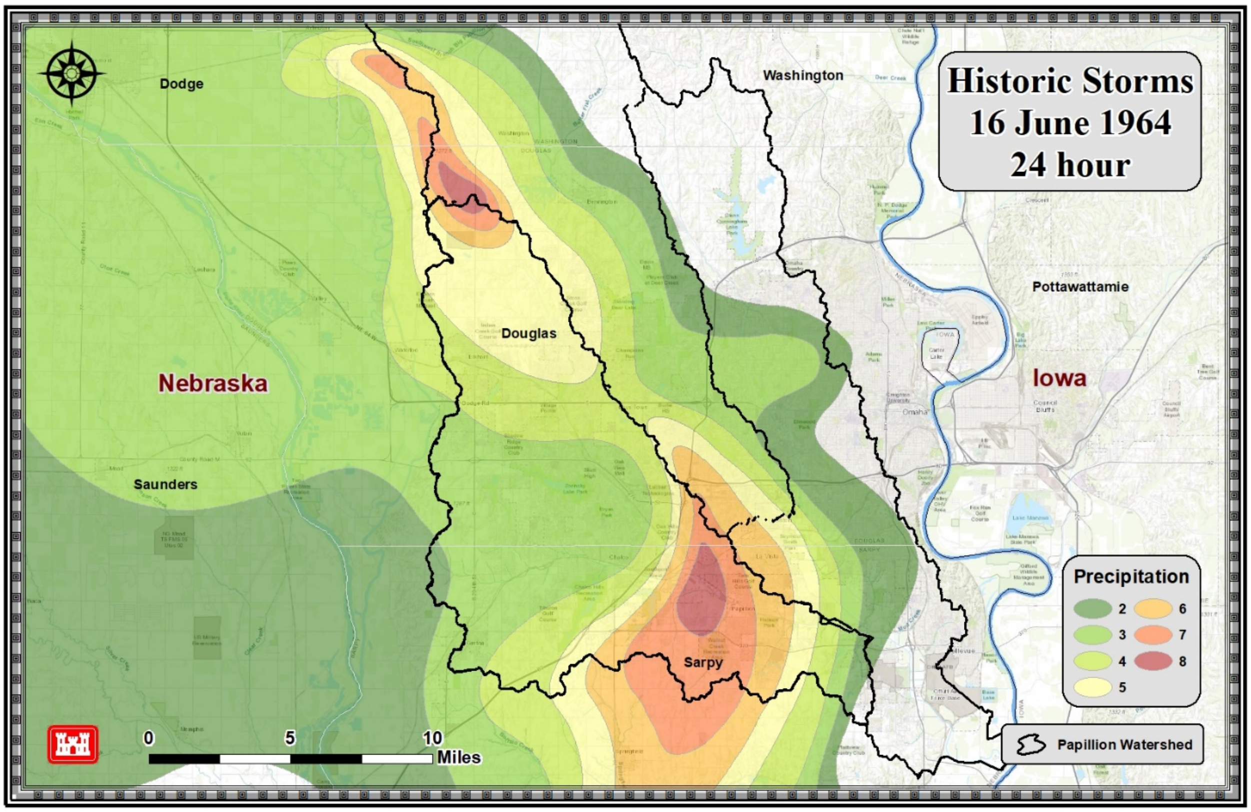


Figure 2. Historic June 1964 Isohyetal Map

6 Data and Models Provided

A series of hydrologic models were provided by the NRD and two reports dated June 2017 and October 2018. Hydrologic models provided were dated March 2017 and September 2018. The existing and future HMS models dated September 2018 and the FYRA report dated October 2018 were used in this study. The difference between the March 2017 and September 2018 HMS models was not known by the Sponsor (both contained the same dams) but the September 2018 model was used in the FEMA Flood Insurance Study (FIS) so it was the model that provided inputs in this study.

7 Hydrologic Model

Two Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS) models, one for existing conditions and one for future build-out conditions (year 2040), were provided by the NRD. These models included 295 subbasins with an average drainage area of 1.34 square miles and nineteen dams, including dams WP-6 and WP-7 on the West Papillion. The dam site WP-1 was added to both the existing and future conditions models because funding had been obtained for its construction.

Table 2 lists the dams in the hydrologic model organized by drainage area.

The HEC-HMS version 4.2 model used the screening of dam sites for TSP is shown in Figure 3. The original model was developed by WEST for the 2010 USACE study and then modified by FYRA for their 2018 study.

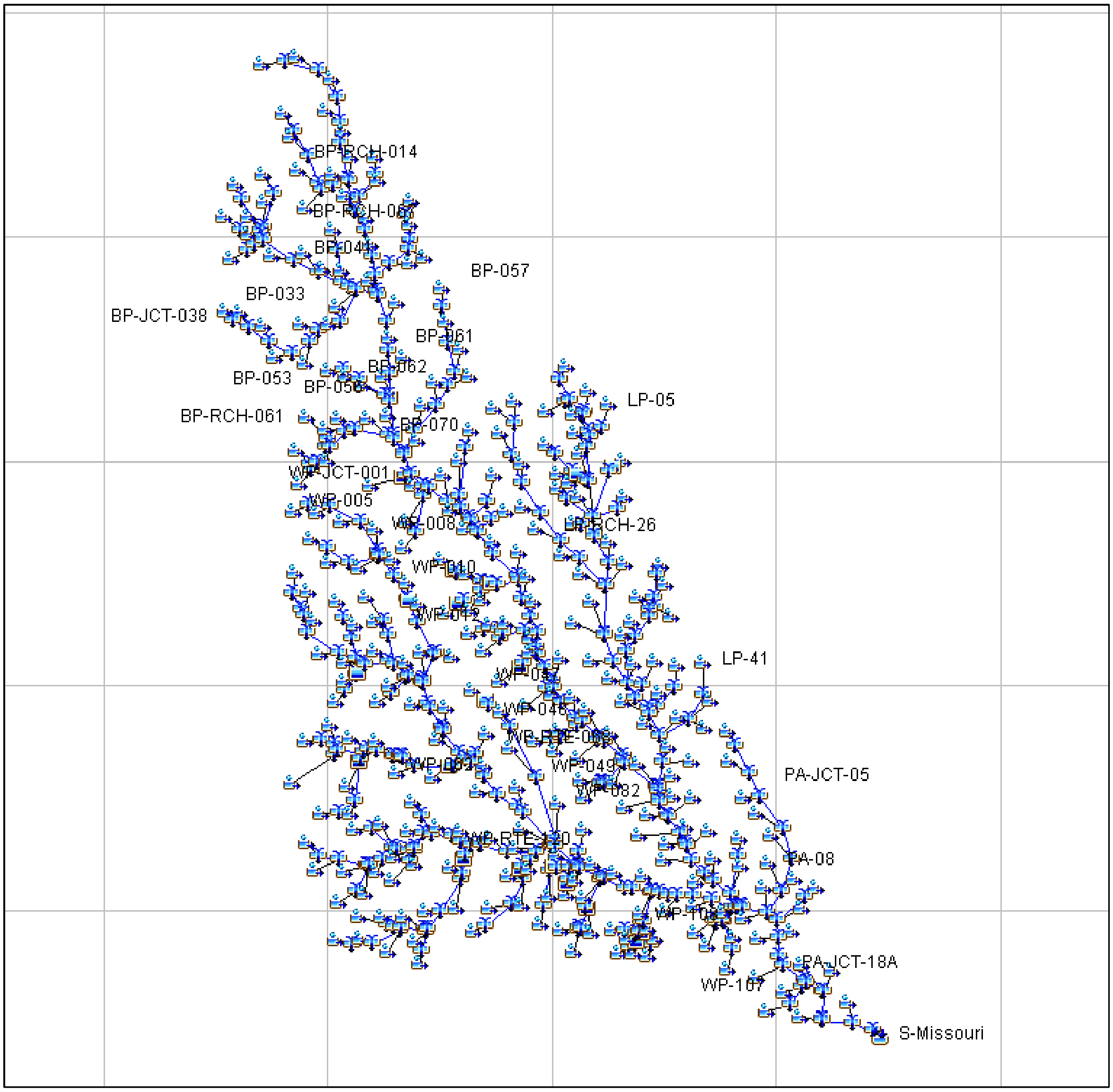


Figure 3. Papillion Creek HMS Model

Table 2. Dams in HMS Models

Dam Site	Drainage Area (sq mi)	Embankment Construction Complete	Nearest Main River Reach
Lake Cunningham (Papio No. 11)	17.8	1974	Little Papillion
Zorinsky Lake (Papio No. 18)	16.4	1984	West Papillion
Wehrspann Lake (Papio No. 20)	13.2	1982	South Papillion
Res D-4 (Upstream of Cunningham)	11.5	1974	Little Papillion
Lake Flanagan (DS No. 15A)	11.1	2018	West Papillion
Standing Bear Lake (Papio No. 16)	6.0	1972	Big Papillion
Prairie Queen Lake (WP-5)	5.2	2015	Papillion Creek
Newport Landing Lake (DS No. 6)	4.6	2000	Big Papillion
Walnut Creek Lake (DS No. 21)	3.3	1998	Papillion Creek
Shadow Lake	2.3	2007	Papillion Creek
Res D-17 (Upstream of Standing Bear)	2.2	1972	Big Papillion
Lake Candlewood	2.2	1973	Big Papillion
Youngman Lake (DS No. 13)	2.0	2006	West Papillion
WP-6	2.0	To be Constructed	Papillion Creek
Res D-18 (Upstream of Standing Bear)	1.7	1972	Big Papillion
WP-1	1.4	To be Constructed	West Papillion
Midlands Lake	0.9	Unknown	Papillion Creek
Longergan	0.9	Unknown	Little Papillion
Boys Town Dam No. 1	0.8	Unknown	West Papillion

8 Existing Conditions

8.1 Method

The existing conditions percent imperviousness was updated in the FYRA modeling to 2013 conditions (FYRA, 2018). Updates were based on changes seen between 2007 and 2013 in aerial photography. The watersheds modified are shown in Figure 4.

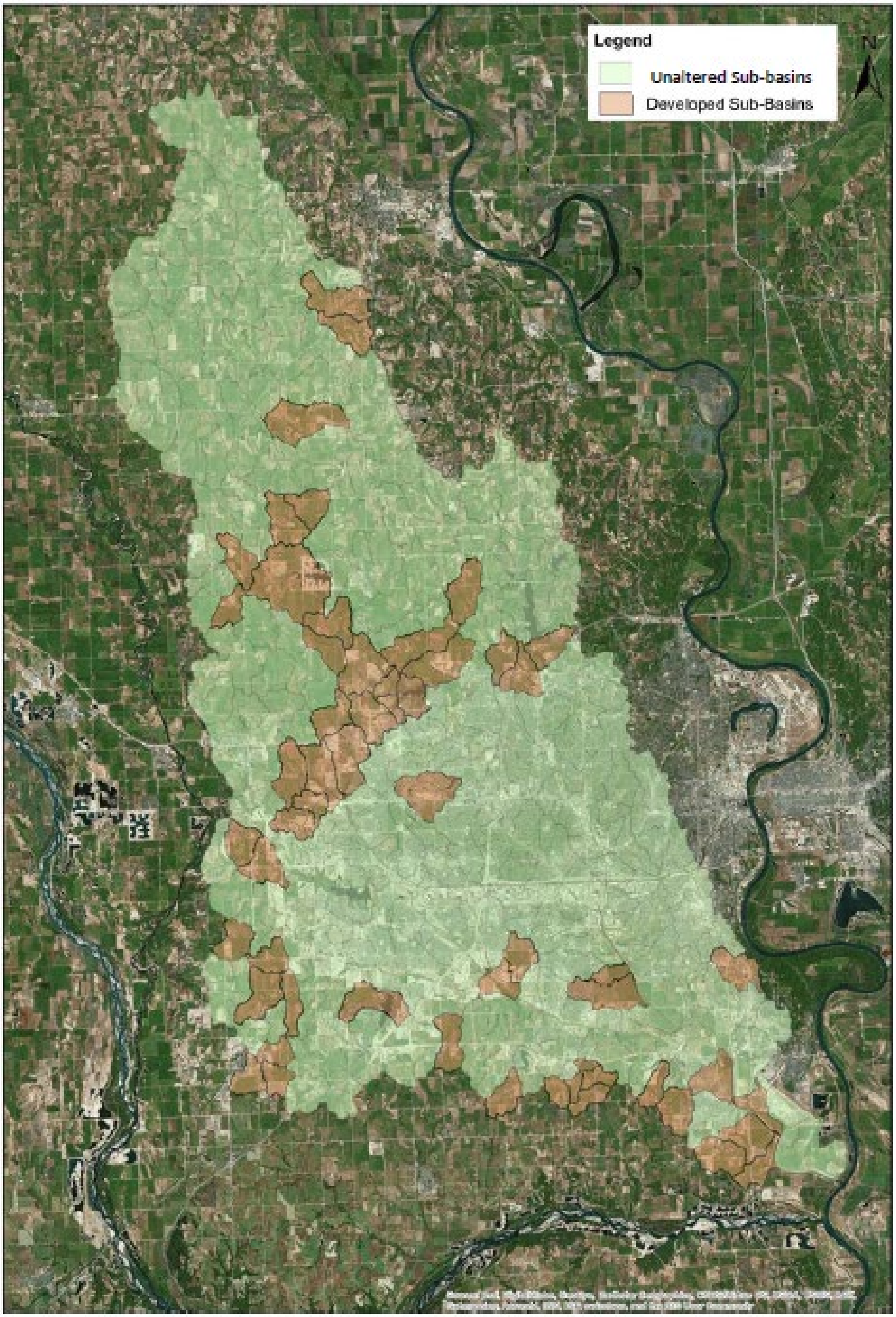


Figure 4. Land Development Between 2007 and 2013 (FYRA, 2018)

8.2 Existing Conditions Results

Figure 5 through Figure 11 summarize the existing conditions peak flow results for Papillion Creek by reach. Figure 11 shows the watershed with these requested flow extents indicated by different colors of stars. Tabular results are shown in Appendix AA. These peak flows were provided to the Omaha District Hydraulics Section for steady-state hydraulic modeling for TSP screening of dam site alternatives. Note that the existing conditions modeling includes dam sites WP-6 and WP-7, which are currently under construction, and WP-1 which has funding for construction obtained. Peak flows for the 10 percent through 0.2 percent annual exceedance probability (AEP) events were determined from the HMS model while other flows were interpolated or extrapolated.

Note that it was found that many of the peak flows from the FYRA model decrease with downstream distance which is counterintuitive as additional drainage area is added. Therefore, additional sensitivity testing was undertaken to determine what flows should be used in the HEC-RAS modeling.

Therefore, while the peak flows presented here were provided for the hydraulics modeling, many that showed attenuation were likely not used in the HEC-RAS modeling but modified with engineering judgment. Refer to the Hydraulics appendix (Appendix B) for more information.

The hydrology models that produced these peak flows were also used to produce the hydrographs for unsteady flow modeling after TSP.

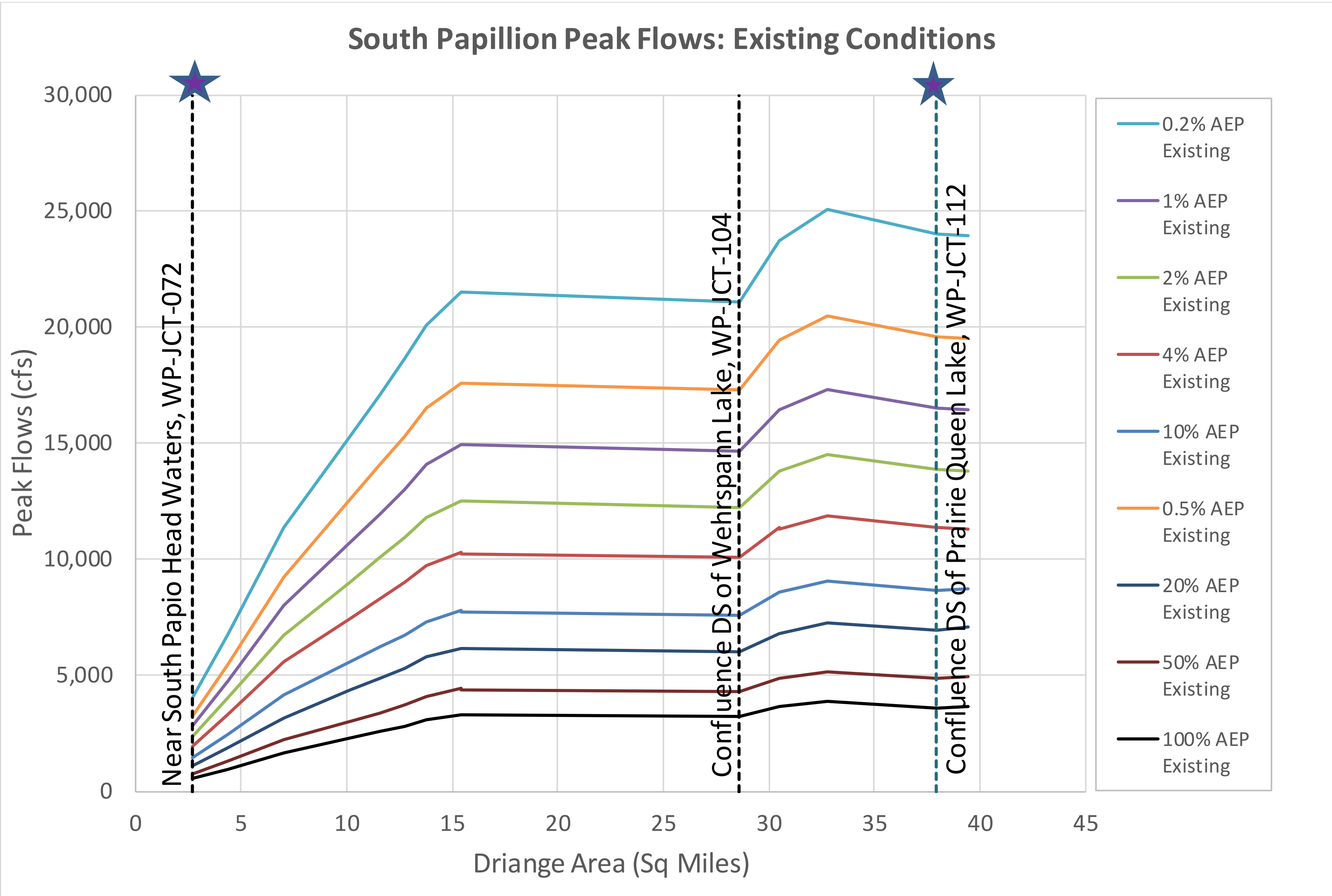


Figure 5. Existing Conditions - South Papillion Creek. See map for purple star extents.

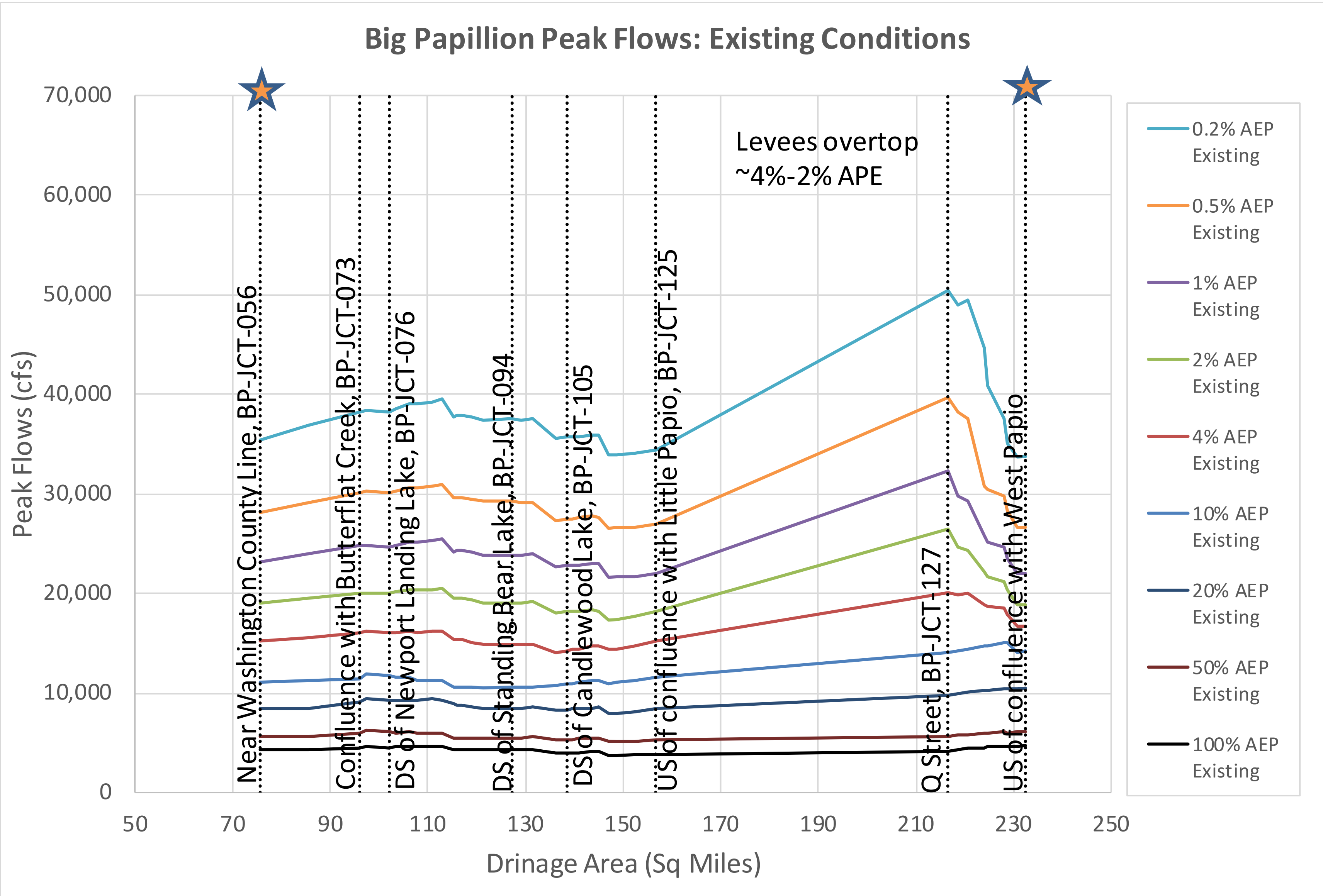


Figure 6. Existing Conditions - Big Papillion Creek. See map for orange star extents.

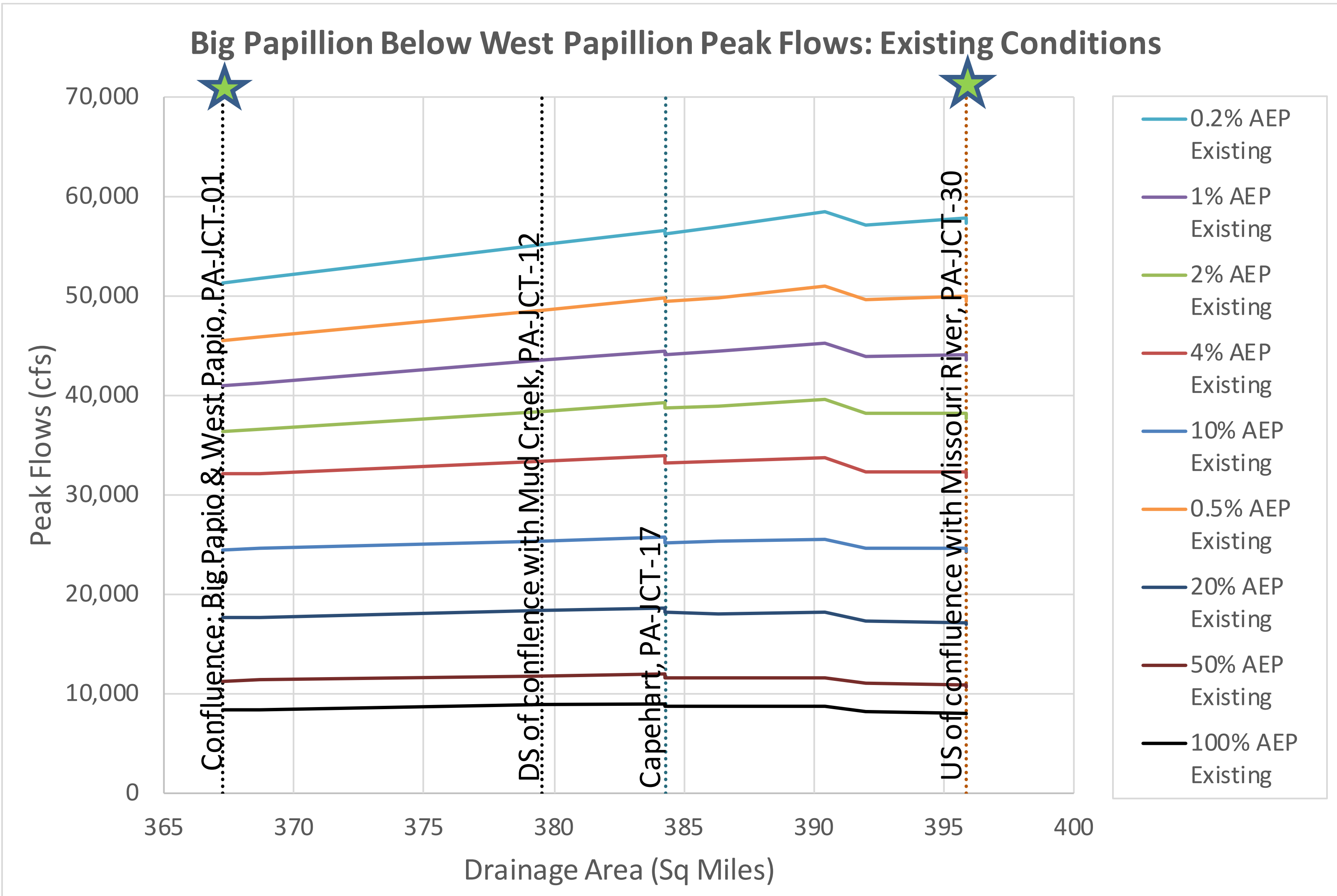


Figure 7. Existing Conditions – Big Papillion Creek below West Papillion Creek. See map for green star extents.

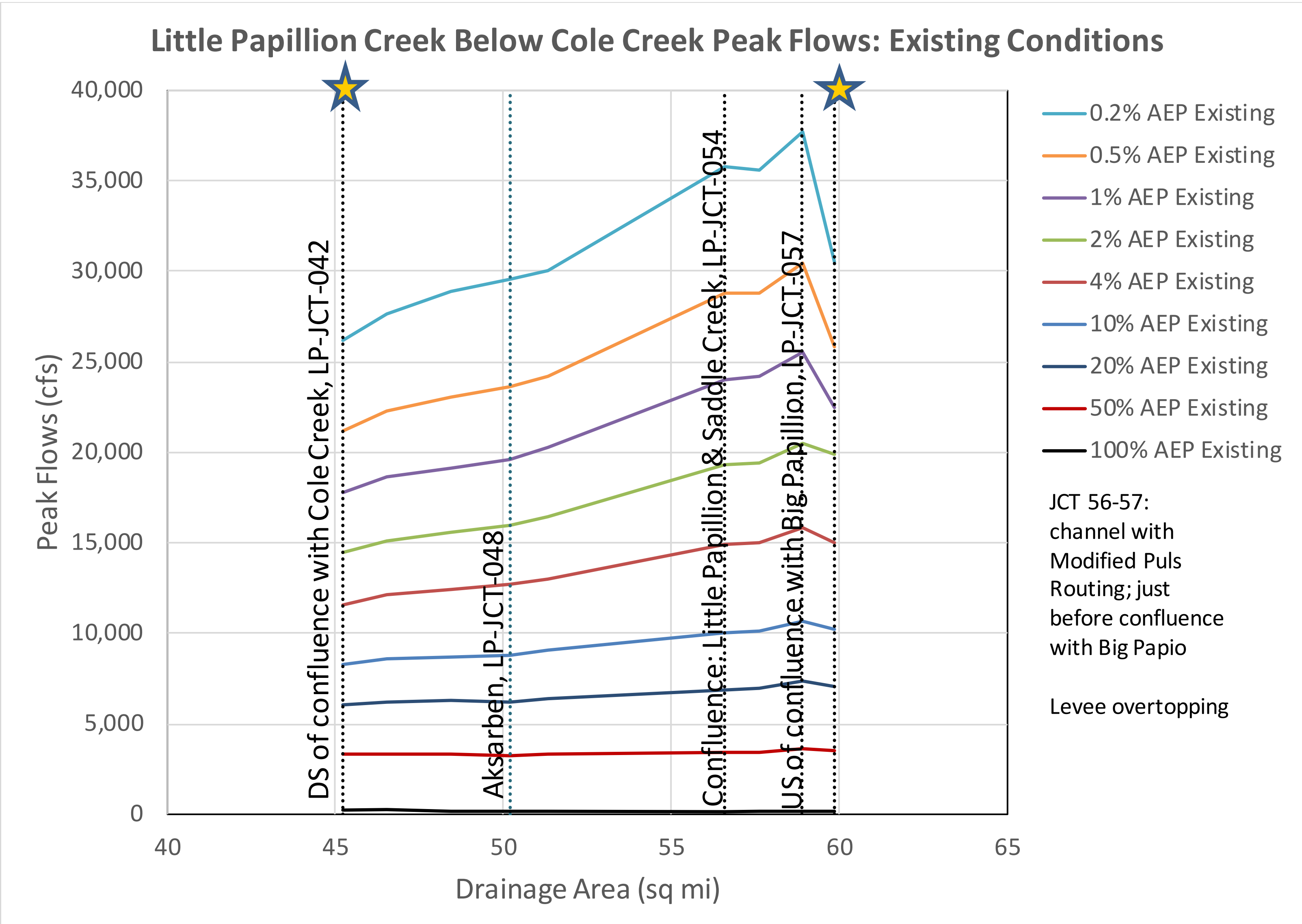


Figure 8. Existing Conditions – Little Papillion. See map for gold star extents.

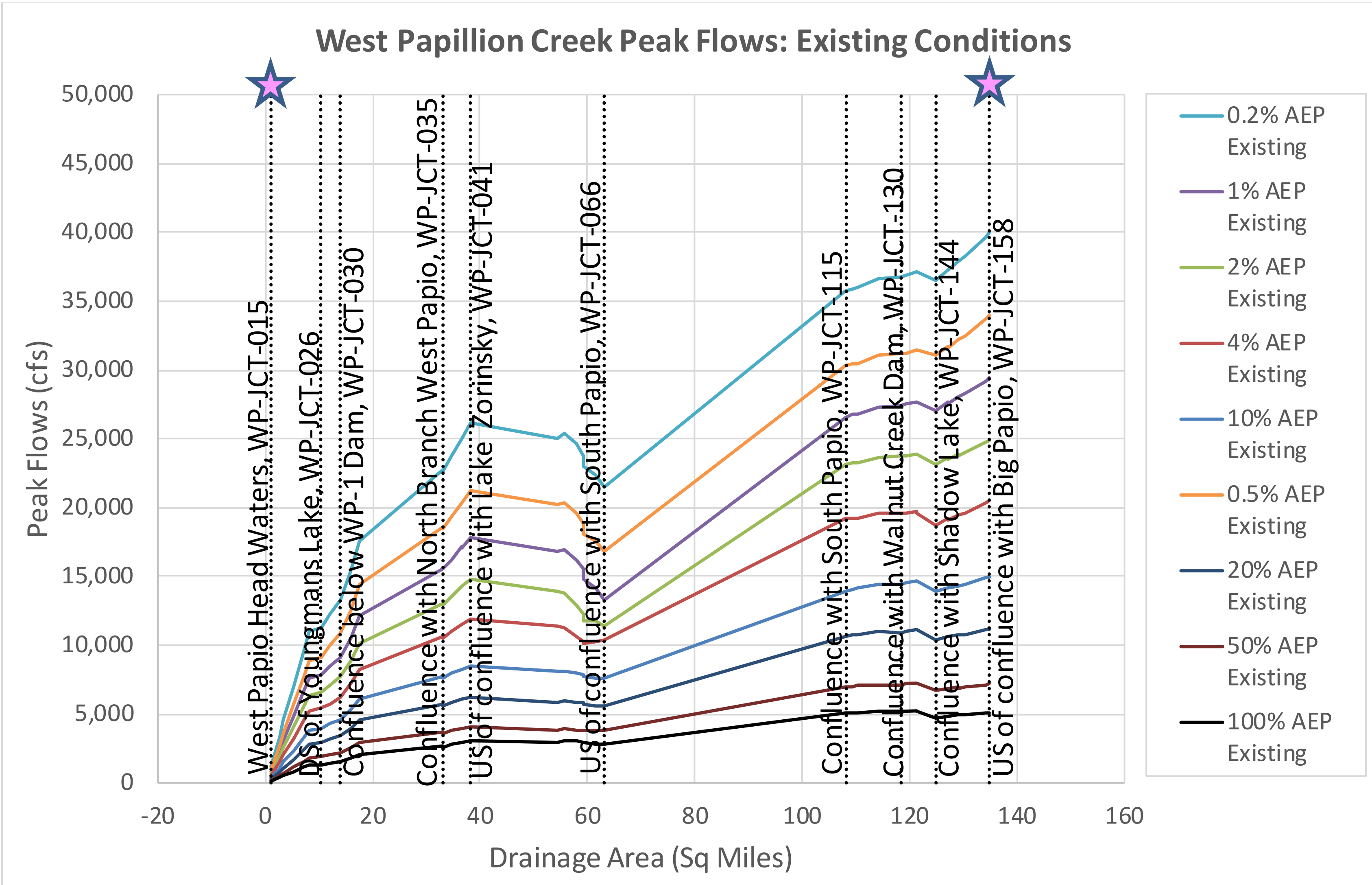


Figure 9. Existing Conditions - West Papillion Creek. See map for pink star extents.

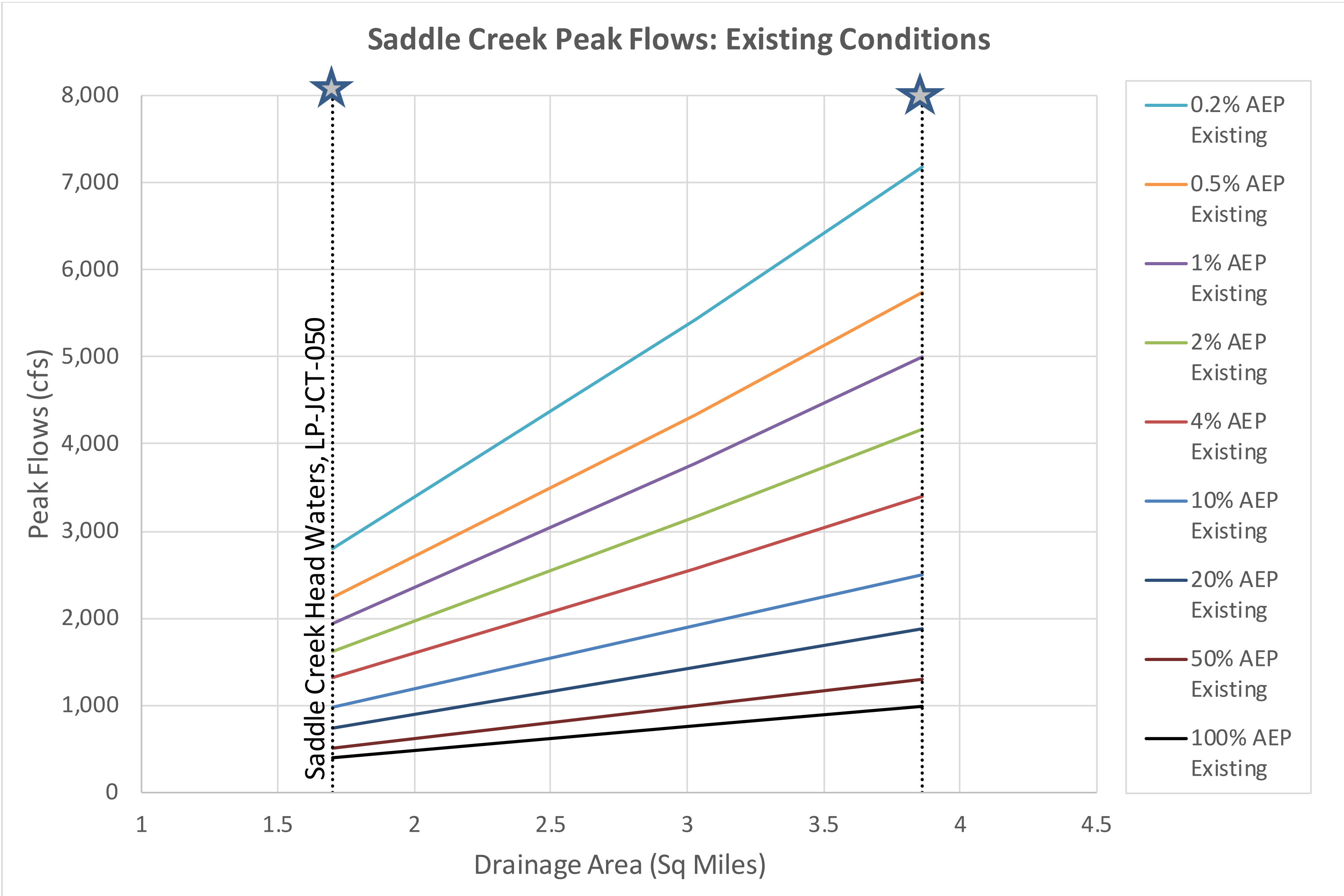


Figure 10. Existing Conditions - Saddle Creek. See map for gray star extents.

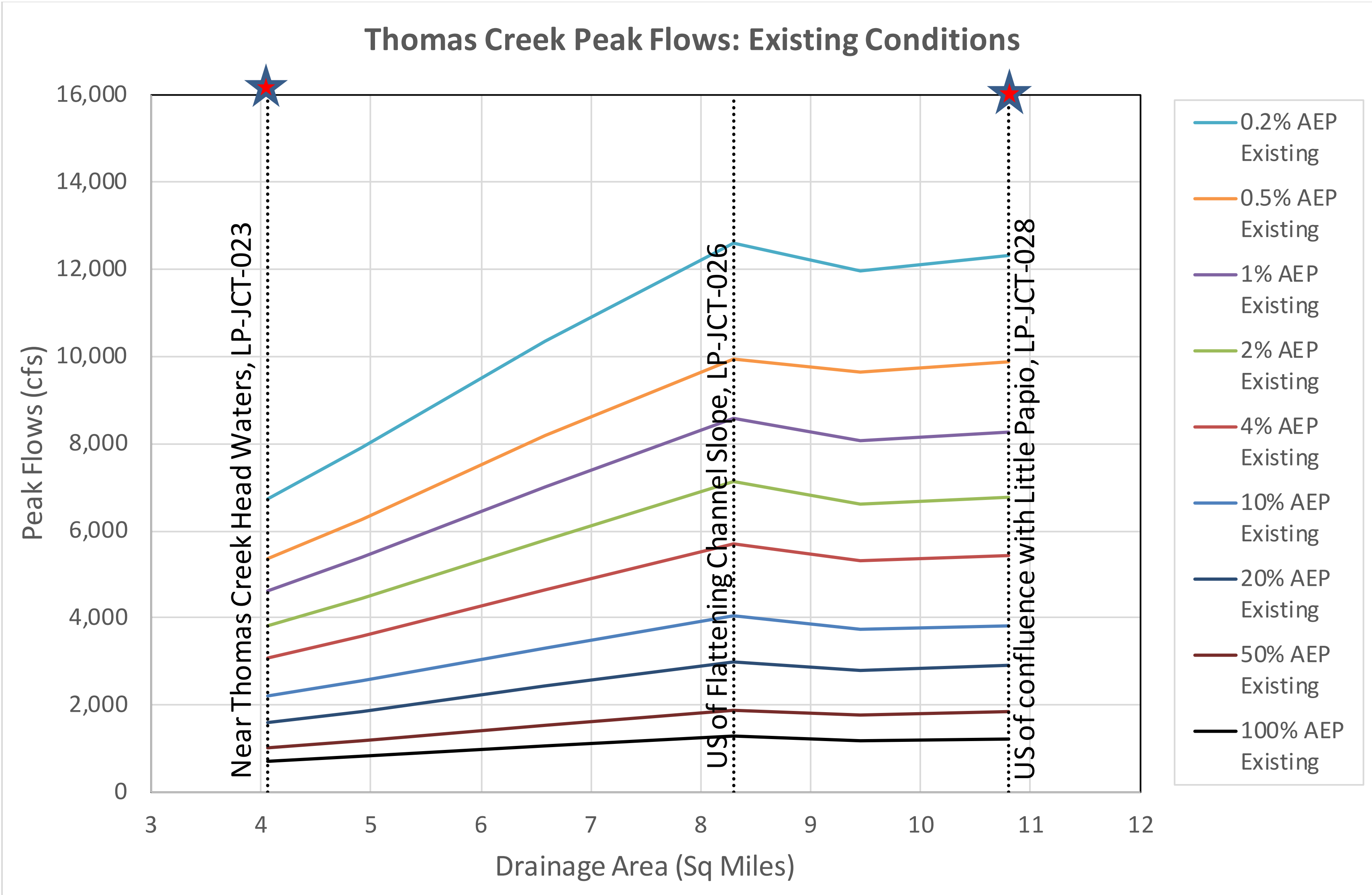


Figure 11. Existing Conditions - Thomas Creek. See map for red star extents.

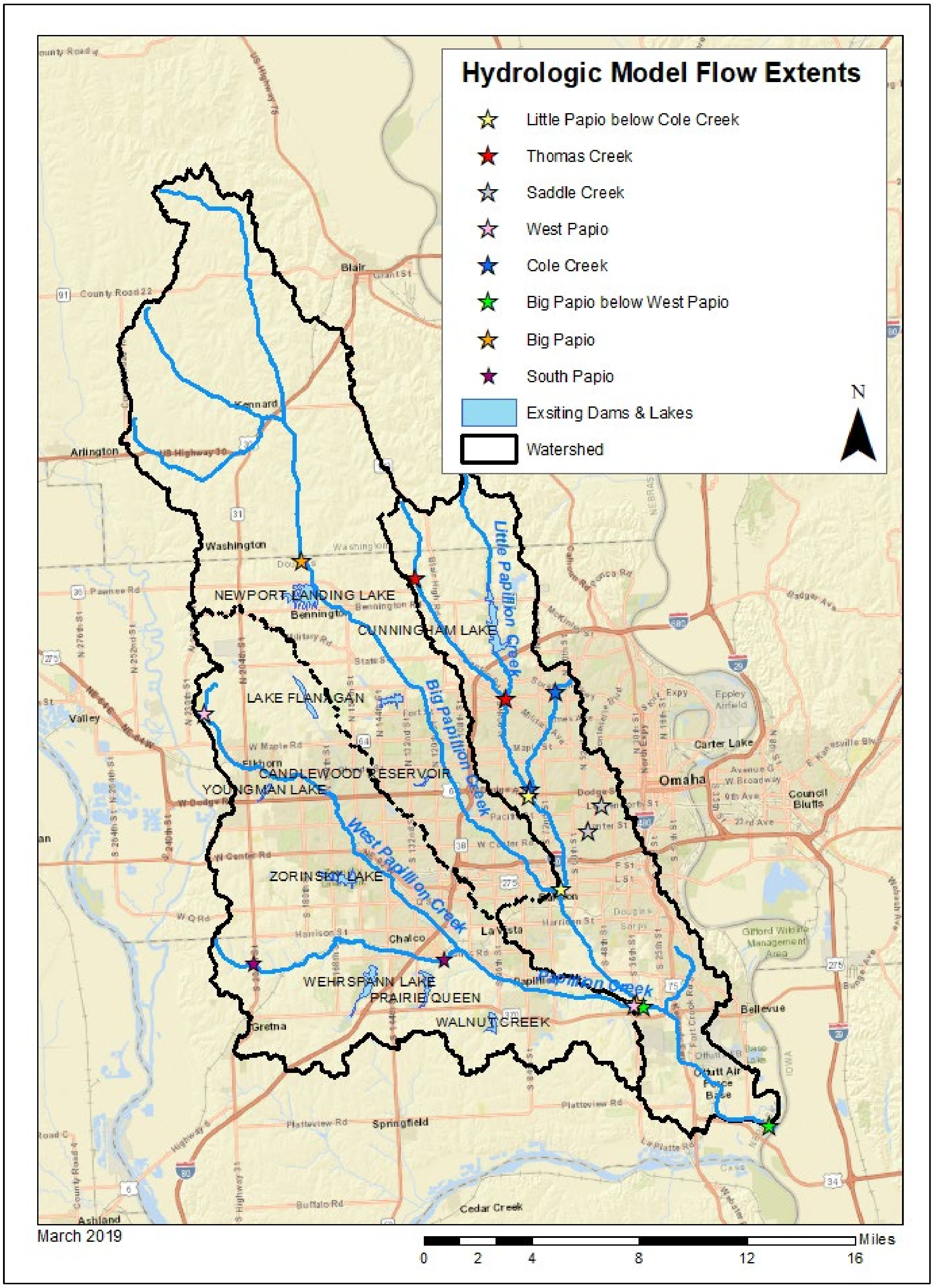


Figure 12. Flow Extents. Use this map with the figures previous to see locations of peak flows.

9 Future Conditions

9.1 Method

Future conditions were modeled by increasing the percent impervious surface of the subbasins in the model to represent build-out. While some past studies on Papillion Creek changed the Clark unit hydrograph (UH) parameters along with the percent imperviousness to represent urban development, no changes to the Clark UH transform parameters or to the channel routing were made for future conditions in the FYRA model used in this GRR study based on model inspection.

Future watershed build-out conditions in the FYRA model used the same increases in percent impervious surface as the 2010 USACE model. A minimum percent impervious value of 10 percent for the full build-out conditions was used to represent development, even though some areas in Washington County are designated as agricultural in the county's master plan. A minimum percent imperviousness of 30 percent was used for the West Papillion subbasins as was estimated in the 2005 study (USACE, 2011). Table 3 shows the build-out percent imperviousness used for each landuse category (USACE, 2011). Full build-out conditions were referenced from city and county jurisdictional comprehensive or master plans including: Douglas County Future Land Use 2040, Washington County Future Land Use by JEO (revised 2005), and Sarpy County Comprehensive Development Plan by RDG & JEO (USACE, 2010). Full build-out was determined in past studies from these sources and not investigated in this study.

Table 3. Impervious Surface by Land Use

Land Use Category	Description	% Impervious
Mixed Residential	Mix of low, medium, and high density residential; homes on up to 3 acres.	30%
Residential Estates	Homes on 3 to 10 acres.	10%
Commercial/Industrial	Commercial, retail business, and industrial areas	80%
Agricultural	Agricultural areas.	1%
Open Space	Parks and open areas	5%
Water	Open water, lakes and streams	100%

9.2 Future Build-Out Conditions Results

Figure 13 through Figure 18 summarize the build-out conditions results for Papillion Creek by reach. Refer to Figure 11 in the previous section for a map showing these flow locations. Appendix AB shows the tables of peak flow results provided to the Omaha District Hydraulics section for stage calculations. Solid lines in the plots are for existing conditions and dashed lines are for build-out conditions. Saddle Creek peak flows are not shown because the watershed is already at build-out; therefore, existing conditions and build-out conditions are the same for Saddle Creek in the model.

Peak flows for the 10 percent through 0.2 percent annual exceedance probability (AEP) events were determined from the HMS model while other flows were interpolated or extrapolated. Other flows needed for economic modeling to produce a benefit-cost-ratio (BCR) were the 50-, 20- and 0.5-percent AEP (2-, 5-, and 200-year) events.

Note that while these peak flows were provided to the Hydraulics, they may not match the flows used in the HEC-RAS modeling. Refer to the Hydraulics Appendix B for more information.

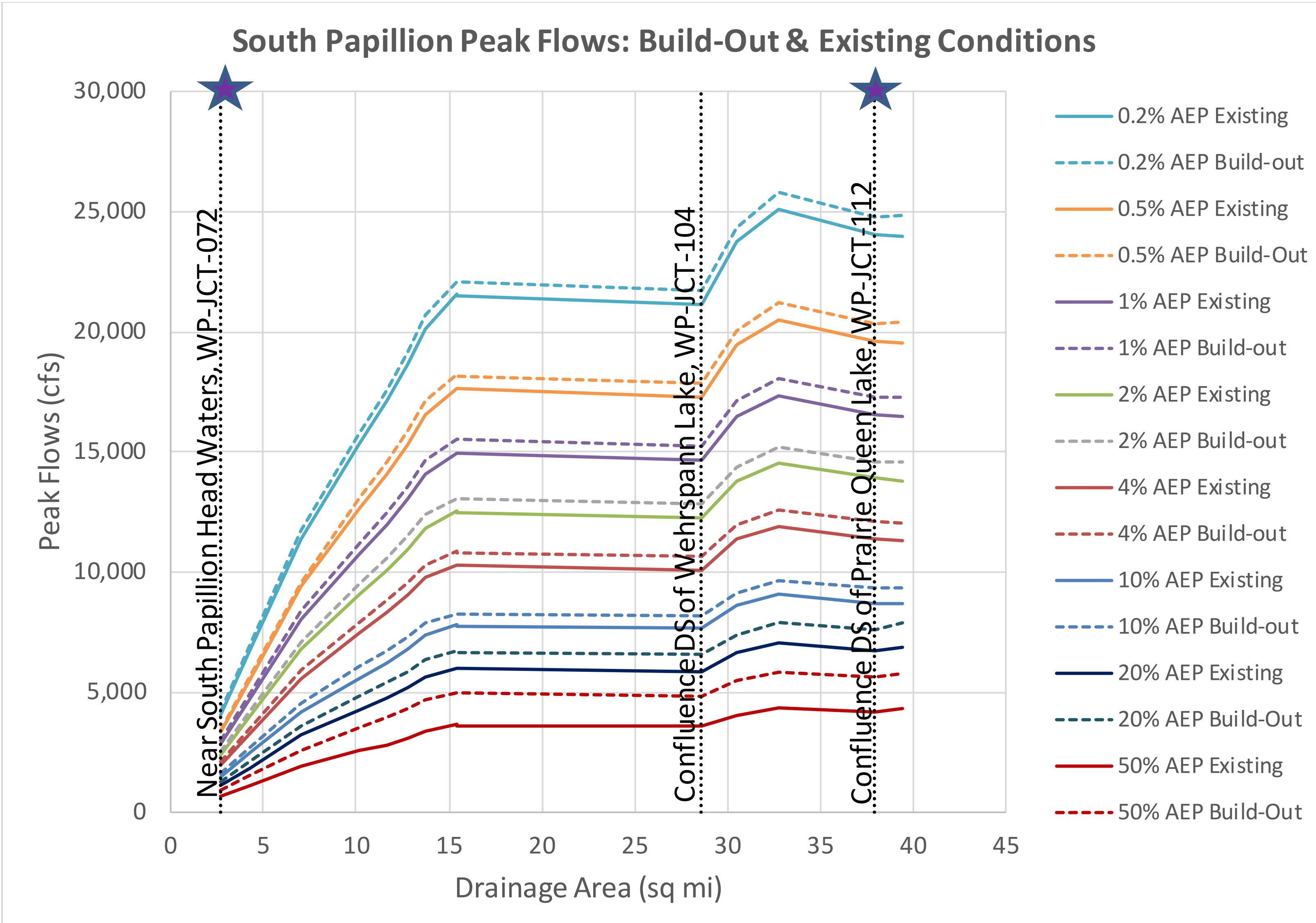


Figure 13. Build-Out Conditions Compared with Existing- South Papillion Creek

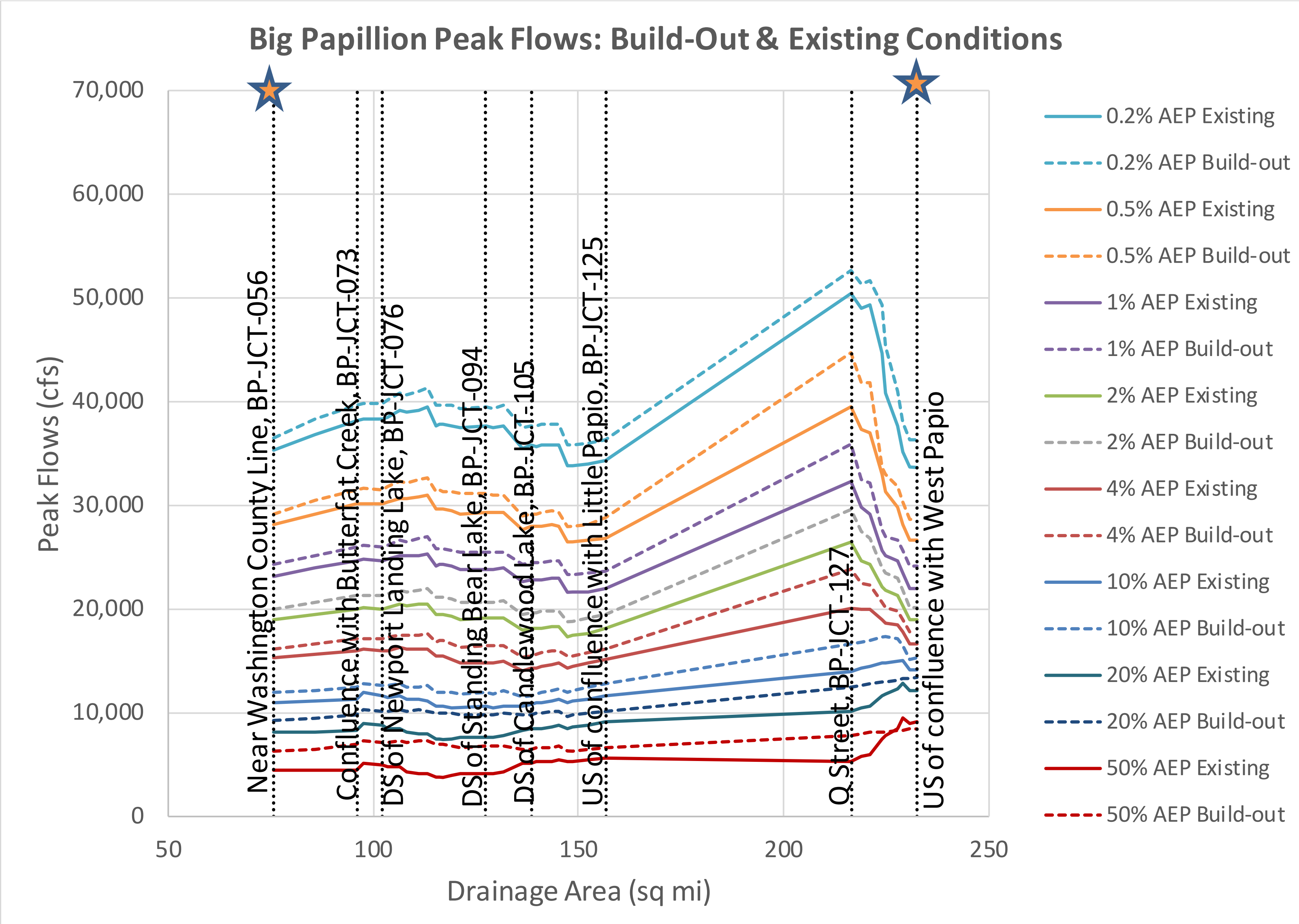


Figure 14. Build-Out Conditions Compared with Existing Conditions - Big Papillion Creek

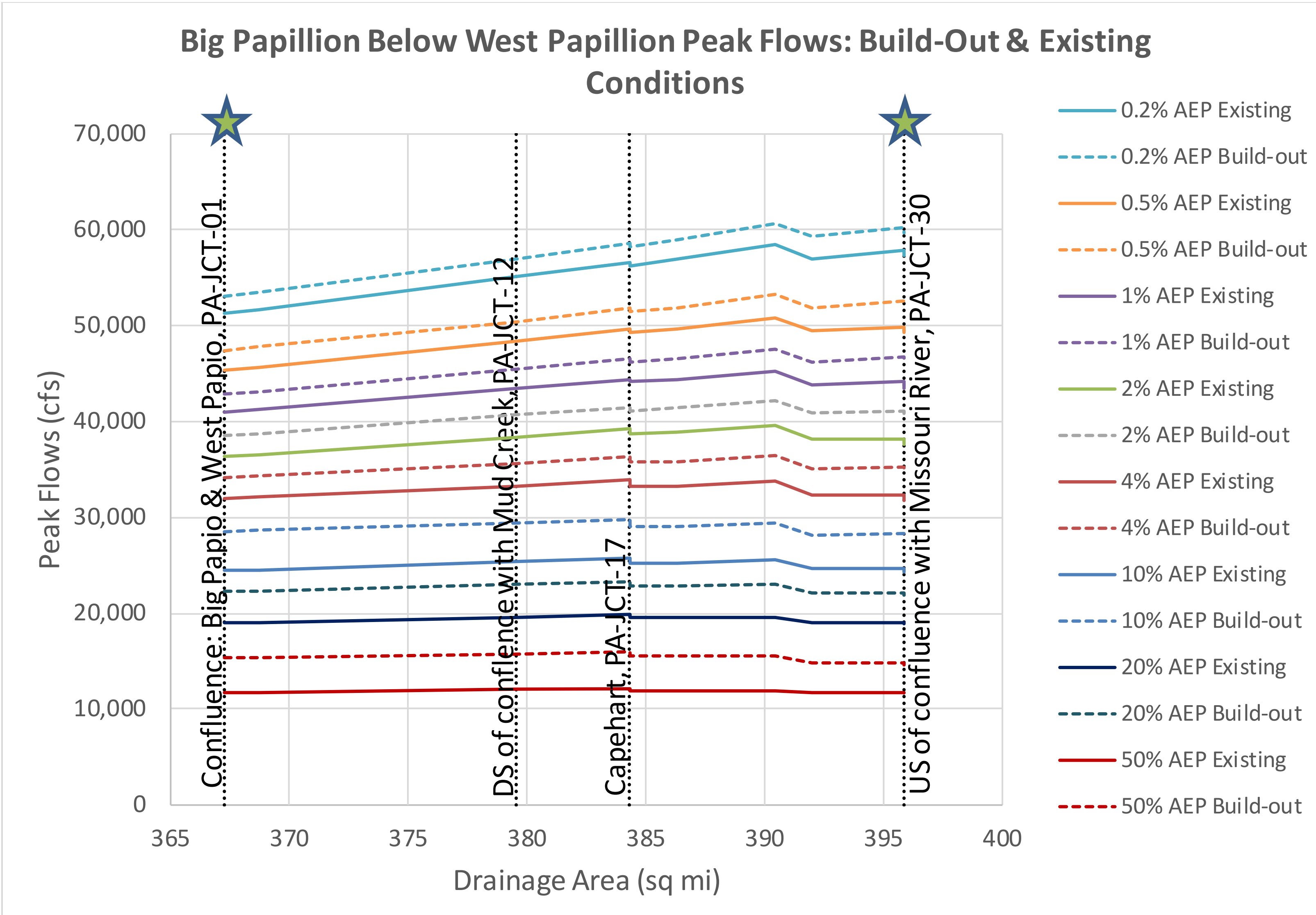


Figure 15. Build-Out Conditions Compared with Existing Conditions – Big Papillion Creek below West Papillion Creek

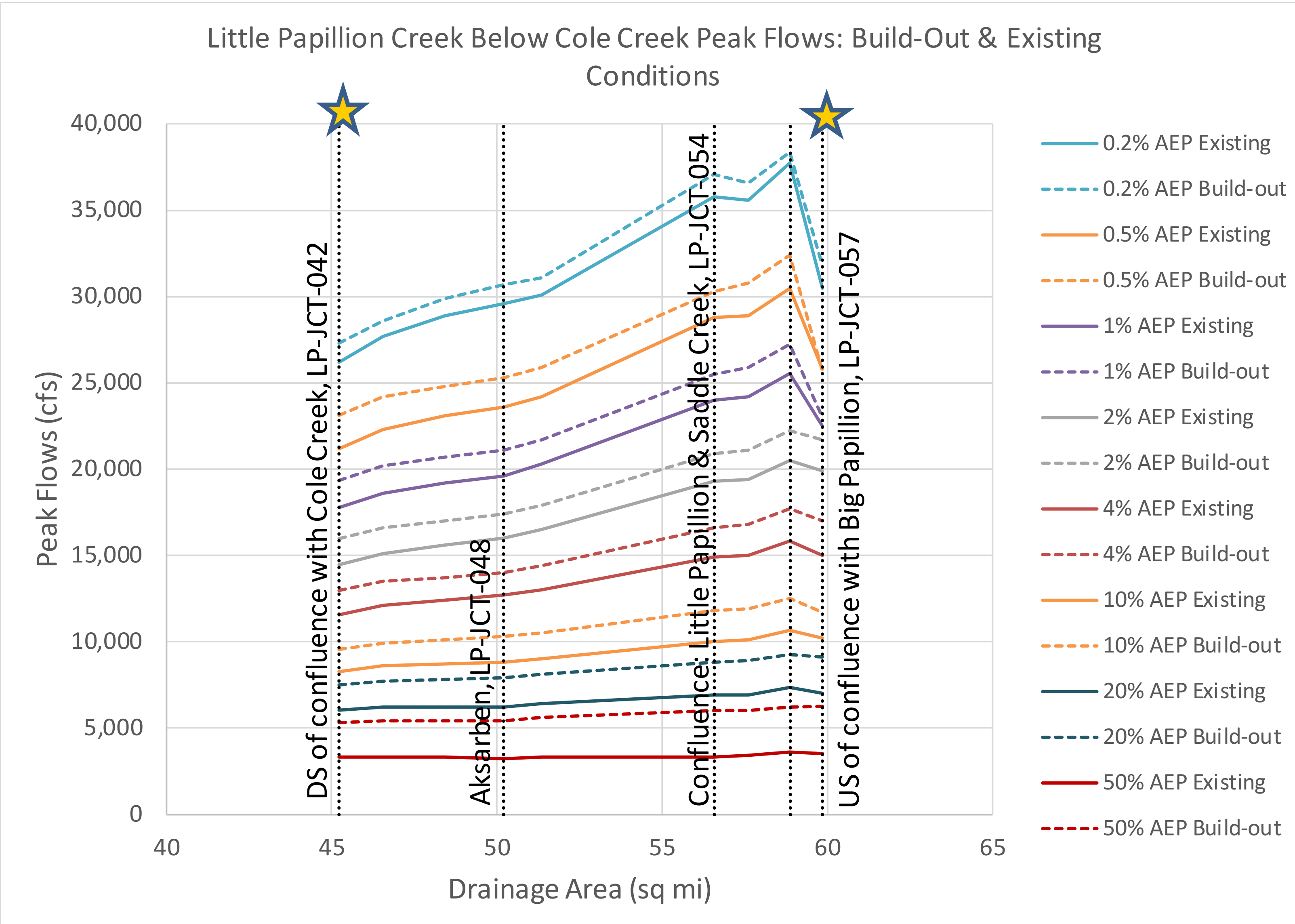


Figure 16. Build-Out Conditions Compared with Existing Conditions – Little Papillion below Cole Creek

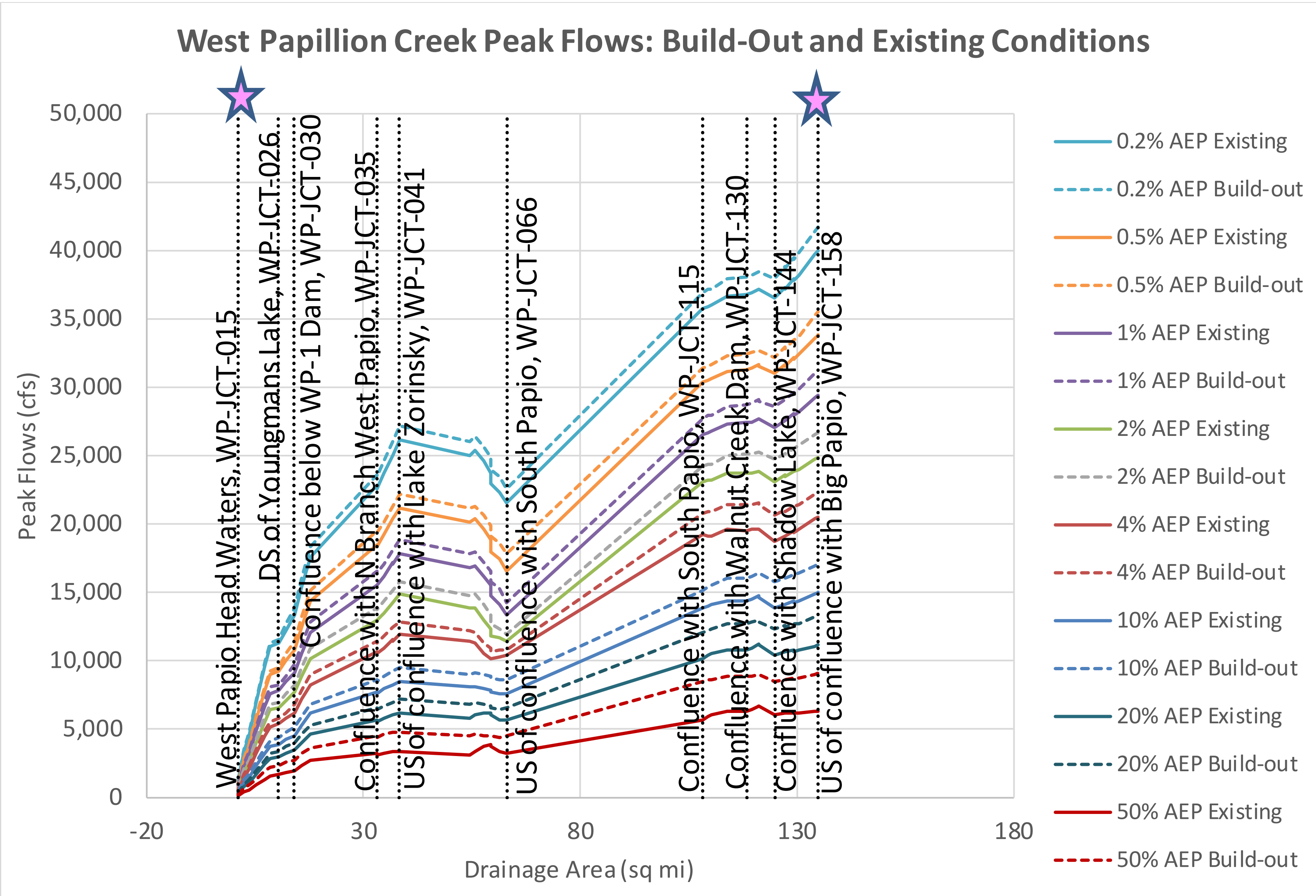


Figure 17. Build-Out Conditions Compared with Existing Conditions - West Papillion Creek

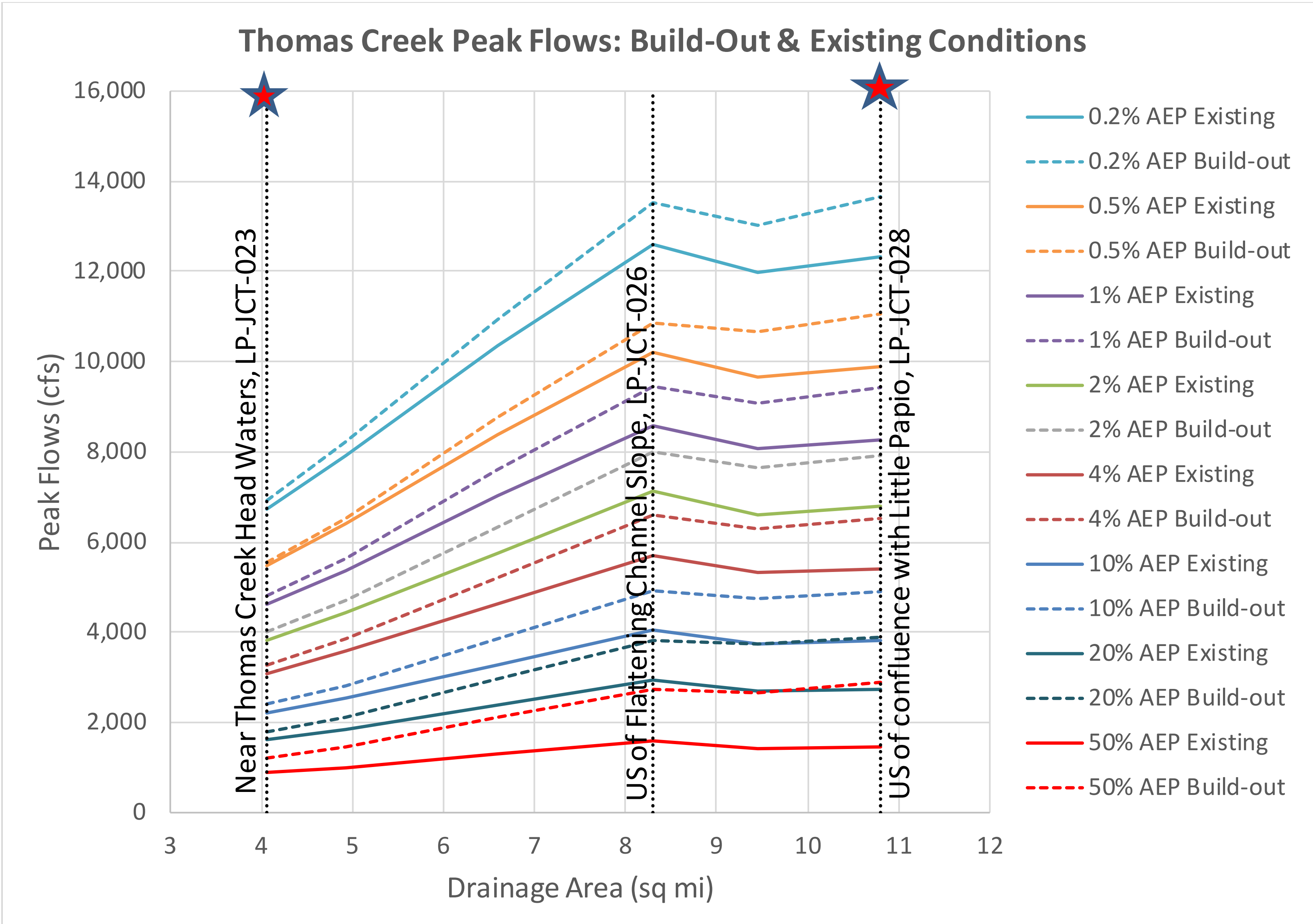


Figure 18. Build-Out Conditions Compared with Existing Conditions - Thomas Creek

10 TSP Dam Site Alternatives Screening

10.1 Method

The purpose of this TSP screening analysis was to determine the effects on peak flows downstream of proposed dam sites. Seven dam sites (DS-7, DS-8A, DS-9A, DS10, DS-12, DS19, and DS-3C) were modeled with the simplified assumption that they would contain all of the runoff events without releases. Modeling without releases was accomplished in HEC-HMS by disconnecting the drainage areas behind the dams from the rest of the model using the Sink element. An example of this is shown in Figure 19. The location of each proposed dam was estimated in HEC-HMS by referencing the drainage area from one of the HDR studies (HDR, 2009) and determining the general location with reference to the map provided by the NRD. Table 4 summarizes characteristics of each of these proposed dam sites and Figure 20 shows the location of the sites.

These dam sites were modeled separately to see their individual effects on downstream peak flows and then all but DS-3C (and its upstream DS-1) were modeled as a system. These peak flows were then provided to the Omaha District Hydraulics Section for modeling in HEC-RAS.

The 2004 HDR report shows three possible locations for DS-3 in Washington County and notes them as DS-3, DS-3B and DS-3C. Construction of DS-3A has been precluded due to the construction of DS-6 by a private developer. Figure 20 shows the locations of the Washington County dam sites evaluated by HDR (HDR, 2004).

DS-3C was selected as the Washington County dam to model in this study based on results from the HDR 2004 Multi-Reservoir Analysis which determined that DS-3C (modeled in conjunction with DS-1 upstream) had the best balance in meeting the evaluation criteria: an acceptable normal pool and max pool when backwater effects on the railroad bridge and the U.S. HWY 30 Bridge were considered, normal pool sustainability, maximization of pool surface area, acceptable flood storage, and consideration top-of-dam (TOD) potential impacts to the City of Kennard and the Village of Washington (HDR, 2004). The future 2040 land use conditions were used in the HDR analysis.

The recommended alternative of the 2004 HDR study was their Alternative 7 which was a combination of DS-1 and DS-3C with the middle normal pool scenario of DS-3C; note that while this alternative was selected as the best, it still violates the TOD criteria in the communities of Kennard and Washington meaning it inundates part of those communities when the pool is at TOD. DS-3C by itself was viewed as a less attractive alternative because only the low normal pool scenario did not violate the bridge criteria at the railroad and US HWY 30. This low normal pool alternative also violated the TOD criteria in the communities of Kennard and Washington but it seems less weight was placed on this in the HDR study than maximizing the pool and not violating the bridge criteria at the railroad and US HWY 30. See Table 18.2 in the 2004 HDR report for more details on the alternatives, their pool elevations, and their violations in criteria (HDR, 2004).

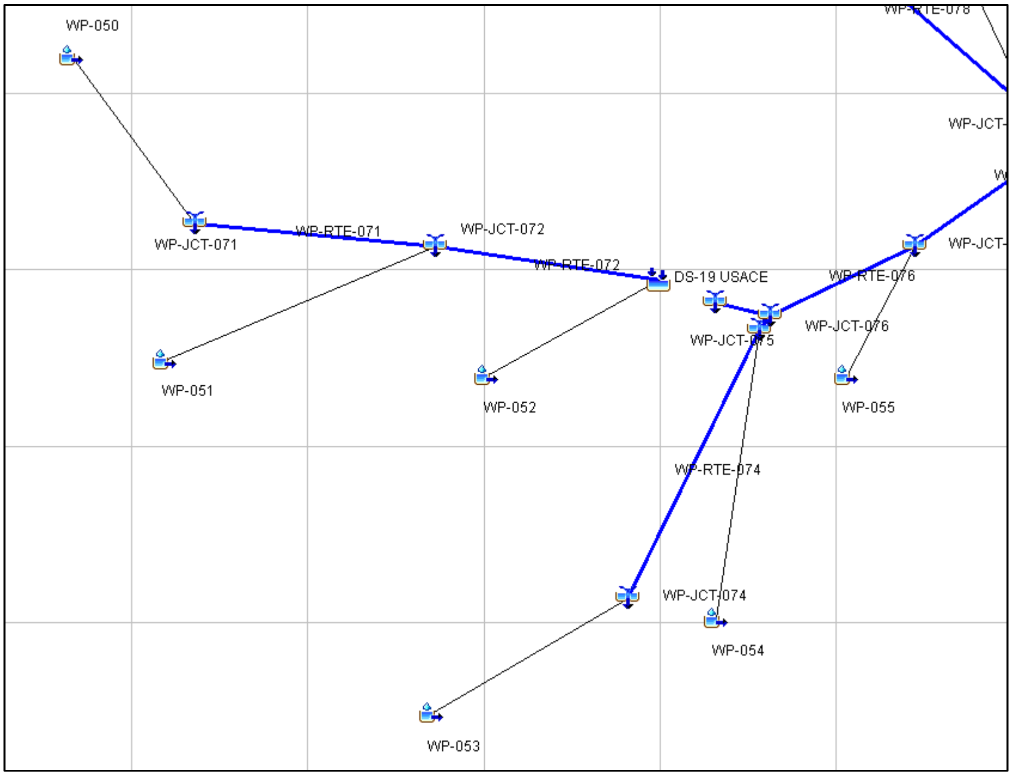


Figure 19. Idealized Dam Site Modeling

Table 4. Proposed Dam Sites in Alternatives Site Characteristics

Dam Site	DA (sq mi)	County	River Reach	Normal/Rec Pool Elev (ft-NGVD29)	Normal Pool Acres (ac)	Spill Crest Elev (ft-NGVD29)	TOD Elev (ft-NGVD29)	Res. Area at TOD (ac)	Source
DS7	2.5	Douglas	Big Papio Ck	1125	47	1135	1142	145	HDR (2004)
DS8A	2.9	Douglas	Big Papio Ck	1125	75	1133	1139	160	HDR (2004)
DS9A	2	Douglas	Big Papio Ck	1119	38	1128	1134	100	HDR (2004)
DS10*	4.9	Douglas	Thomas Ck	1170	97	1181	1189	295	HDR (2004)
DS12	2.6	Douglas	West Papio Ck	1212	70	1219	1226	215	HDR (2004)
DS19*	4.3	Sarpy	South Papio Ck	1165	100	1174	1183	300	HDR (2004)
DS3C	23.3	Washington	Big Papio Ck	1134	1,900	1142	1151	4,350	HDR (2004)
DS1	97.5	Washington	Big Papio Ck	1162	365	1173	1183	1,290	HDR (2004)

*These were updated in future design reports so elevations may be different in later sections of this report.

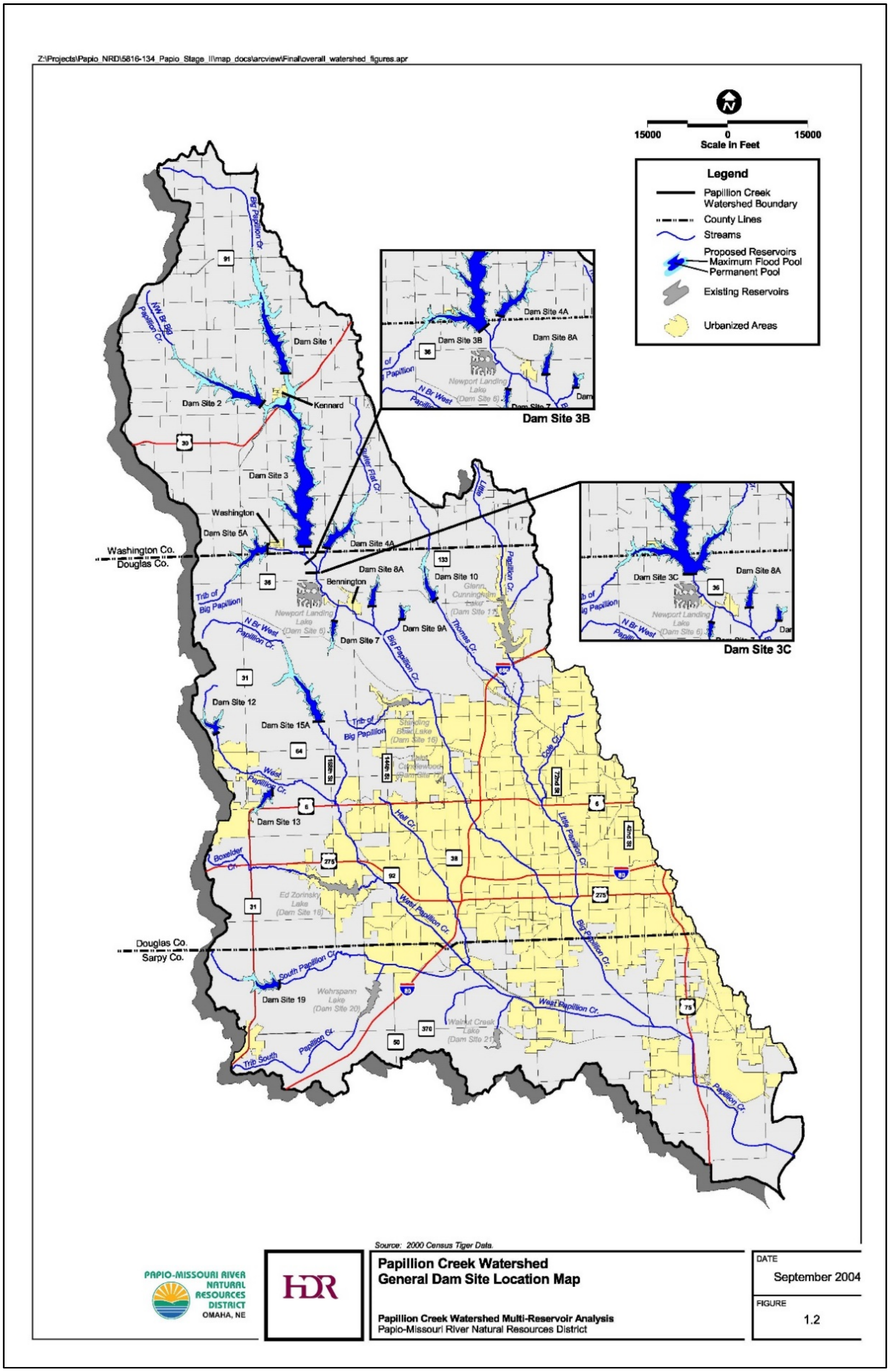


Figure 20. Washington County proposed dams considered in HDR 2004 screening.

10.2 TSP Dam Site Alternatives Screening Results

This TSP screening analysis was used to determine if a dam site or a combination of sites had Federal interest. Seven dam sites (DS-7, DS-8A, DS-9A, DS10, DS-12, DS19, and DS-3C & DS-1) were modeled with the simplified assumption that they would contain all of the 50% AEP through 0.2% AEP events (2- through 500-year events).

Table 5 summarizes the largest and average impacts to peak flows downstream by reach. Appendix AC contains the tables of peak flows provided for each alternative to the Omaha District Hydraulics Section. Note that only the tables for reaches showing changes from the existing conditions are shown in the appendix due to the large number of dam site alternatives simulated. For example, the DS-3C (and DS-1) alternative will only have tables for the Big Papillion reach because that is the only reach the dam site(s) affected.

Dam site alternatives are summarized below:

- DS3C & DS1: Dam site 3C in Washington County modeled along with DS-1 upstream because this was the selected alternative in the 2004 HDR study.
- All but DS-3C: Dam sites 7, 8A, 9A, 10, 12, and 19 modeled as a system.
- DS19: Dam site 19 modeled by itself.
- DS10: Dam site 10 modeled by itself.
- DS12: Dam site 12 modeled by itself.
- DS8A: Dam site 8A modeled by itself.
- DS7: Dam site 7 modeled by itself.
- DS9A: Dam site 9A modeled by itself.

Table 5. Summary of Dam Site Alternatives on 1% AEP Peak Flows by Reach. Zero values mean no change in comparison with existing conditions.

Alternative	Reach	Decrease in 1% AEP Peak Flows Compared with Existing Condition	
		Largest Decrease (cfs)	Average Decrease (cfs)
DS3C & DS1	South Papillion	0*	0
DS3C & DS1	Big Papillion	24,780	9,410
DS3C & DS1	Little Papillion	0	0
DS3C & DS1	West Papillion	0	0
DS3C & DS1	Saddle Creek	0	0
All but DS3C	South Papillion	4,770	3,600
All but DS3C	Big Papillion	2,120	943
All but DS3C	Little Papillion	2,550	788
All but DS3C	West Papillion	2,650	1,240
All but DS3C	Saddle Creek	0	0
DS19	South Papillion	4,770	3,600
DS19	Big Papillion	2,050	351
DS19	Little Papillion	0	0
DS19	West Papillion	2,610	548
DS19	Saddle Creek	0	0
DS10	South Papillion	0	0
DS10	Big Papillion	1,470	184
DS10	Little Papillion	2,550	788
DS10	West Papillion	0	0
DS10	Saddle Creek	0	0
DS12	South Papillion	0	0
DS12	Big Papillion	110	23
DS12	Little Papillion	0	0
DS12	West Papillion	2,280	699
DS12	Saddle Creek	0	0
DS8A	South Papillion	0	0
DS8A	Big Papillion	560	137
DS8A	Little Papillion	0	0
DS8A	West Papillion	0	0
DS8A	Saddle Creek	0	0
DS7	South Papillion	0	0
DS7	Big Papillion	360	172
DS7	Little Papillion	0	0
DS7	West Papillion	0	0
DS7	Saddle Creek	0	0
DS9A	South Papillion	0	0
DS9A	Big Papillion	220	89
DS9A	Little Papillion	0	0
DS9A	West Papillion	0	0
DS9A	Saddle Creek	0	0

11 TSP Dry Dam vs Recreation Pool Comparisons

11.1 Method

A TSP-level investigation of dry dam versus wet dam heights was undertaken to determine how building a dry dam opposed to a wet dam would impact lake takings. Dams with recreation pools in this report are called wet dams while dams without recreation pools are called dry dams. All the proposed dam sites considered in this analysis (sites DS3C, DS19, DS10, DS12, DS8A, DS7, and DS9A) were compared.

Elevation-storage curves and pool elevations were referenced from the 2004 HDR study and its appendices. Note that the elevation-storage curves used in this section are different from the curves used in the later section where the dam is updated to USACE criteria to check design compliance to USACE standards. Also note that results will vary between this section and the updated USACE criteria sections because routing of a 10-percent AEP event is used in the later section and not here.

The dry dams were assumed to have no permanent pool and it was assumed they could be drained completely for this TSP general analysis. The storage of the recreation pool, and permanent pool below it, was estimated from elevations in the HDR 2004 report and then subtracted from the total storage to the top of dam (TOD). The new storage and the elevation-storage curve were then used to determine the TOD elevation of the dry dam alternative. Figure 21 shows this process.

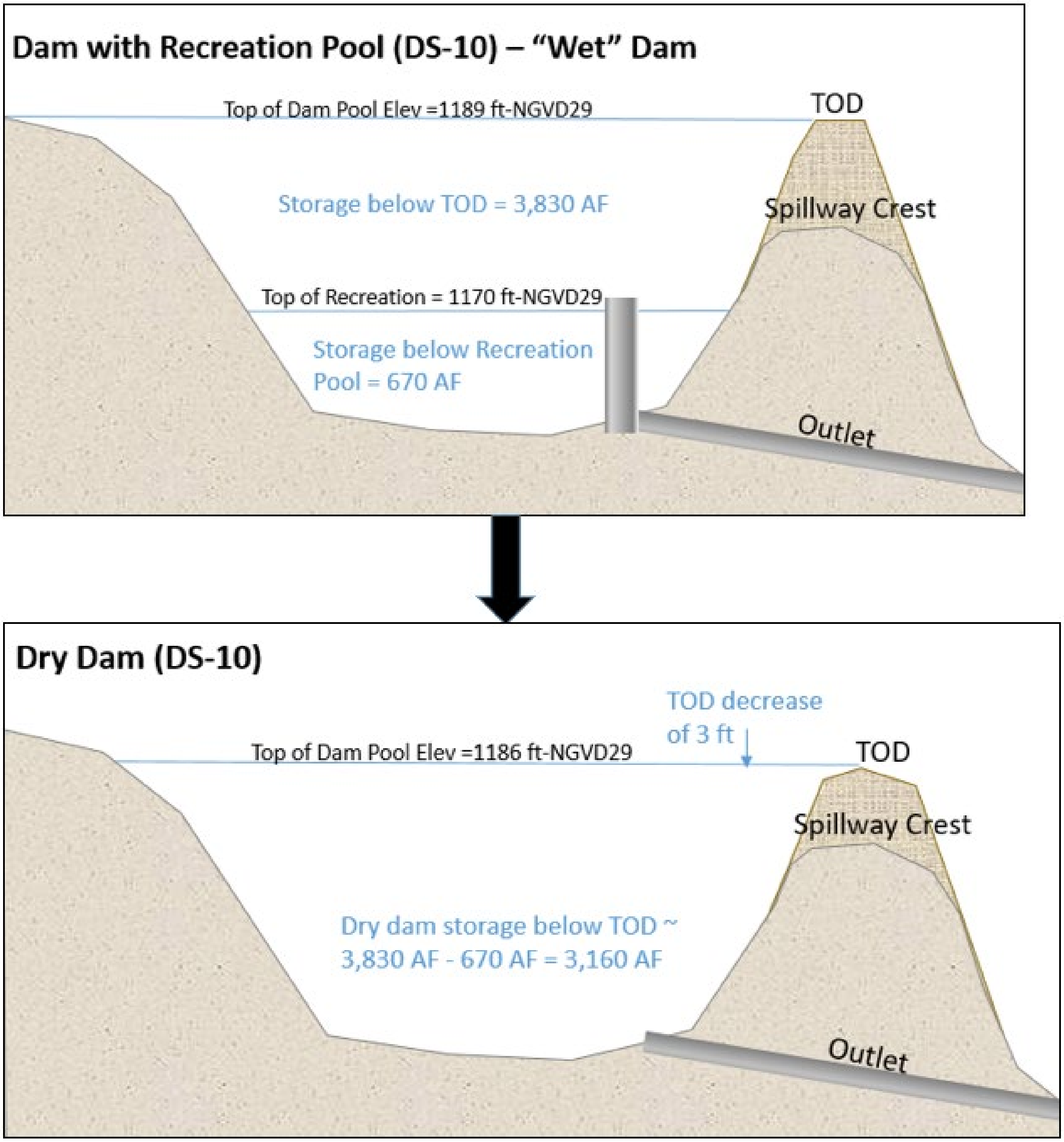


Figure 21. Dam Converted to Dry Dam (drawing conceptual and not to scale)

11.2 TSP Dry Dam vs Recreation Pool Results

The estimated difference in TOD elevations for the seven dam sites investigated in this study are shown in Table 6. These results assume no permanent pool (dry dam) and that the reservoir can be drained completely. All elevations and storage values are from the 2004 HDR report and its appendices.

These results indicate that TOD elevations could be decreased 1.6 to 9.5 feet if the recreation pool is eliminated and the site is constructed as a dry dam.

Table 6. Dry Dam vs. Recreation Pool Comparison

Site	Wet Dam TOD Elev (ft-NGVD29)	Dry Dam TOD Elev (ft-NGVD29)	Change in Dam Height (ft)
DS3C	1151	1141.55	9.5
DS19	1183	1181.42	1.6
DS10	1189	1186.02	3
DS12	1226	1222.67	3.3
DS8A	1139	1131.15	7.8
DS7	1142	1137.39	4.6
DS9A	1134	1129.06	4.9

12 Channel Modifications Check

12.1 Method

The effects of channel widening were modeled in HEC-RAS by the Omaha District Hydraulics Section. However, channel modifications often affect peak flows. The effects of these channel modifications on peak flows were tested in HEC-HMS by entering the modified channels from the HEC-RAS model into HEC-HMS. This was important to check as modifications in the HEC-RAS cross sections for the alternatives can result in changes in the peak flows which could lead to iterative modeling between the HEC-HMS and HEC-RAS models if the changes are large enough. Unlike HEC-RAS, HEC-HMS version 4.2 can only simulate channel cross sections with eight points. For this reason, the channel cross sections with modifications were simplified before being added to HEC-HMS.

Reach lengths in the HEC-HMS model were checked against those in the ArcMap GIS software program for the reaches with channel modifications to help ensure consistency between the hydrologic and hydraulic modeling. In the case of some reaches the percent difference in reach length was over 15 percent. In the case of these reaches an additional junction had to be added in HEC-HMS to represent the lengths of the reaches accurately when compared with lengths in GIS which represent placement in the HEC-RAS model. Junctions added included WP-JCT-RR on the West Papillion and junctions LP-JCT-Keystone and LP-JCT-Grover on the Little Papillion. The lengths were adjusted to be consistent with the original existing conditions. The final reach lengths are shown in Table 7.

Simplified channel cross sections and their locations are shown in Figure 22 through Figure 26. The cross sections of the HEC-RAS modified/widened channels are compared with the original HEC-HMS existing condition's channel cross sections they replaced in the HEC-HMS model in Figure 27 through Figure 32.

Note that the cross sections in HEC-RAS for the existing conditions do not match the existing conditions cross sections used in the HEC-HMS model. For example, comparing the HEC-RAS widened cross section for the South Papillion channel with the HEC-HMS existing cross section (Figure 26) makes it look like the channel modifications involve channel deepening as well as widening. This is not the case as seen in Figure 33 where the same cross section for the South Papillion channel is compared with its existing conditions channel from HEC-RAS.

Note that the West Papillion cross sections were changed after this analysis was completed. While one updated cross section was used in place of the two shown, the cross section nearest the confluence is very similar to the updated cross section and would likely not affect the results of this section. The largest increase in the difference in peak flows was near the confluence. For this reason, this analysis was not updated with the new West Papillion cross section.

Table 7. Reaches in GIS and HEC-HMS

Reach	Junctions	GIS Length (ft)	HMS Length (ft)	% Diff in Length
South Papillion Creek				
156th Street to West Papio Confluence	WP-JCT-088 to WP-JCT-114	24,504	22,000	-10.2
Big Papillion Creek				
Blondo Street to Center Street	BP-JCT-103 to BP-JCT-116	20,505	23,150	12.9
West Papillion Creek				
Center Street Bridge to L Street Bridge (100' bench)	WP-JCT-040 to WP-JCT-062	11,946	13,000	8.8
L Street Bridge to BNSF Railroad Crossing (220' bench)	WP-JCT-062 to WP-JCT-RR	15,457	15,457	0
Little Papillion Creek				
Keystone Drive to Western Avenue	LP-JCT-Keystone to LP-JCT-32	7,116	7,116	0
Western Ave to Dodge Street	LP-JCT-32 to LP-JCT-42	4,500	4,944	9.9
Saddle Creek to Grover Street	LP-JCT-54 to LP-JCT-Grover	2,621	2,621	0

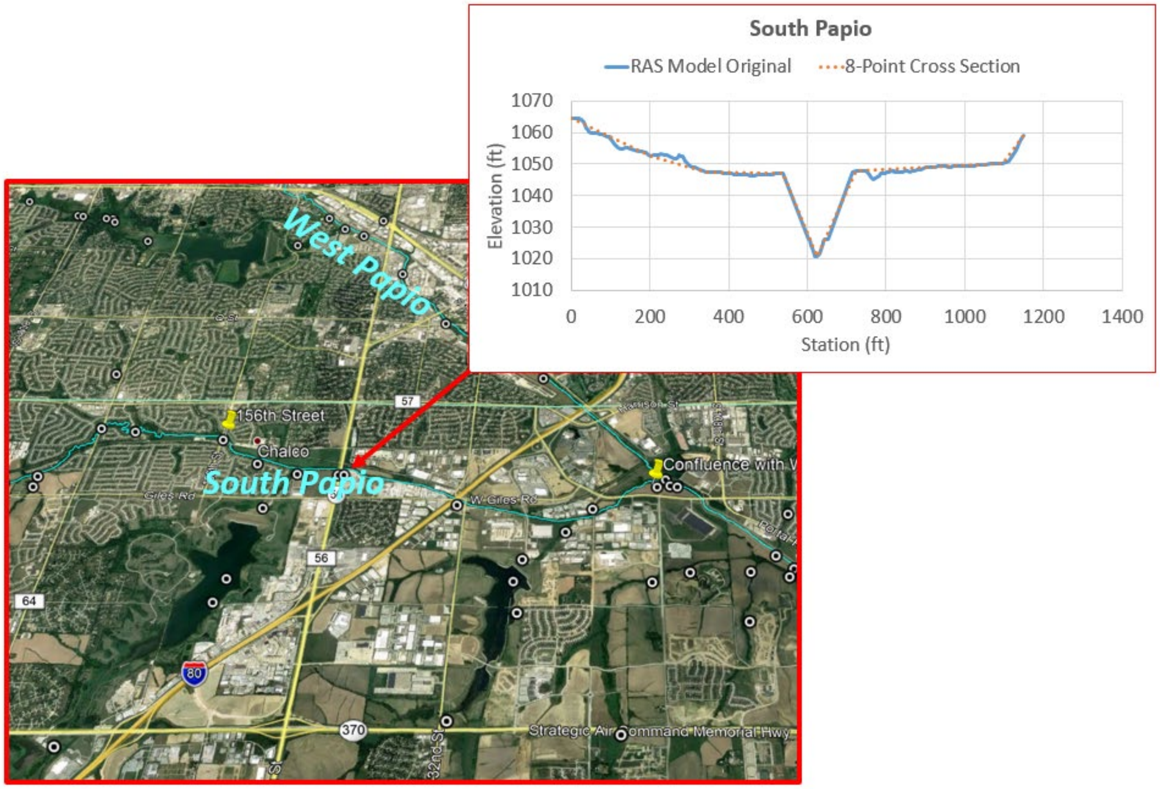


Figure 22. Channel Modifications South Papillion. Modified HEC-RAS channel cross section shown with simplified 8-point cross section.

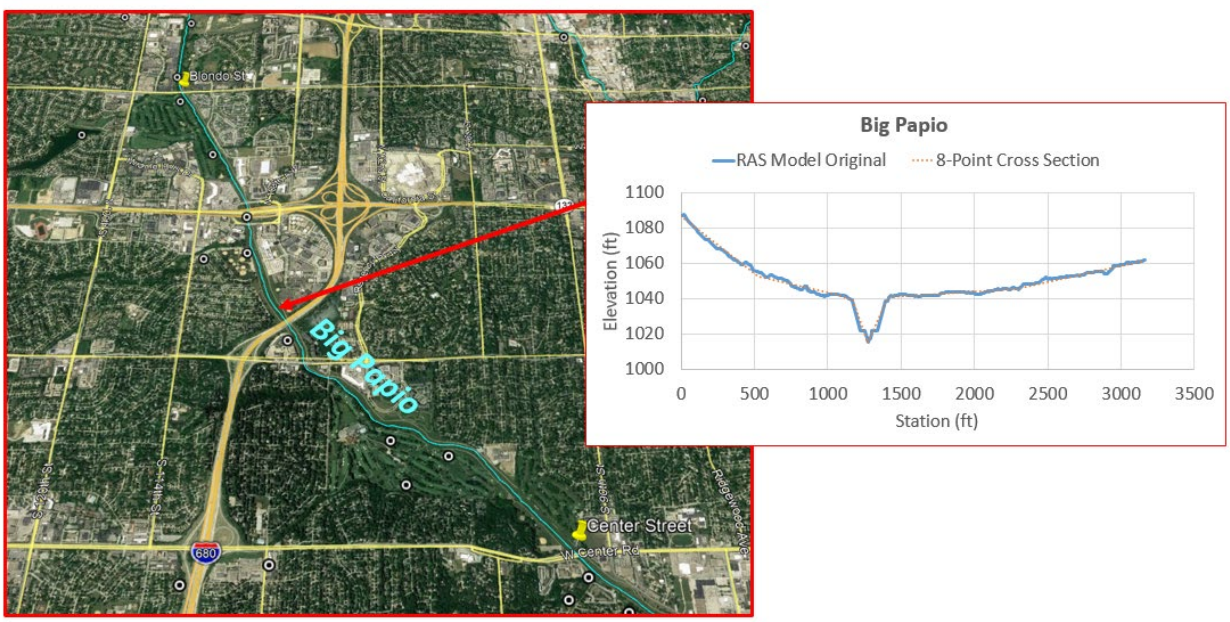


Figure 23. Channel Modifications Big Papillion. Modified HEC-RAS channel cross section shown with simplified 8-point cross section.

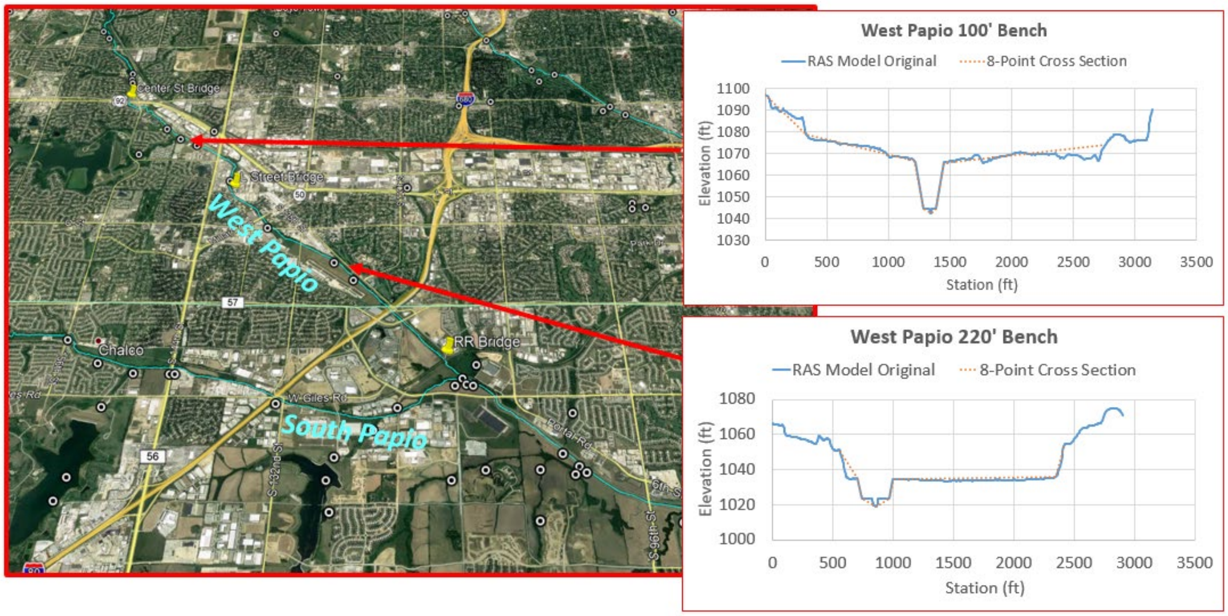


Figure 24. Channel Modification West Papillion. Modified HEC-RAS channel cross section shown with simplified 8-point cross section.

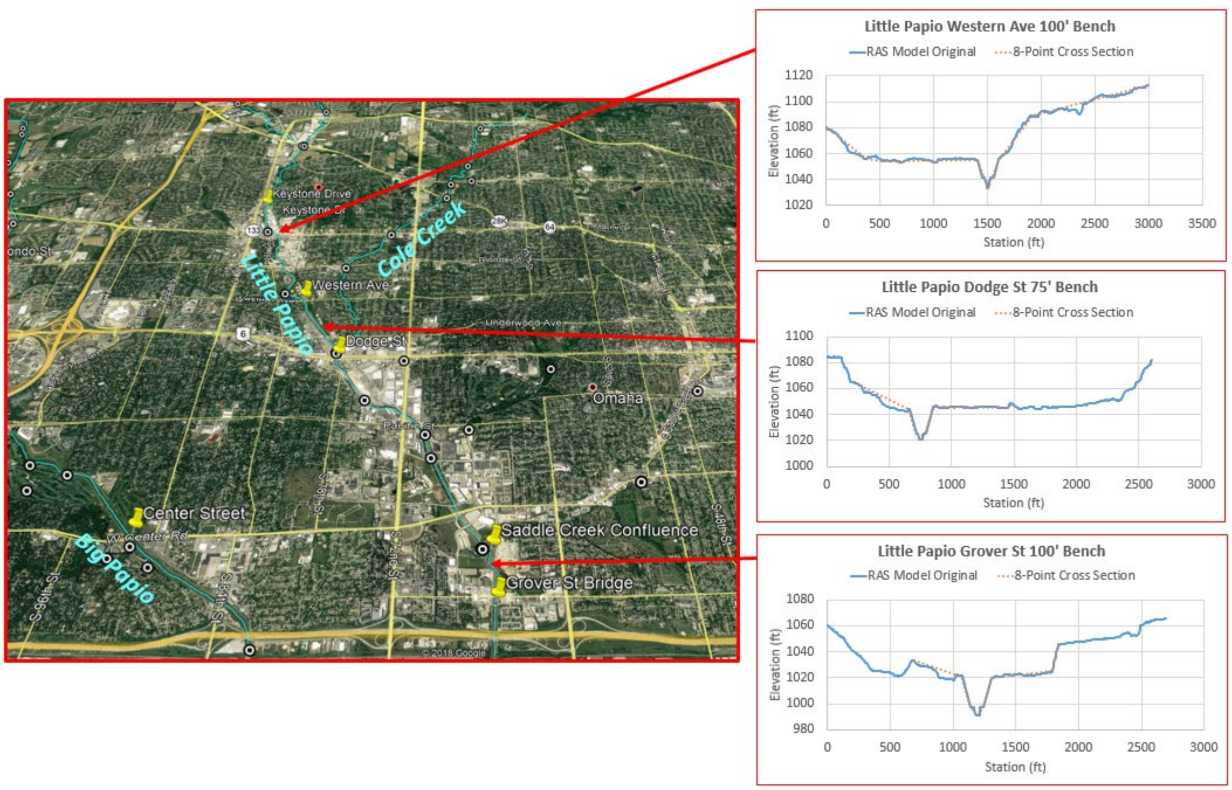


Figure 25. Channel Modification Little Papillion. Modified HEC-RAS channel cross section shown with simplified 8-point cross section.

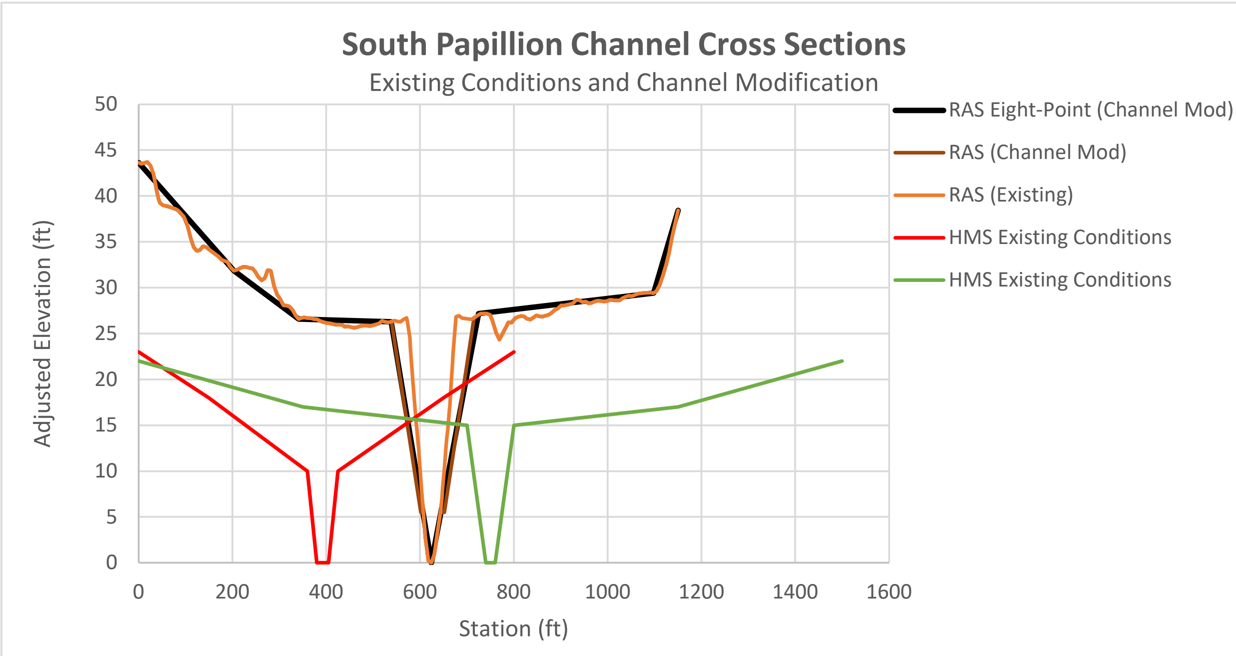


Figure 26. South Papio HEC-HMS cross sections of existing conditions model and model with channel modifications. The cross section in black is the eight-point cross section shown in the previous figures determined from the HEC-RAS model data. The other cross sections are those originally in the HEC-HMS existing conditions model.

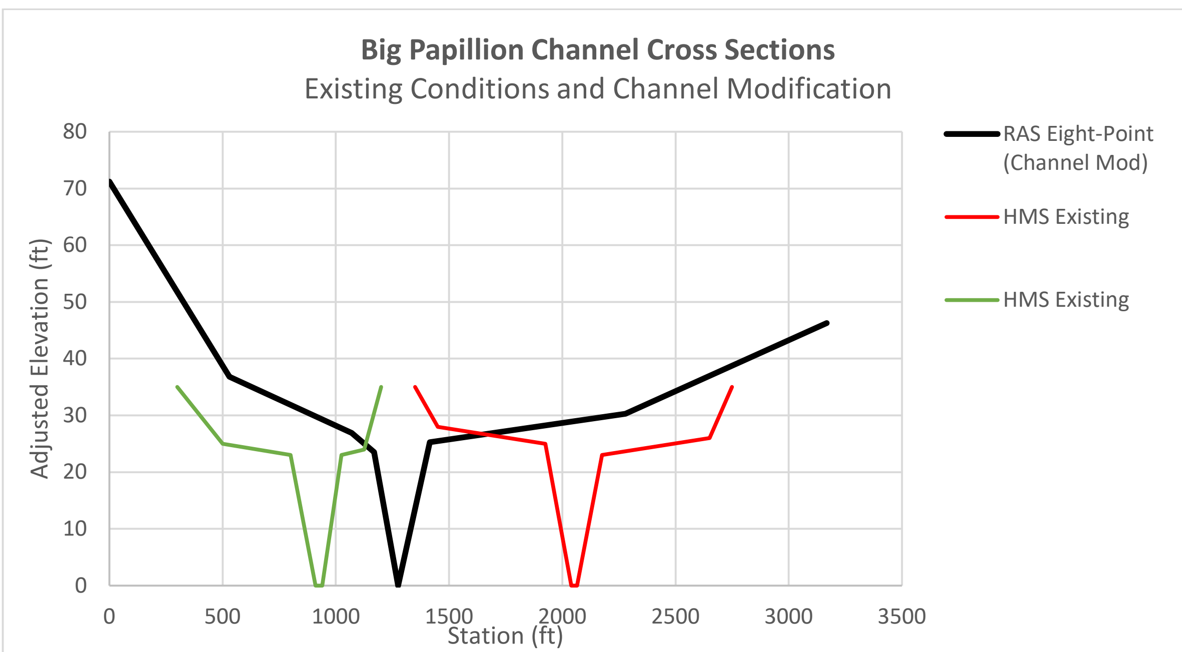


Figure 27. Big Papio HEC-HMS cross sections of existing conditions model and model with channel modifications. The cross section in black is the eight-point cross section shown in the previous figures determined from the HEC-RAS model data. The other cross sections are those originally in the HEC-HMS existing conditions model.

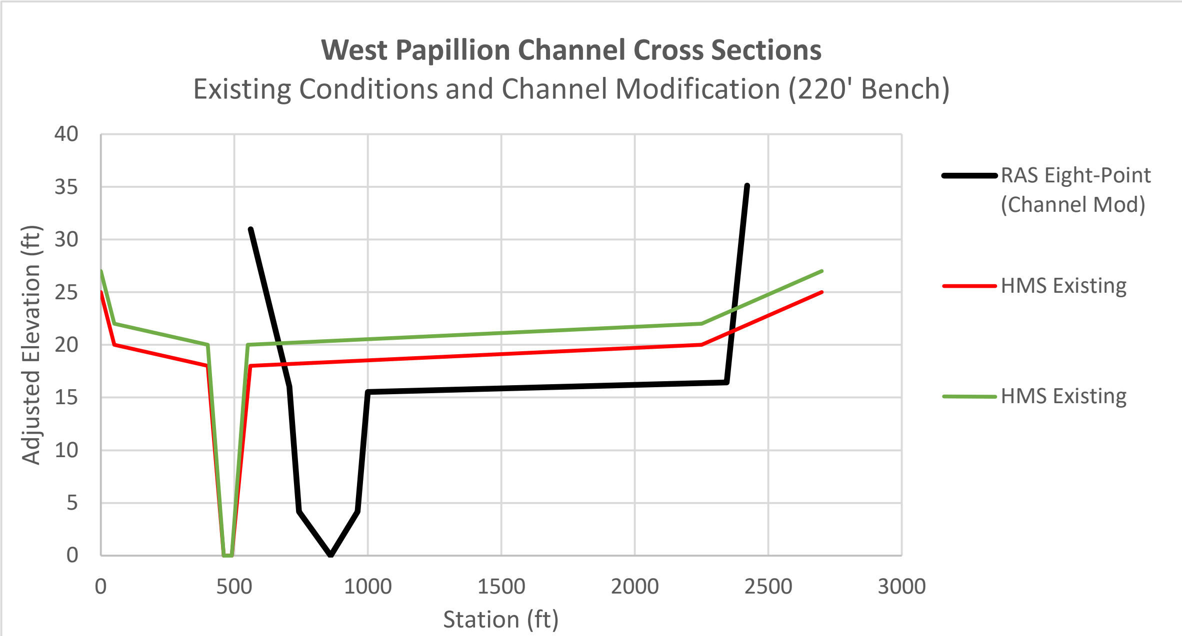


Figure 28. West Papio (220 ft bench) HEC-HMS cross sections of existing conditions model and model with channel modifications. The cross section in black is the eight-point cross section shown in the previous figures determined from the HEC-RAS model data. The other cross sections are those originally in the HEC-HMS existing conditions model.

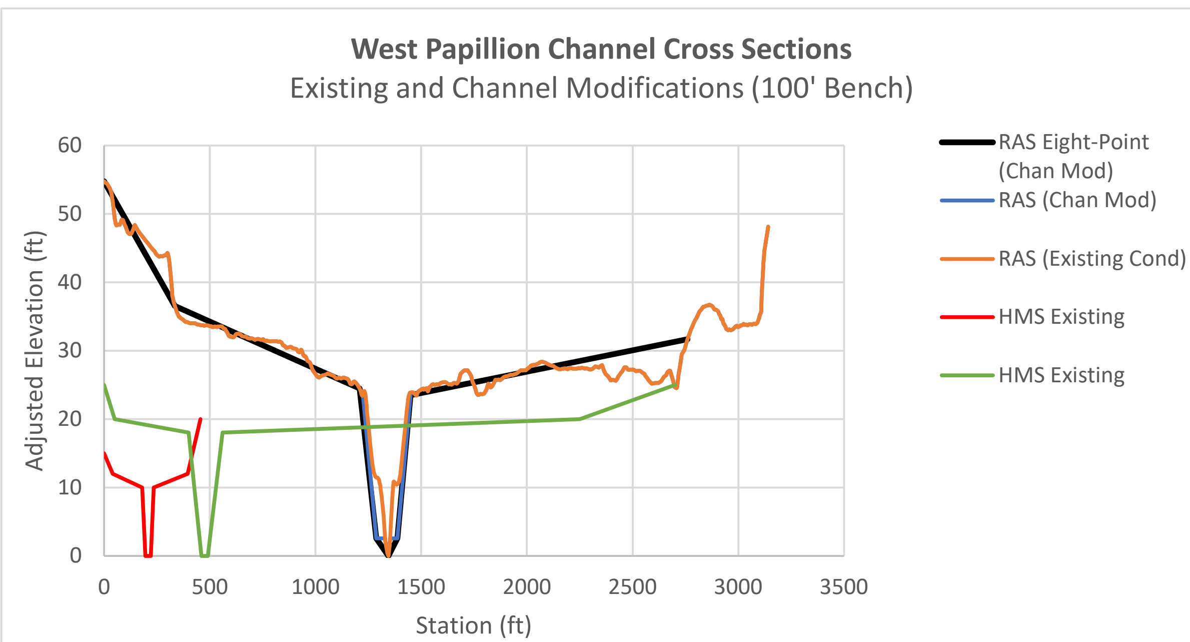


Figure 29. West Papio (100 ft bench) HEC-HMS cross sections of existing conditions model and model with channel modifications. The cross section in black is the eight-point cross section shown in the previous figures determined from the HEC-RAS model data. The other cross sections are those originally in the HEC-HMS existing conditions model.

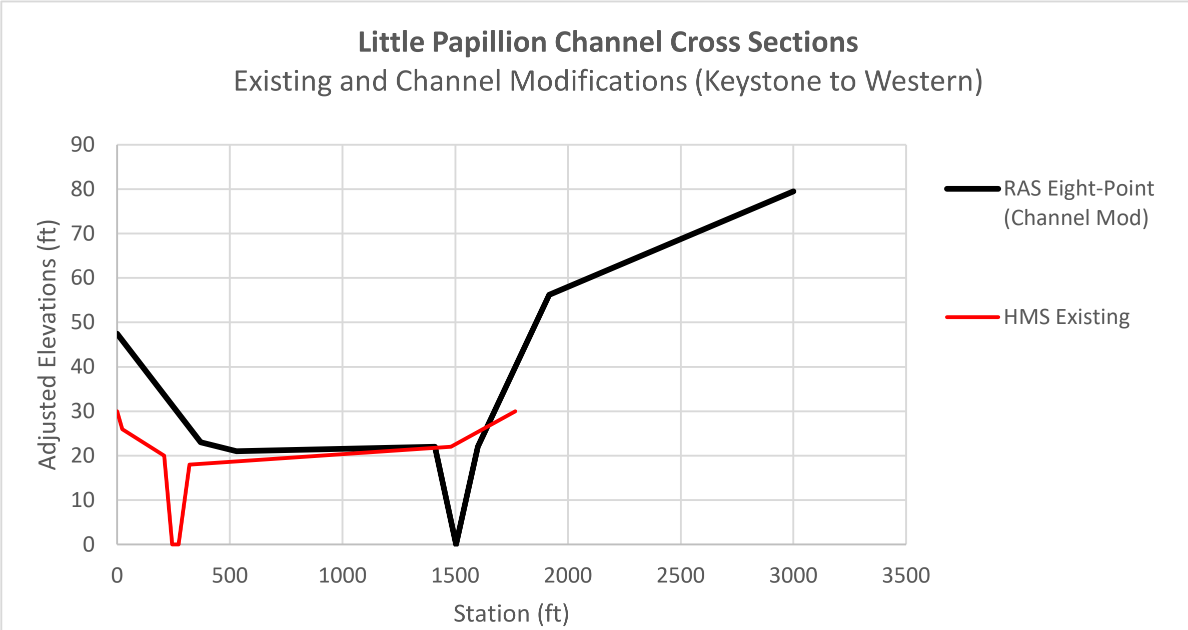


Figure 30. Little Papillion HEC-HMS cross sections of existing conditions model and model with channel modifications (Keystone to Western). The cross section in black is the eight-point cross section shown in the previous figures determined from the HEC-RAS model. The other cross sections are those originally in the HEC-HMS existing conditions model.

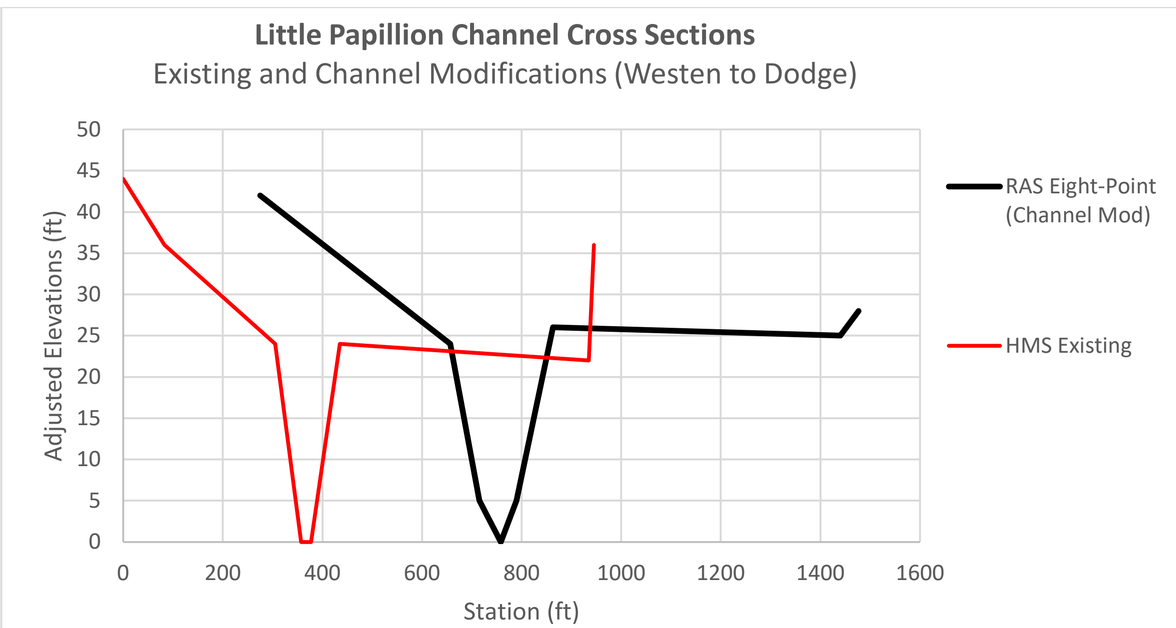


Figure 31. Little Papillion HEC-HMS cross sections of existing conditions model and model with channel modifications (Western to Dodge). The cross section in black is the eight-point cross section shown in the previous figures determined from the HEC-RAS model. The other cross sections are those originally in the HEC-HMS existing conditions model.

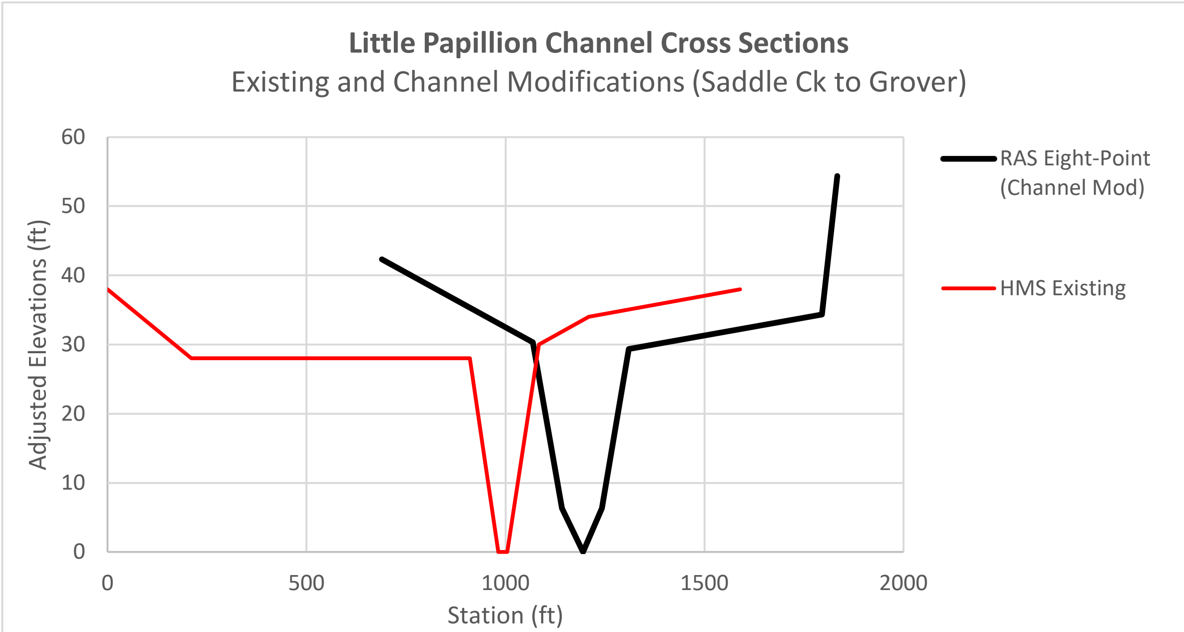


Figure 32. Little Papillion cross sections of existing conditions model and model with channel modifications (Saddle Ck to Grover)

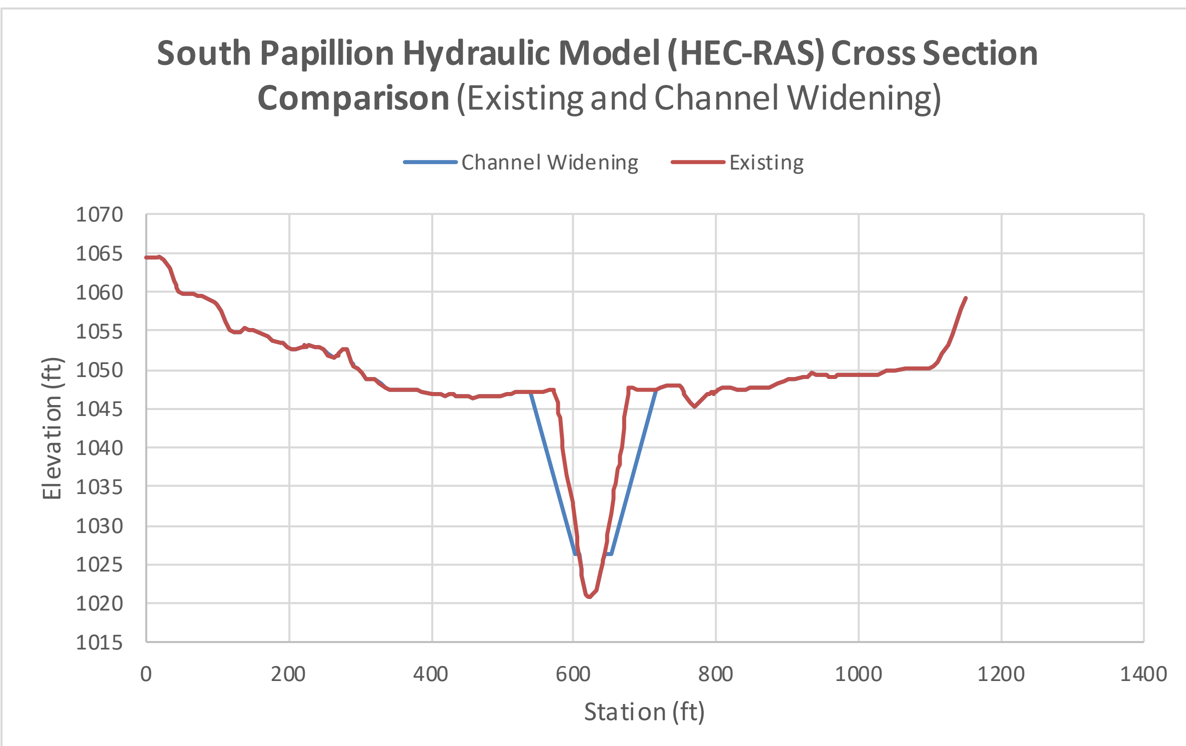


Figure 33. South Papillion HEC-RAS existing and widened channel cross sections. Used to illustrate channel deepening was not part of the channel modification.

12.2 Channel Modification Check Results

Table 8 through Table 11 show a summary of changes in peak flows with channel modifications. Changes larger than 15 percent in comparison with existing channels were flagged. Positive values mean that the peak flows increased with the channel modifications. The maximum, average, and minimum peaks are shown. Not all the peak flows in the modeling are shown.

Changes in peak flows with channel modification were considered negligible for South Papillion, Little Papillion, and Big Papillion. The 19-percent change in peak flows was investigated further for West Papillion Creek. It was determined that only one junction (WP-JCT-114 upstream of WP-JCT-115) created the large increase in peak flow that then continued downstream and that junction was at the confluence of West Papillion with South Papillion. Channel modifications on both reaches altered the shape and timing of the hydrographs into the confluence and resulted in this larger increase in peak flows as the hydrograph flows added together.

It was decided to maintain the peak flows in the HEC-RAS model and not provide updates from HEC-HMS and enter into iterative modeling. This was decided because additional time-consuming iterative modeling may not produce more realistic results for a screening-level analysis. In addition, the HEC-RAS modeling will be updated after the tentatively selected plan (TSP) to unsteady modeling so spending additional time on the current modeling will not carry through to the later stages of the project.

Figure 34 summarizes this finding by comparing the channel modifications hydrographs with the existing conditions hydrographs. Note that the 0.2 percent AEP (500 year) event with the 150 square mile storm area is used for all junctions in this figure for simplicity. In the model results, the 150 square mile storm area is used at the confluence and smaller storm areas are used for the two tributaries (West and South Papillion).

Table 8. South Papillion - Channel Mods Compared with Existing

Statistic	Existing Conditions vs Channel Modifications (%)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	3.6	6.6	6.2	6.5	6.3
min	0	0	-0.1	0	0
avg	0.6	0.9	0.8	0.9	0.9

Statistic	Existing Conditions vs Channel Modifications (cfs)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	330	800	910	1,140	1,600
min	0	0	-10	0	0
avg	51	111	120	159	215

Table 9. Big Papillion - Channel Mods Compared with Existing

Statistic	Existing Conditions vs Channel Modifications (% Difference)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	0	0.4	2.3	4.3	10.1
min	-0.9	-1.2	-0.6	-2.2	-2.2
avg	-0.2	0	0.2	0.4	1.7

Statistic	Existing Conditions vs Channel Modifications (cfs)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	0	140	880	1,860	5,840
min	-230	-230	-160	-500	-860
avg	-41	7	91	237	1,083

Table 10. Little Papillion - Channel Mods Compared with Existing

Statistic	Existing Conditions vs Channel Modifications (% Difference)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	0	0	0	0	2.6
min	-1.4	-1.2	-0.9	-0.8	-0.7
avg	-0.3	-0.3	-0.3	-0.2	0.4

Statistic	Existing Conditions vs Channel Modifications (cfs)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	0	0	0	10	610
min	-140	-180	-180	-180	-260
avg	-30	-41	-45	-45	102

Table 11. West Papillion - Channel Mods Compared with Existing

Statistic	Existing Conditions vs Channel Modifications (% Difference)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	3.8	11.2	17.2	21.2	19
min	-1.3	-0.4	0	0	0
avg	0.2	2.4	4.3	5.9	7.7

Statistic	Existing Conditions vs Channel Modifications (cfs)				
	10 YR	25 YR	50 YR	100 YR	500 YR
max	300	1,290	2,460	3,600	8,690
min	-190	-70	0	0	0
avg	-3	374	861	1,557	3,354

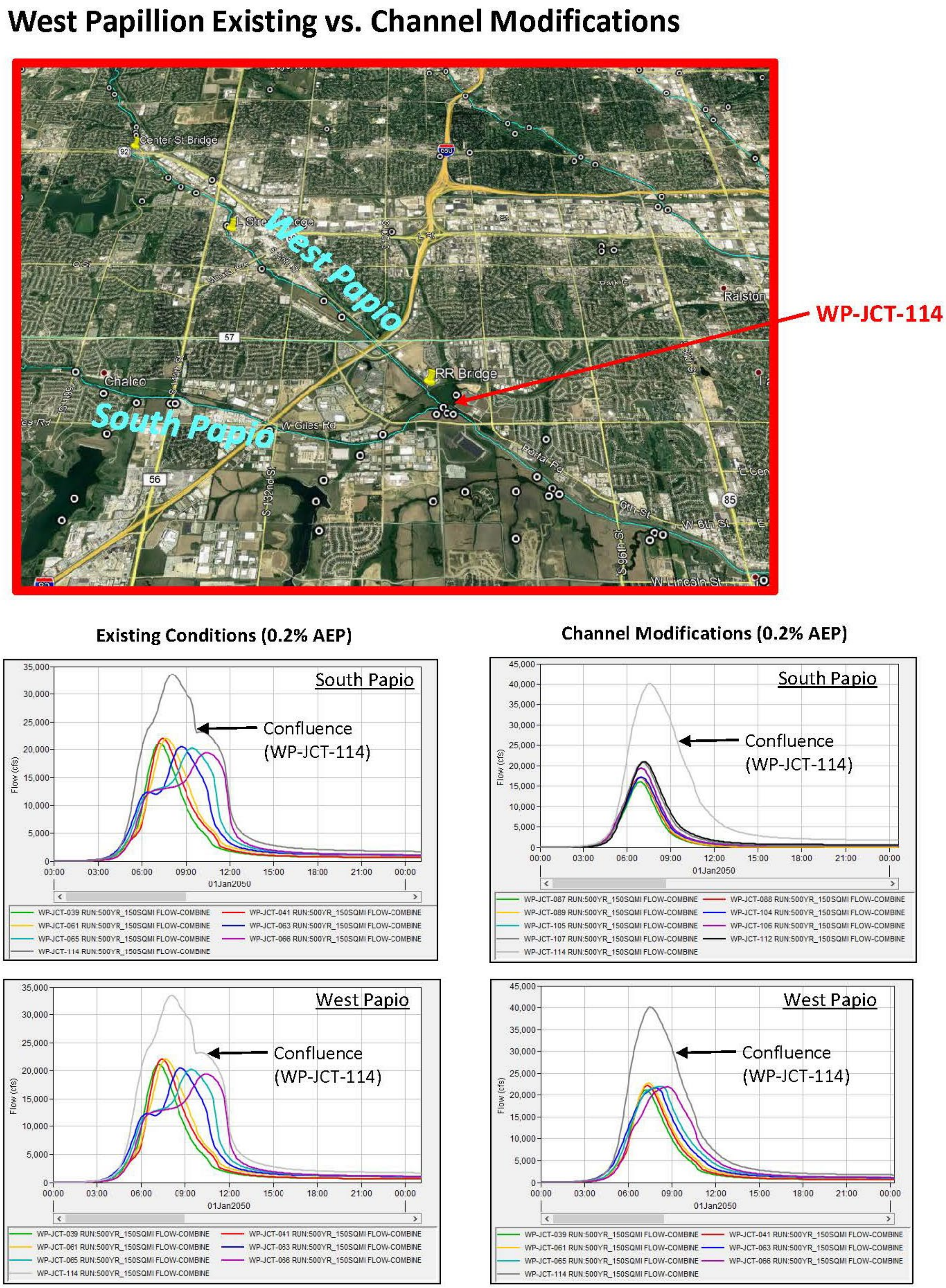


Figure 34. West Papillion & South Papillion Hydrograph Changes with Channel Modification. This figure shows that the large increase in peak flows at a single junction (WP-JCT-114) is the result of an alteration in hydrograph shape and timing of tributary hydrographs flowing into the junction.

13 TSP Dam Site 10 Update for Compliance with Current USACE Hydrologic Regulations

This section of the report was intended to assess the existing design of proposed Dam Site 10 (DS10) for compliance with current USACE regulations set forth by ER 1110-8-2(FR) *Inflow Design Floods for Dams and Reservoirs* (USACE, 1991). The existing design was prepared by USACE in 1975 and is documented in the Papillion Creek and Tributaries Lakes Nebraska Specific Design Memorandum NO. MPC-33 Site 10 (referred to as DM moving forward). Additionally, this analysis investigates an alternative design of the dam as a dry dam which has no permanent pool.

Note that this section's analysis was screening level with a high amount of uncertainty and the HMR51&52 maximum precipitation update was not specific to the DS10 site.

Refer to Appendix A-1 for site-specific modeling of DS10 that was undertaken after TSP.

The Papillion Creek and Tributaries Lakes, Nebraska project was authorized by the Flood Control Act of 1968 (Public Law 90-483, "substantially in accordance with the recommendations of the Chief of Engineers in Rouse Document No. 349, Ninetieth Congress"). Site 10 was one of the multipurpose dams and lakes recommended.

DS10 is located on Thomas Creek, a tributary of the Little Papillion Creek. The location is about 2.5 miles east and 0.5 mile north of Bennington, Nebraska, near Omaha, Nebraska. The dam and reservoir site is primarily in Douglas County, but about one-half of the drainage area is in Washington County, Nebraska. A map of the watershed as prepared by USACE in 1975 can be seen in Figure 35.

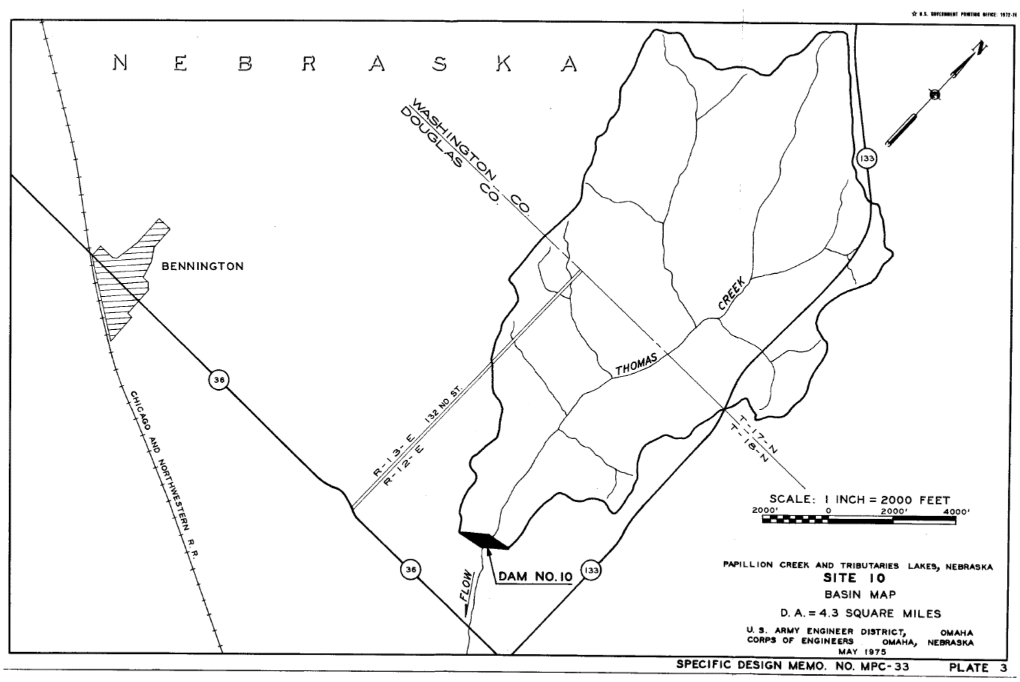


Figure 35. DS10 Drainage Basin Map (USACE, 1975)

13.1 HEC-HMS Model

Figure 36 shows the simple HEC-HMS version 4.2 model used in this section of the report. The 4.3 square mile Thomas Creek watershed was modeled as a single basin and DS10 used elevation-storage-discharge curves from the 1975 DM.

Note that this modeling was updated after TSP and is described in Appendix A-1 for DS10.

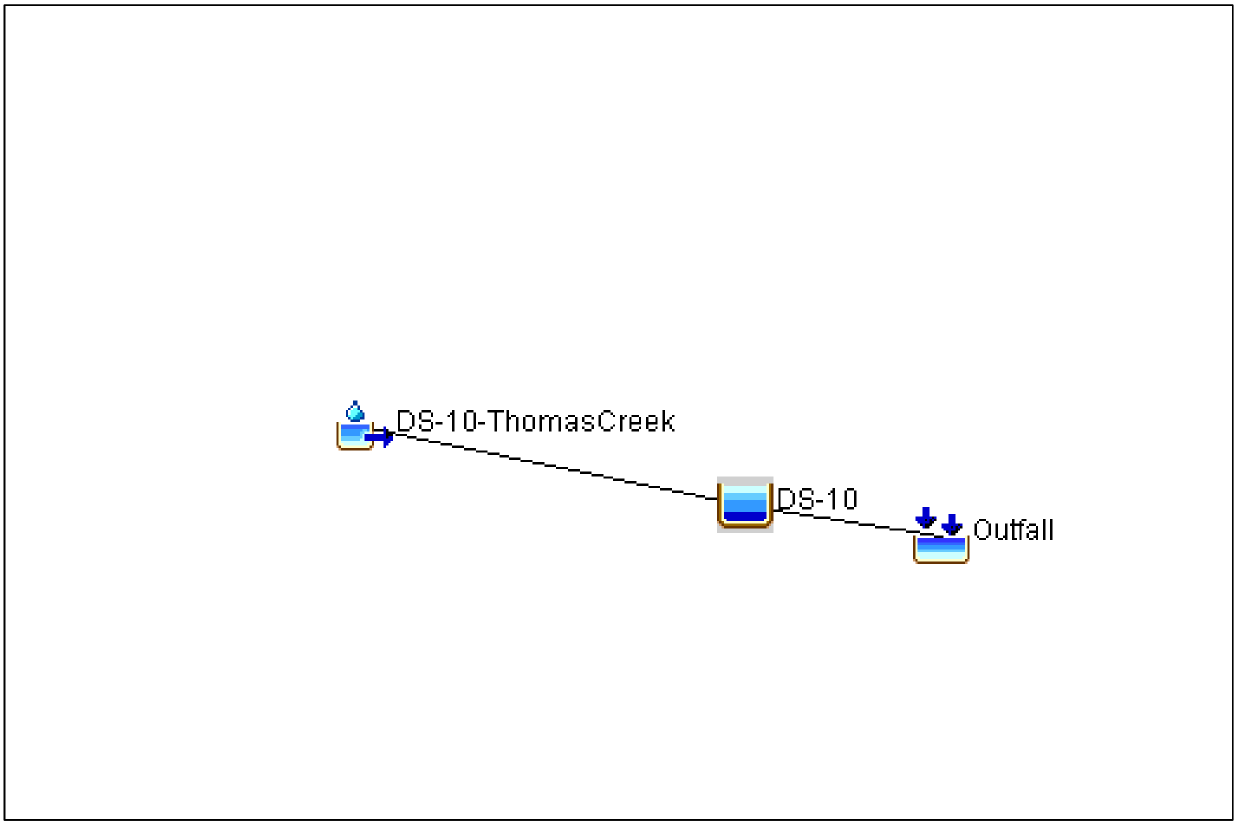


Figure 36. Simplified HEC-HMS model for DS10

13.2 Unit Hydrograph

The unit hydrograph used in TSP is from the 1975 design (USACE, 1975). This unit hydrograph was based on an analysis of available flood hydrograph data at the Irvington stream gaging station. The average 1-hour unit hydrograph developed for the Irvington location was converted to a 30-minute unit graph for use at DS10 in the 1975 design, since the drainage area for this site was small at only 4.3 square miles. The unit graph is shown in Figure 37. Also shown are the adjustments made in the natural condition unit hydrograph to reflect the effects of urbanization and inflow into full pool. The peaking effect for a major flood event was also considered in the unit graph adjustments. The adjusted unit graphs were used in developing the standard project and probable maximum inflow hydrographs for DS10 in the 1975 design.

Current regulations, ER 1110-8-2(FR), require unit hydrograph peaking of 25 to 50 percent. While the 1975 study predates the ER, hydrograph peaking was performed in the original analysis and was assumed sufficient for this screening-level assessment.

The unit hydrograph used in the Papillion Creek GRR study for the screening-level analysis was determined by reproducing the 1975 probable maximum flood (PMF) inflow with documented rainfall and watershed parameters. Figure 38 shows the model fit to the documented PMF in the old DM (USACE, 1975). This model used the Clark unit hydrograph method to represent the rainfall-runoff response of the watershed as opposed to entering the 30-minute unit hydrograph into the model so shorter time steps could be used if needed to capture the peak flow well. Reproducing the past PMF added more confidence in what was used in the past study and is helpful because many of the watershed parameters will remain consistent even though the PMP will be updated in this screening-level analysis.

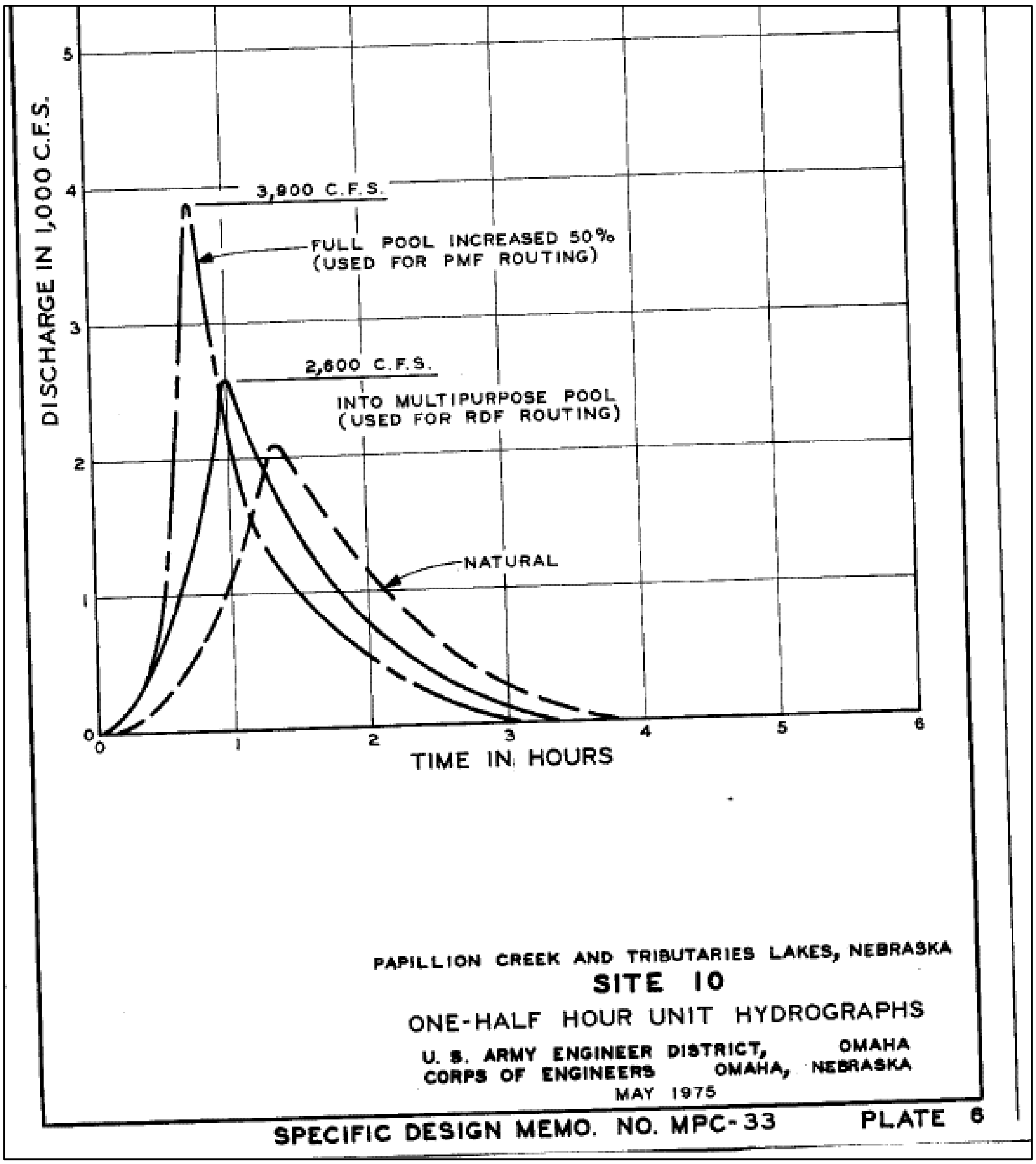


Figure 37. DS10 30-Minute Natural and Peaked Unit Hydrographs (USACE, 1975)

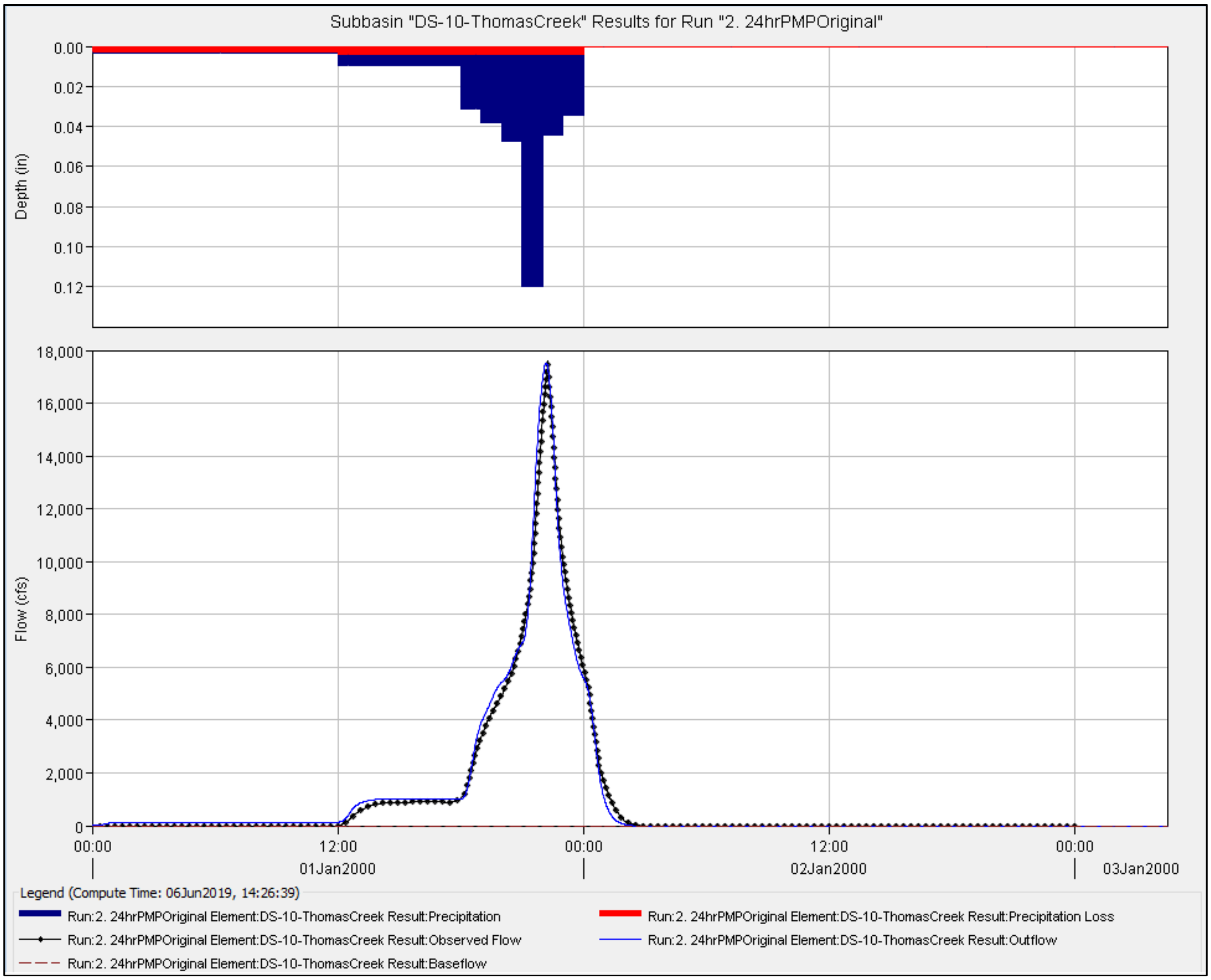


Figure 38. Adopted Reproduction of 1975 PMF into DS10. Tc = 0.7 hour and R = 0.38.

13.3 Precipitation

At the TSP level, the probable maximum precipitation (PMP) was updated from Hydrometeorological Report No. 33 (HMR 33) to an HMR 52 derived PMP. In an effort to use existing data to inform the TSP, it was determined applicable to use the existing PMP for the 5.9 square mile drainage area Papillion Creek Dam Site 16 (Standing Bear) developed by WEST Consultants, Inc (2013). Both HMR 33 rainfalls for the PMP totaled 24.86 inches in 24 hours so direct use of the DS-16 data for DS10 is prudent. HMR 52 produces a rainfall event totaling 33.27 inches in 24 hours, an increase of over 8 inches. A comparison of the HMR 52 and HMR 33 PMPs from DS16 by WEST is shown in Figure 39.

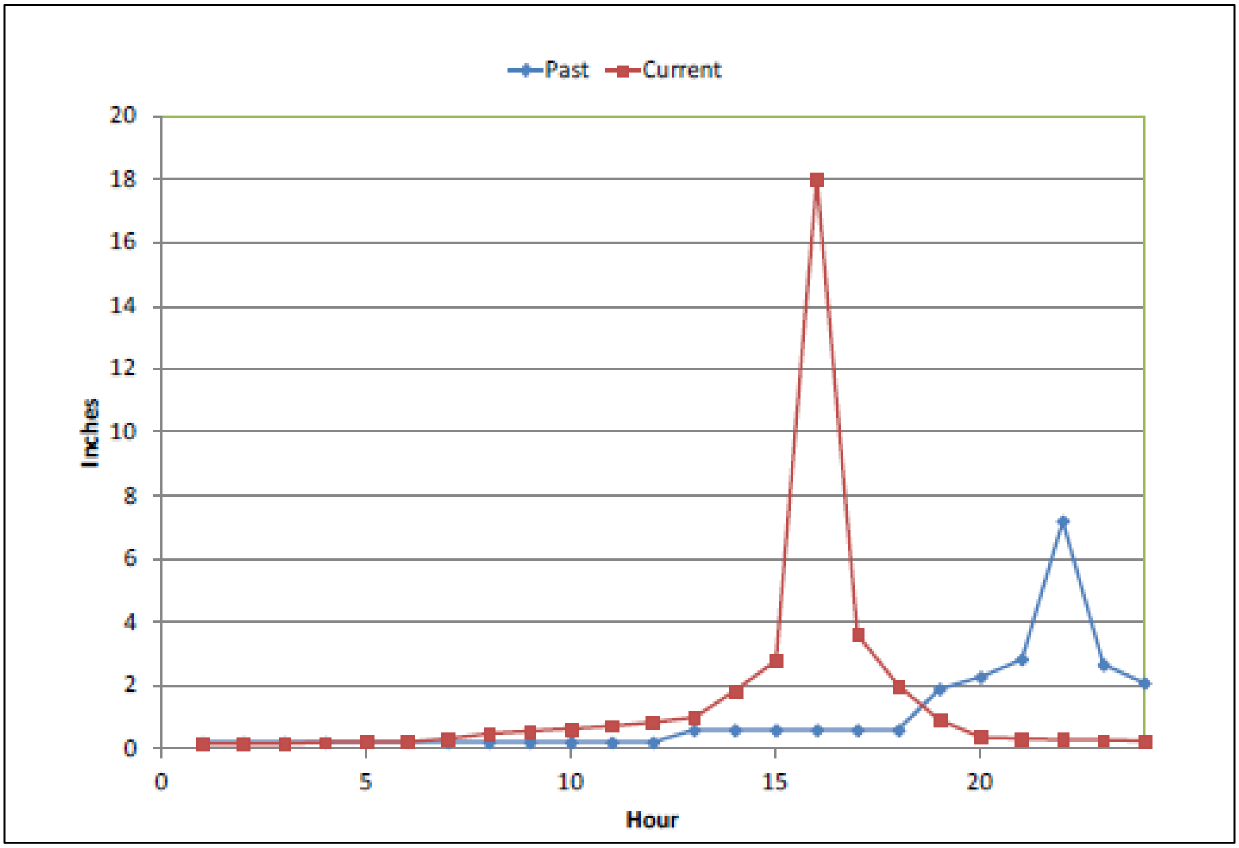


Figure 39. Comparison of DS16 HMR 52 and HMR 33 PMPs from WEST 2013.

13.4 Original Design

The following screen captures from the USACE Design Memorandum (DM) (USACE, 1975) provide pertinent original dam design information for DS10. The m.s.l. datum is the local project (LP) datum. DS10 is close to the existing Cunningham Lake (DS11) where the vertical datum conversion is NAVD88 elev = LP elev + 0.243 ft. This is the vertical datum conversion used for this proposed site in later sections involving real estate.

1.6 Sediment. The sediment storage allocation for Site 10 was based on a varying sedimentation rate. A detailed discussion of these rates is included in Section II of this report. The estimated 100-year sediment deposition for Site 10 is 880 acre-feet in the multi-purpose pool and 150 acre-feet in the lower portion of the flood control zone.

1.7 Multipurpose Pool. The multipurpose pool elevation selected for the Site 10 reservoir is 1188.5 feet, m.s.l. This will provide adequate storage space for the required sediment deposition (880 acre-feet) plus a small increment of storage (260 acre-feet) that can be utilized for making releases into Little Papillion Creek for environmental and aesthetic purposes. The additional 260 acre-feet does not significantly affect design features of the dam such as spillway crest elevation or top of dam.

1.8 Reservoir Design Flood. The standard project flood has been selected as the reservoir design flood for all of the proposed Papillion Creek dams. Rainfall values for the Site 10 standard project storm were taken from EM 1110-2-1411. Losses of 3.00 inches initially and 0.30 inch per hour infiltration were used for the 75 percent of the area that is expected to remain pervious in character after urbanization of the basin. For the remaining 25 percent of the area, which was assumed to be pavement or roof-tops, runoff was assumed to be 100 percent. Runoff was, therefore, computed for both the pervious and impervious areas and then weighted to obtain total runoff for the basin. The rainfall, loss and runoff values are shown in Table 3. The standard project flood hydrograph for the period affecting the peak discharge is shown on Plate 7. The total 96-hour volume of the standard project flood is 2246 acre-feet, including 96 acre-feet of base flow runoff (12 c.f.s. for 96 hours).

1.9 Reservoir Design Flood Routing. The reservoir routing for the standard project flood at Site 10 is shown on Plate 7. A reservoir drawdown curve showing the elapsed time required to evacuate the reservoir from the top of flood control elevation to the conservation pool is presented on Plate 8. These data indicate that 50 percent of the flood control storage can be evacuated in 3.3 days and 75 percent in about 5.1 days.

1.10 Spillway Design Flood. The probable maximum flood has been selected as the event to be used in designing emergency spillways for the Papillion Creek dams. Rainfall values for the probable maximum storm were taken from Hydrometeorological Report No. 33 with an adjustment as outlined in EC 1110-2-27. The maximum 24-hour period of the storm was used in the computation for Site 10. Losses were the same as for the standard project flood, except it was assumed that the initial loss is satisfied prior to the maximum 24-hour storm period. The rainfall, loss and runoff values are shown in Table 4. The probable maximum flood hydrograph, which has a peak discharge of 17,600 cubic feet per second and a volume of 4,700 acre-feet, including base flow, is shown on Plate 9.

1.11 Spillway Design Flood Routing. Numerous reservoir routing studies for the probable maximum flood were made for Site 10 in order to determine the most economical earthwork balance between spillway excavation and embankment height that would meet the criteria of limiting the maximum spillway velocity to 6 feet per second. The selected spillway design based on these studies is 320 feet wide with a crest elevation of 1202.0 feet, m.s.l. The results of routing the probable maximum flood through the reservoir with this spillway under varying beginning pool conditions are summarized in Table 5. The inflow-outflow hydrographs and pool elevation curve for the condition beginning with a half-full flood control pool are shown on Plate 9.

TABLE 5
RESERVOIR ROUTING SUMMARY FOR PROBABLE MAXIMUM FLOOD

Beginning Pool Condition Description	Elevation (feet, m.s.l.)	Maximum Pool Elevation (feet, m.s.l.
Flood control pool empty	1188.5	1206.3
*Flood control pool ½ full	1195.3	1207.2
Flood control pool full	1200.4	1207.9

* Selected design condition.

1.12 Freeboard - General. Freeboard for the Papillion Creek dams will, in general, be based on the criteria outlined in EC 1110-2-27. It is proposed to provide, as a minimum, the higher of either: (1) 3.0 feet above freeboard reference level "B" (full pool routing of SDF); or (2) 5.0 feet above freeboard reference level "C" (half-full pool routing of SDF). An exception to these minimum criteria is proposed for the dams controlling smaller drainage areas. It is proposed for these smaller areas that the minimum freeboard be established at 3.0 feet above reference level "C", provided that the conditions outlined below can be met.

1.12.1 The drawdown time from top of flood control to half-full flood control pool is 5 days or less.

1.12.2 For the spillway design flood routing beginning at a half-full flood control pool, the duration of pool level within 5.0 feet of embankment top does not exceed 12 hours.

1.12.3 The design wave run-up plus set-up is 3.0 feet or less.

1.12.4 The spillway design flood routing beginning on full flood control pool does not overtop the embankment.

1.13 Freeboard - Site 10. For Site 10 the conditions discussed above are as follows:

1.13.1 Drawdown time from top of flood control pool to half-full flood control pool is 3.3 days (see Plate 8).

1.13.2 Duration of pool level within 5.0 feet of embankment top for SDF routing on half-full flood pool is about 4.0 hours (see Plate 9).

1.13.3 Design wave run-up plus set-up is 3.1 feet.

1.13.4 Maximum pool reached in routing SDF on full pool is 2.6 feet below embankment top.

1.14 The results of flood routings summarized in paragraph 3.13 show that Site 10 meets criteria for 3.0 feet of freeboard. Reservoir drawdown time to a half-full flood control is only 3.3 days. The other criteria for 3.0 feet of freeboard are easily met. It is proposed to establish the top of dam at elevation 1210.5 feet, m.s.l. which will provide 3.3 feet of freeboard.

1.16 Storage Allocations. The proposed storage allocations for Site 10 are given in Table 6.

TABLE 6
STORAGE ALLOCATIONS - SITE 10

Purpose	Elevation Range (feet, m.s.l.)	Incremental Storage (acre-feet)	Gross Storage (acre-feet)
Sediment and Water Quality	1170.0 to 1188.5	1,140	1,140
Flood Control	1188.5 to 1200.4	1,957	3,097
*Surcharge	*1200.4 to 1202.0	403	3,500
	*1202.0 to 1207.2	1,350	4,850
Freeboard	1207.2 to 1210.5	1,050	5,900

The total surcharge storage from top of flood control to the design maximum pool elevation is 1,753 acre-feet, of which 403 acre-feet are between top of flood control (1200.4) and spillway crest (1202.0) and 1,350 acre-feet between spillway crest and design maximum pool elevation (1207.2).

The proposed flood control storage space of 1,957 acre-feet is based on the standard project flood reservoir routing shown on Plate 7.

SECTION IV - HYDRAULICS

1. OUTLET CAPACITIES: The capacities of the outlet were determined from consideration of the following general criteria:

1.1 The reservoir releases for the more frequent floods will be restricted in order to provide a high degree of downstream flood protection. This will include consideration of coincident flows from other proposed reservoirs within the basin.

1.2 For floods up to and including the reservoir design flood, the discharges from the outlet works will not exceed the bankfull capacity of the downstream channel.

1.3 The outlet works will have sufficient capacity to evacuate 75 percent of the reservoir design flood (SPF) within ten days in order to provide flood storage for possible recurring events. Table 9 indicates the maximum releases through the outlet works for various flood frequencies, the relationship of these discharges with the drainage area, and the existing bankfull capacity:

TABLE 9
PEAK OUTLET WORKS RELEASES

	50 yr. Flood	100 yr. Flood	Reservoir Design Flood	Channel Bankfull Capacity
Discharge capacity, c.f.s.	68.	90	190	2800
Unit discharge, cfs/sq. mi.	16.45	21.38	23.16	169
Downstream channel depths, ft.	4.8	4.8	5.0	10.0
Percent bankfull capacity	9	12	13	100

9. EMERGENCY SPILLWAY: The emergency spillway will consist of an open channel through the right abutment. In section the channel

would have a 320-foot bottom width with 1V on 3H side slopes. In profile it would have a 200-foot flat crest near the upstream end at elevation 1202.0. Downstream of the crest section the channel will have a bed slope of 0.002. Total length of the spillway will be about 950 feet. The emergency spillway rating curve shown on Plate 14 was developed from water surface profiles computed by standard backwater methods. A relatively high Manning's "n" value of 0.030 was selected to allow for variations in vegetative growth on the spillway and some localized erosion. An estimated entrance loss of 0.20 V^2 /2g was used. A critical depth control will occur where the spillway channel emerges from the hillside. Flow will be subcritical for the entire length of the spillway, and velocities will become progressively higher as flow progresses downstream. Any erosion, which would most likely start at the downstream end, must progress the entire length of the spillway before the changes to the spillway design flood will occur. The maximum discharge from the emergency spillway would be 8400 c.f.s. Critical depth and critical velocity at the spillway exit will be 2.75 feet and 9.3 ft/sec., respectively. Maximum velocity at the downstream end of the crest section would be 5.76 ft/sec., and at the upstream end of the crest section, the maximum velocity would be 4.63 ft/sec. Duration of high flows would be very short. Flows would exceed 6,000 c.f.s. for about 3 hours and 3,000 c.f.s. for 4 hours. The entire spillway channel will be excavated in loess. In order to reduce the potential for erosion, the downstream end of the channel will be overexcavated approximately 5 feet and backfilled with compacted material.

In summary, according to the DM, DS10 was designed with the following criteria:

- Spillway design flood was the probable maximum flood (PMF) determined from a 24-hour PMP calculated with HMR No. 33 methods with adjustments made based on EC 1110-2-27 guidance. The initial loss was zero inches (saturated conditions) and the constant loss rate was 0.3 inches per hour. The watershed upstream (drainage area 4.3 square miles) was assumed to have 25 percent impervious surface. The antecedent reservoir elevation was assumed to be with half the flood pool filled. The PMF event for this watershed had a peak discharge of 17,600 cfs and a volume of 4,700 AF. The adopted antecedent pool elevation was 1195.3 feet-PD (flood control pool ½ full) and the maximum pool was 1207.2 feet-PD.
- Reservoir design flood was assumed to be a standard project flood (SPF) produced from 15.81 inches over 96 hours. The initial soil loss rate before the flood was assumed to be 3 inches and the constant loss rate was 0.3 inches per hour.
- Unit hydrographs for the rainfall-runoff response were determined from available flood hydrograph data available at the Irvington stream gauge station. This was converted from a 1 hour to a 30 minute unit hydrograph for DS10 due to the small size of the watershed (4.3 square miles). Adjustments were made to the natural conditions unit hydrograph to reflect urbanization. Peaking was also applied to the unit hydrograph to better represent a major flood event. The unit hydrograph with these adjustments was used for both the spillway design flood (PMF) modeling and the reservoir design flood, which was the outdated standard project flood (SPF).

The reproduction of the original design focused on the spillway design flood, the PMF. After the PMF was reproduced in HEC-HMS, the dam itself was added to the model based on curves in DM No. MPC-33. The PMF was routed through the dam with a starting elevation of 1195.3 feet-PD (flood control pool ½ full). This PMF routing in the old DM assumed that both the outlet (with coefficient 0.75) and the spillway were operational; the maximum PMF pool reached 1207.1 ft-PD. The maximum pool elevation documented in DM No. MPC-33 was 1207.2 ft-PD.

Table 12 shows the adopted model parameters for the reproduction of the 1975 PMF. This reproduction of the 1975 PMF modeling and dam outflow was assumed acceptable. Table 13 and Figure 40 show these results.

Table 12. Adopted 1975 PMF Reproduction Model Parameters for TSP

Model Parameter	Value
General	
Storage Area (square miles)	4.3
24-hour PMP total depth (inches)	24.85
24-hour PMP max hour depth (inches)	7.2
Soil Loss	
Initial soil loss (inches)	0
Constant soil loss rate (inches per hour)	0.3
Percent imperviousness	25
Rainfall-Runoff Transform	
Clark unit hydrograph time of concentration (tc, hours)	0.7
Clark unit hydrograph storage – R	0.38
Model	
Computation time steps (minutes)	1

Table 13. Comparison of 1975 DM and Reproduced Results

	1975 DM	Reproduction
Max PMF Inflow (cfs)	17,600	17,500
Max PMF Outflow (cfs)	8,400	8,400
PMF Inflow Volume (AF)	4444	4667
Max Pool Elevation (ft-PD)	1207.2	1207.1

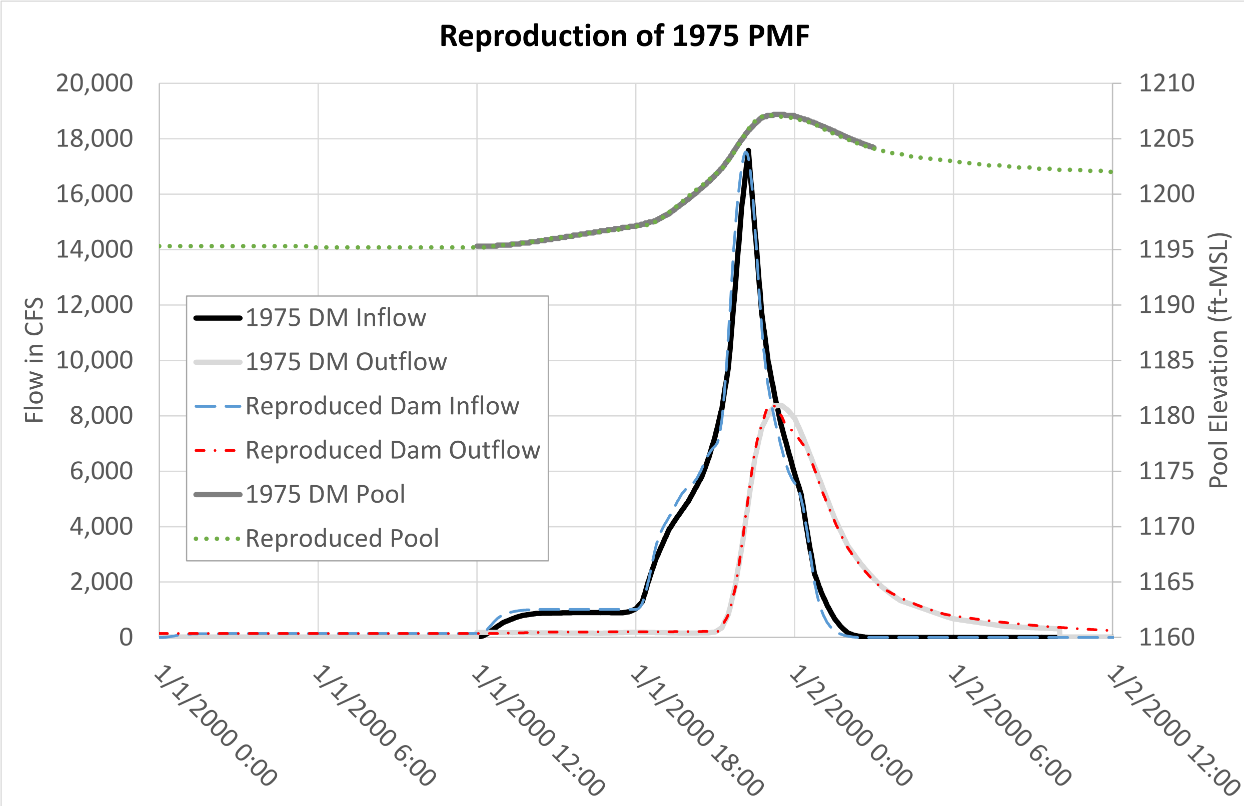


Figure 40. 1975 PMF Adopted Reproduced Results. MSL is project datum (PD).

13.5 Inflow Design Flood and Reservoir Routing Update

The original model developed inflow design flood hydrographs based on guidance from the time period. In addition to tentatively updating the PMP with existing information at TSP, other ER 1110-8-2(FR) changes included in this analysis were:

- Minimum starting elevation for routing the IDF will be assumed as the full flood control pool level or the elevation prevailing five days after the last significant rainfall of a storm that produces one-half the IDF, whichever is most appropriate. The top of flood control pool was assumed for this cursory update.
- Reservoir regulation outlets should not be assumed operable during the occurrence of an IDF.

The original design routings assumed a starting pool of one half the flood pool filled (1195.3 ft-PD) and assumed the outlet works operable. These assumptions were updated to a starting pool at the top of the flood pool (1200.4 ft-PD) and outlet works inoperable. The spillway was unchanged with a perched crest elevation of 1202.0 ft-PD.

13.6 Results

The original PMF peak inflow to the reservoir was 17,600 cfs and it produced a maximum pool elevation of 1207.2 ft- PD. The updated peak inflow to the reservoir is 35,000 cfs and produced a maximum pool elevation of 1210.0 ft-PD. If the reservoir design was to remain the same, in order to adhere to the minimum freeboard requirements of an assumed 3 feet, the dam would need to be raised 2.5 feet from an elevation of 1210.5 ft-PD to an elevation of 1213.0 ft-PD with the updated HMR 52 PMF.

Another scenario was tested to see how the reservoir would perform if it was a dry dam with no sediment and water quality pool. The original design assumed a sediment and water quality pool with storage of 1140 acre feet. For this scenario the flood control pool was lowered 1140 acre feet for the dam with the permanent pool to 1957 acre feet, an equivalent elevation of about 1194 ft-PD, which is an 8 foot drop from original design. The resulting maximum pool elevation during PMF routing was 1202.5 ft-PD, which leaves 8 feet of freeboard. A reconfiguration of dam height and spillway size would be warranted as 8 feet of freeboard is likely excessive. Also, cutting a spillway to a lower elevation and reducing the dam height would likely lead to an excess of fill.

No optimization in spillway cut and embankment fill was assessed at this point in the study. Theoretically, there is some elevation between 1194 ft-PD (dry dam top of flood control) and 1200.4 ft-PD (wet dam top of flood control) to which the spillway could be lowered, assuming a dry dam, to meet minimum freeboard requirements.

Another scenario was tested that assumed the original design spillway elevation was lowered 1.6 feet from its perched elevation of 1202.0 ft-PD to the top of flood pool elevation of 1200.4 ft-PD. For this scenario the maximum pool elevation was 1208.6 ft-PD. If the reservoir design was to remain the same, in order to adhere to the minimum freeboard requirements, the dam would need to be raised 1.1 feet from an elevation of 1210.5 ft-PD to an elevation of 1211.6 ft-PD if three feet freeboard is decided to be sufficient.

Results are summarized in Table 14. Note that these dry dam results are different from those presented in an earlier section because they use different elevation-storage curves and this section's analysis includes routing over the spillway. The elevation-storage curve used in this analysis was the DS10 curve in the 1975 DM (USACE, 1975). This is different from the curve used in earlier dry dam analysis where the 2004 HDR report elevation-storage curve was used. The 2004 curve was estimated from a 30-meter DEM. Due to this difference in input data and analysis method, the results are not comparable.

Table 14. DS10 Reservoir Routing Summary

Updated PMF Scenario	Dam Overtopped	Max Pool Elevation (ft-PD)	Freeboard (ft) (1210.5 ft-PD Top of Dam)	Required Dam Height/ Increase with min. freeboard (ft) [1]
Updated Base	No	1210.0	0.5	1213.0 / 2.5
Dry Dam	No	1202.5	8.0	1205.5 / -5.0 [2]
Lower Spillway to Top of Flood Pool	No	1208.6	1.9	1211.6 / 1.1

[1]Minimum freeboard assumed to be 3 feet.
[2]No dam raise needed; can lower dam height 5 feet

13.7 Conclusion

The original dam design for DS10 completed by the USACE back in 1975 is inadequate to pass the updated IDF based on methodology and requirements in ER 1110-8-2(FR) and HMR 52. In order to meet these requirements, and assuming the outlet works and spillway assumptions from 1975, it is estimated that a minimum dam crest elevation of 1213 ft is necessary, which involves a dam raise of 2.5 feet to include a minimum freeboard of 3 feet.

If the dam was repurposed to be a dry dam, the crest of the spillway could be lowered 8 feet to elevation 1194 ft-PD and the dam crest could be as low as 1205.5 ft-PD, which is 5.0 feet lower than the current design. Again, this is a TSP level analysis and was refined later and presented in Appendix A-1 for DS10. In addition, lowing the spillway 1.6 feet from the original designed perched elevation to the top of flood control pool elevation results in a max pool of 1208.6 ft-PD. In order to meet minimum freeboard requirements, it is estimated that a minimum dam crest elevation of 1211.6 ft-PD is necessary, which is a dam raise of 1.1 feet.

Note that this analysis used the 1975 USACE elevation-storage curve and not the 2004 HDR curve that Section 10 of this report uses. There is a significant difference between the two curves (almost 15 feet). This difference is noted in the section of study risks. The 2004 HDR analysis sets the TOD at 1189 ft-NGVD29 for the middle pool scenario with freeboard determined with the freeboard hydrograph event (FHE). The storage at this elevation based on the 2004 HDR curve is 3834 AF. Then this same storage is considered with the 1975 USACE DM curve, the TOD elevation is 1202.8 ft-NGVD29. This is almost a 15-foot difference.

14 TSP Dam Site 19 Update for Compliance with Current USACE Hydrologic Regulations

This section of the report was intended to assess the existing design of proposed Dam Site 19 (DS19) for compliance with current USACE regulations set forth by ER 1110-8-2(FR) *Inflow Design Floods for Dams and Reservoirs* (USACE, 1991). Additionally, this study will investigate alternative designs as a dry dam where there is no permanent pool. This section uses the NAVD88 vertical datum to remain consistent with the HDR study from which the modeling data were drawn.

Note that this analysis is still screening level. In particular, the HMR51&52 maximum precipitation update was not specific to the DS19 site. and not site-specific in terms of the probable maximum precipitation (PMP). It also uses the HDR design as a starting point, and this design is not to USACE standards. For this reason, the analysis has a high amount of uncertainty that will be decreased later in the study when a site-specific PMP is developed and modifications are made to bring the design more in-line with USACE standards.

Refer to Appendix A-2 for the more in-depth update of DS19 to site-specific data after TSP.

14.1 HEC-HMS Model

Figure 41 shows the HEC-HMS version 4.3 model used in this section of the report. The 4.3 square mile contributing area is modeled as three subareas (areas 0.94, 1.75, and 1.63 square miles) and the dam elevation-storage-discharge curves are from the 2018 HDR study.

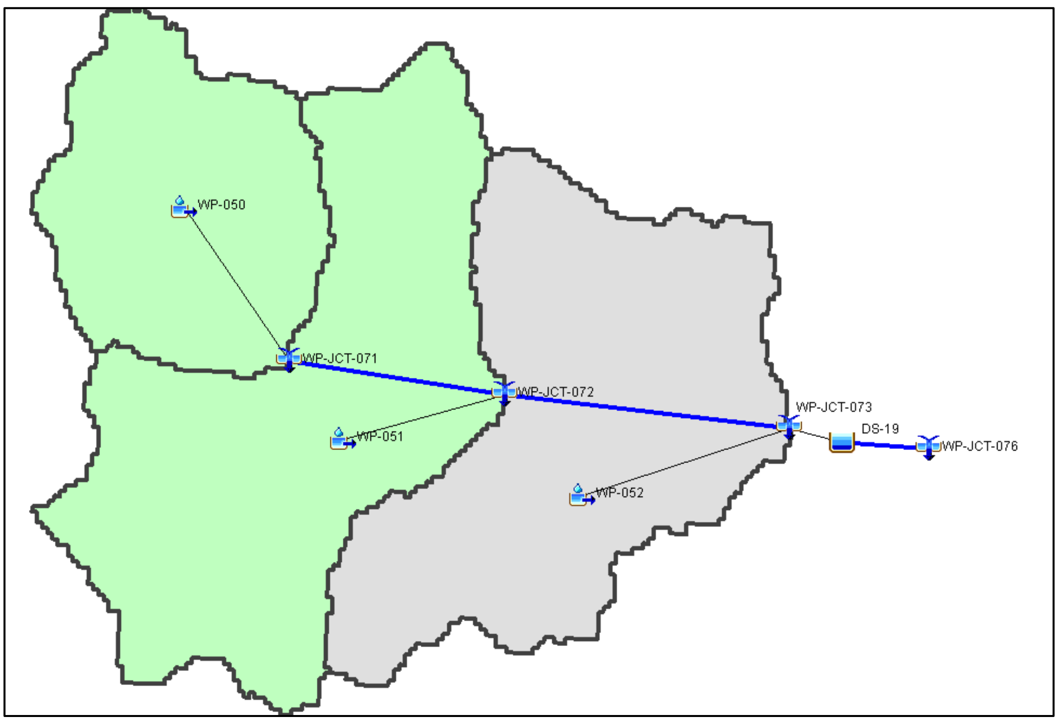


Figure 41. HMS model for DS19

14.2 Unit Hydrograph

A map of the watershed as prepared by HDR can be seen in Figure 42. The original model used Clark unit hydrograph parameters for three subbasins (subareas of 0.94, 1.75, and 1.63 square miles) that make up the proposed dam's 4.3 square mile watershed. The Clark parameters were assumed representative of the subbasins for this assessment and were not investigated further; however, the original unit hydrograph was peaked by 50 percent to account for the basin's nonlinear response to large storm events such as the probable maximum precipitation (PMP). The hydrograph peaking and updated Clark parameters can be seen in Table 15 and Figure 43.

Table 15. Unit Hydrograph Peaking Summary

	Unit Hydrograph Characteristics 0% Peaked				Unit Hydrograph Characteristics 50% Peaked			
	WP-050	WP-051	WP-052	Combined	WP-050	WP-051	WP-052	Combined
Peak Discharge (CFS)	278	548	657	1370	418	822	986	1953
Tc (hrs)	0.91	0.93	0.8	-	0.496	0.497	0.308	-
R (hrs)	1.34	1.22	0.8	-	0.731	0.651	0.308	-
Parameter Scaling Factor	-	-	-	-	0.546	0.534	0.385	-
Peak Percentage (%)	-	-	-	-	150%	150%	150%	143%

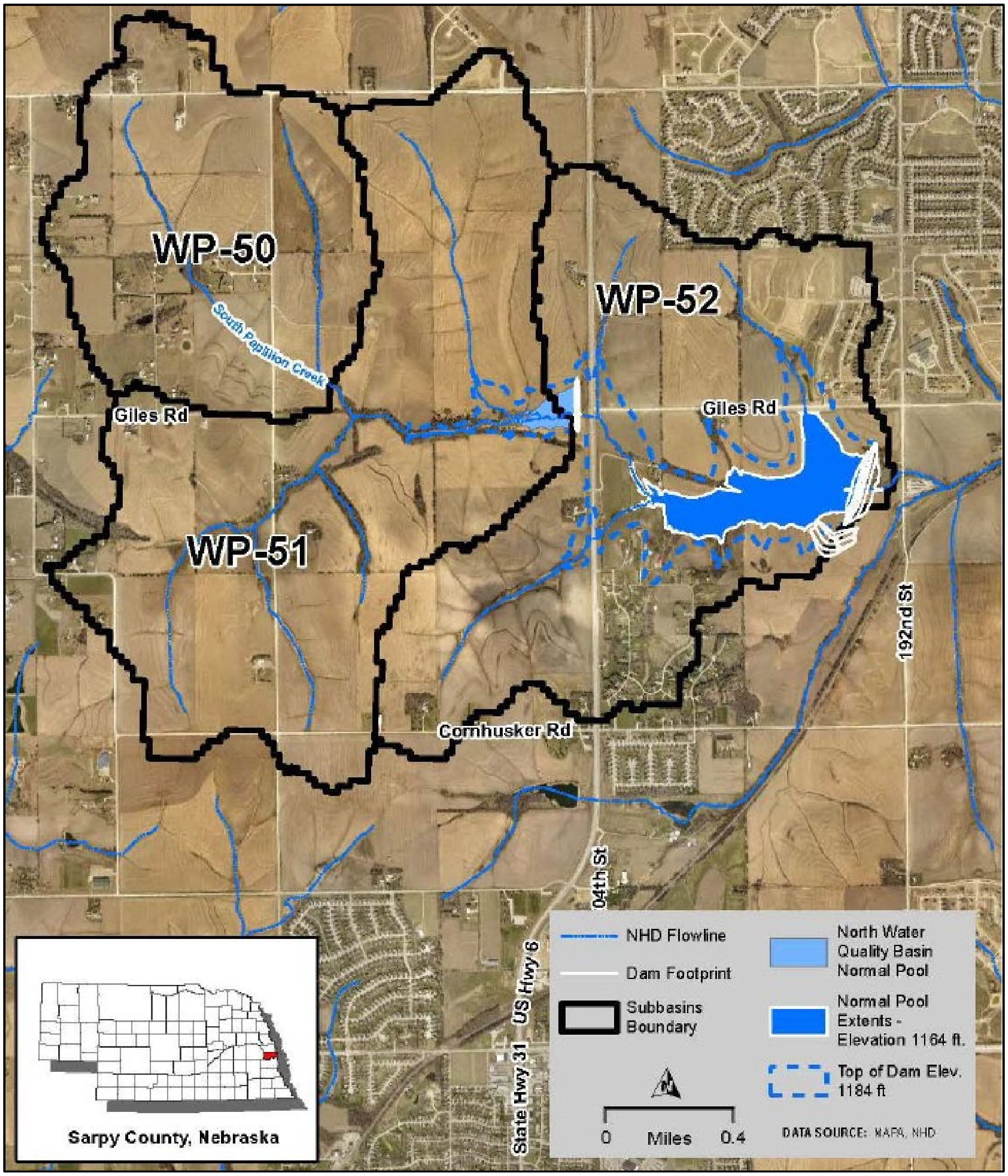


Figure 42. DS19 Drainage Basin Map (HDR, 2018b)

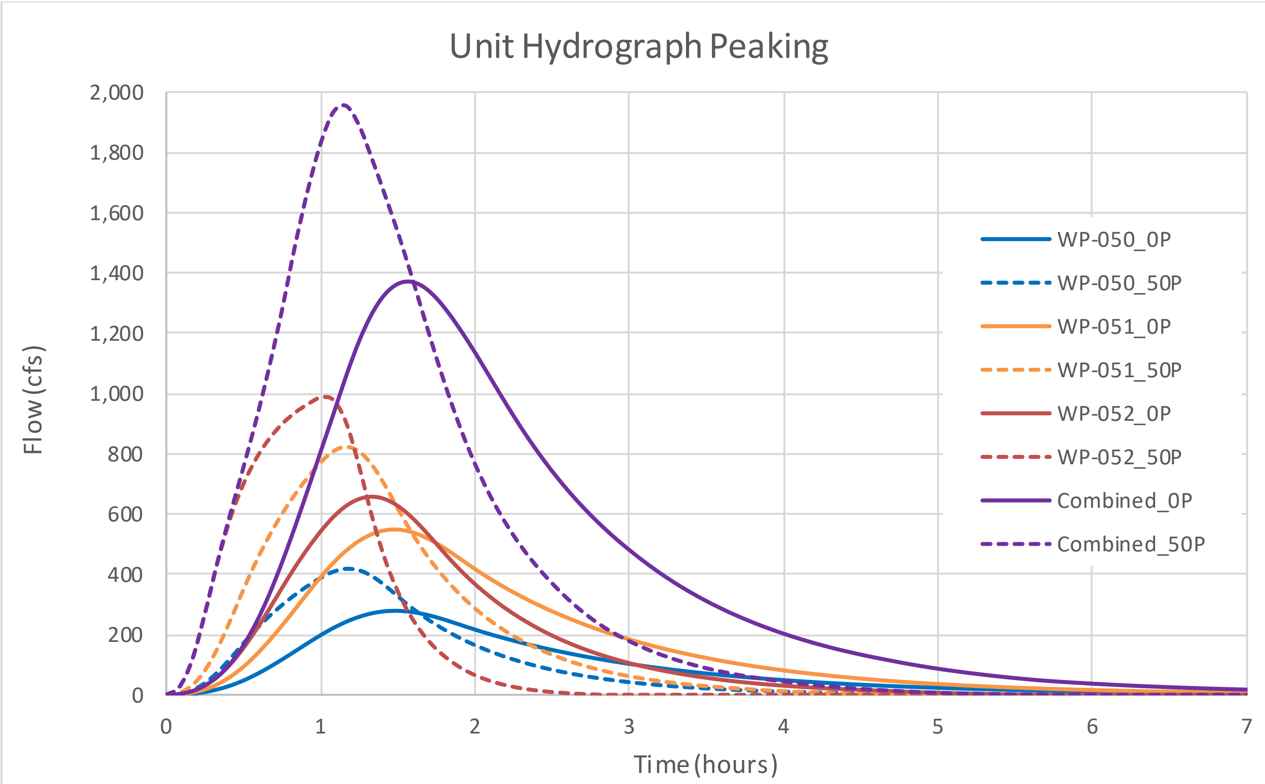


Figure 43. DS19 Clark Unit Hydrographs with and without Peaking (1-Inch Excess Rainfall)

14.3 Precipitation

The probable maximum precipitation (PMP) used in the Papillion GRR TSP screening was updated from the Nebraska Statewide PMP (not accepted as Federal standard) to an HMR 52 derived PMP (which is USACE accepted criteria). In an effort to use existing data, it was determined applicable to use the existing PMP from Standing Bear Dam and Reservoir (Site 16). Standing Bear has a 5.9 square mile drainage area and is another dam in the study watershed.

The original PMP for Standing Bear Dam was determined from a 12-hour local storm event to produce a total of 22.48 inches whereas the updated PMP produces 28.19 inches over 12 hours, which is a 25 percent increase. The updated 24-hour PMP has a cumulative total depth of 31.18 inches.

Based on criteria from Technical Release 210-60, Earth Dams and Reservoirs (TR-60) (USDA, 2019), the auxiliary spillway hydrograph (ASH) should be produced from a combination of the 100-year storm and PMP in accordance with Table 16. The original and updated rainfall totals can be seen in Table 17.

Table 16. Spillway Hydrologic Criteria from TR-60 (USDA, 2019)

Class of Dam	Product of storage (AC-FT) × effective height (FT	Existing or planned upstream dams	Precipitation data for[1]	
			Auxiliary spillway hydrograph	Freeboard hydrograph
Low hazard[2]	less than 30,000	none	P_{100}	$P_{100}+0.12(PMP–P_{100})$
	greater than 30,000		$P_{100}+0.06(PMP–P_{100})$	$P_{100}+0.26(PMP–P_{100})$
	All	any[3]	$P_{100}+0.12(PMP–P_{100})$	$P_{100}+0.40(PMP–P_{100})$
Significant hazard	All	none or any	$P_{100}+0.12(PMP–P_{100})$	$P_{100}+0.40(PMP–P_{100})$
High hazard	All	none or any	$P_{100}+0.26(PMP–P_{100})$	PMP

Table 17. DS19 Cumulative Rainfall Totals

	Original DM				Updated from Papio 16		
	12-Hour Duration				12-Hour Duration		24-Hour Duration
	100-year	500-year	ASH	PMP	PMP	PMP Increase	PMP
Rainfall total (inches)	6.67	9.06	10.78	22.48	28.19	25%	31.18

14.4 Inflow Design Flood and Reservoir Routing

The original model developed inflow design flood hydrographs based on guidance from TR-60, which is summarized in Table 16 of the previous section. For this high hazard dam, the design criteria for the auxiliary spillway hydrograph (earthen spillway) is a combination of the 100-year precipitation and the PMP. The freeboard hydrograph is produced by the PMP. Additionally, TR-60 recommends the use of the 100-year storm to produce the primary storm hydrograph. For this dam, HDR conservatively used the 500-year storm to produce the primary spillway (outlet) hydrograph.

Note that the USDA-NRCS in TR-60 calls the lower level outlet the primary spillway while USACE calls it the outlet. Likewise, the NRCS auxiliary spillway is called just the spillway in USACE.

The primary spillway (PS) design consists of a 6-foot by 9-foot rectangular riser with trash rack, with a 340-foot long 48-inch reinforced concrete cylinder pipe (RCCP) that extends through the dam embankment where it discharges into a concrete stilling basin. Flow into the primary spillway (outlet) is initially controlled by weir flow but becomes restricted by full pipe flow as reservoir pool depth increases. The auxiliary spillway (AS) is a typical earth cut, vegetated spillway located on the south overbank of the dam. The auxiliary spillway is trapezoidal in shape with a bottom width of 200-feet and side slopes of 3H:1V.

TR-60 states the following criteria for reservoir routing:

- When routing the principal spillway (outlet) hydrograph, provide adequate retarding storage and the associated principal spillway discharge to meet the 10-day drawdown requirement and allow no discharge through the auxiliary spillway (earthen spillway).
- Route the auxiliary and freeboard hydrographs through the reservoir starting with the water surface at the highest of: elevation of the lowest ungated spillway, or pool elevation after 10 days of drawdown from the maximum stage attained when routing the principal spillway hydrograph.
- Provide a minimum of 3 feet difference in the elevation between the auxiliary spillway and the settled top of dam.
- Set the dam crest at an elevation adequate to prevent overtopping during the passage of the freeboard hydrograph.

The original model adheres to the guidance above, however, the USACE follows a more conservative approach described in ER 1110-8-2(FR). The general procedure for selecting and routing the inflow design flood (IDF) for the updated model is outlined below:

- Minimum starting elevation for routing the IDF will be assumed as the full flood control pool level or the elevation prevailing five days after the last significant rainfall of a storm that produces one-half the IDF, whichever is most appropriate.
- A minimum of three feet of freeboard is required between the maximum pool elevation resulting from the IDF and the top of dam.
- When the IDF pool hydrograph is within three feet of the maximum pool for 36 hours or longer, or where the project has been designated with little surcharge for the maximum pool above the full pool elevation, the minimum freeboard will be five feet for embankment dams.

Reservoir regulation outlets should not be assumed operable during the occurrence of an IDF. The IDF in the case of DS19 is the PMF.

14.5 Results

Figure 44 and Table 18 show results for the wet dam and dry dam routings for TSP level analysis. The original model set the normal pool and principal spillway (outlet) crest elevation at 1164.0 feet-NAVD88. The auxiliary spillway crest and top of dam crest were set to 1177.0 feet-NAVD88 and 1184.0 feet-NAVD88, respectively (HDR, 2018b). The updated model maintains these elevations and routes the updated IDF through the reservoir based on the aforementioned procedures from ER 1110-8-2(FR).

The original peak inflow to the reservoir was 18,261 cfs and produces a maximum pool elevation of 1183.5 feet-NAVD88. The updated HMR 52 peak inflow to the reservoir is 27,900 cfs and produces a maximum pool elevation of 1185.53 feet-NAVD88, leading to overtopping of the dam embankment. In order to adhere to the minimum freeboard requirements, the dam would need to be raised to an elevation of 1189.4 feet-NAVD88 to hold the maximum pool elevation of 1186.34 feet-NAVD88 plus three feet of freeboard.

Another scenario was tested to see how the reservoir would perform if it was a dry dam with no permanent pool. In this case, the original 500-year hydrograph was routed through the dry reservoir with the primary spillway crest (outlet) left at 1164.0 feet-NAVD88. The maximum pool elevation was 1172.4 feet-NAVD88 so the auxiliary spillway crest was then set to 1173.0 feet-NAVD88. Although the pool elevation five days after the antecedent flood dropped to the primary spillway elevation of 1164.0 feet-NAVD88, the IDF was routed through the reservoir with an initial pool elevation set to the full flood control elevation of 1173.0 feet-NAVD88. The resulting maximum pool elevation was 1182.96 feet-NAVD88 which would require a minimum dam elevation of 1186.0 feet-NAVD88 to satisfy minimum freeboard requirements.

With a dry dam, it is possible that the primary spillway (outlet) elevation could be lowered to reduce overall dam height. For comparison purposes, a final scenario was tested with the primary spillway elevation arbitrarily lowered by ten feet to elevation 1154.0 feet-NAVD88; a low-level outlet would also be needed to drain the pool below the principal spillway elevation. The 500-year hydrograph was routed through the dry reservoir with a starting pool elevation set to 1130.0 feet-NAVD88 and produced a maximum pool elevation of 1171.92 feet-NAVD88 so the auxiliary spillway crest was set to 1172.0 feet-NAVD88. Five days after the antecedent flood routing, the pool elevation dropped to 1154.0 feet-NAVD88. The IDF was routed with a starting pool elevation of 1172.0 feet-NAVD88 which produced a maximum pool elevation of 1182.09 feet-NAVD88 and would require a minimum dam elevation of 1185.1 feet-NAVD88 to satisfy freeboard requirements. As noted above, this scenario arbitrarily set the principal outlet elevation and maintained head-discharge assumptions. Additional consideration is likely needed to determine elevations and sizing of the outlet works and spillway to meet project needs.

More detailed dry dam modeling for DS19 was completed after TSP. Refer to Appendix A-2 for this hydrology.

Table 18. DS19 Reservoir Routing Summary

Updated PMP Scenario	Dam Overtopped	Max Pool Elevation (ft-NAVD88)	Required Dam Height with min. freeboard (ft-NAVD88)
0P	yes	1185.02	N/A*
50P	yes	1185.53	N/A
50P Higher Dam	no	1186.34	1189.4
50P Dry Dam	no	1182.96	1186.0
50P Dry Dam / Lower PS by 10-ft	no	1182.09	1185.1

*Dam overtops so need to increase dam height and simulate again to determine dam height (see 50P Higher Dam scenario)

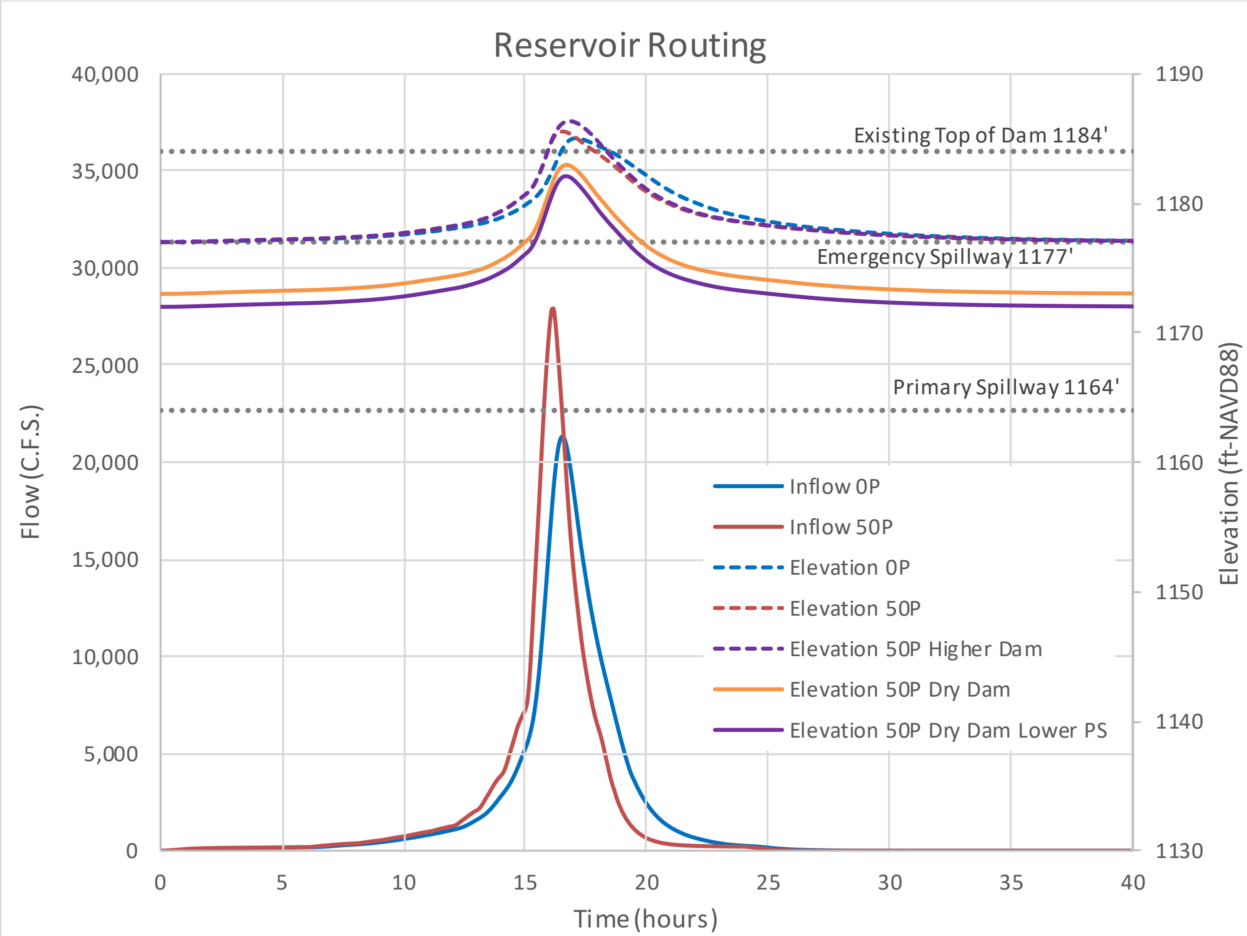


Figure 44. DS19 IDF Reservoir Routings.

14.6 Conclusion

The original dam design is inadequate to pass the updated IDF based on methodology and requirements in ER 1110-8-2(FR). In order to meet these requirements, and assuming the outlet works and spillway assumptions from HDR, it is estimated that a minimum dam crest elevation of 1189.4 feet-NAVD88 is necessary, a dam raise of 5.4 feet.

If the dam was repurposed to be a dry dam, the crest of the auxiliary spillway could be lowered to elevation 1173.0 feet-NAVD88 and the dam crest could be as low as 1186.0 feet-NAVD88, a dam raise of 2.0 feet. It has also been determined that lowing the primary spillway elevation would further result in a lower auxiliary spillway and, in turn, a lower dam crest. In this arbitrary case when the principal spillway was lowered 10 feet, the resulting dam crest with minimum freeboard was 1185.1 feet-NAVD88, a dam raise of 1.1 feet. A more detailed analysis is recommended to determine the optimal primary and auxiliary spillway sizes and crest elevations for this scenario. A low level outlet would also be needed to drain the pool below the principal outlet works.

Note that this analysis was for TSP level. Refer to Appendix A-2 for additional modeling after TSP using site-specific data for DS19.

15 TSP Pools for Real Estate Acquisition

This section describes the pools used to estimate real estate acquisitions for DS10 and DS19 for the TSP screening analysis. This analysis is important because it provides an estimate of real estate costs attributed to flood risk management (FRM) and costs attributed to recreation. The dry dam captures the FRM real estate costs and the wet dam captures the additional costs for having a pool for recreation.

Refer to Hydrology Appendices A-1 and A-2 for estimated real estate acquisitions used in the designs after TSP using site-specific data.

Maximum PMF pool extents for DS10 and DS19 as wet and dry dams were estimated using an HMR 52 PMF developed for the existing Standing Bear Dam site (Papillion Creek No. 16). These maximum PMF results were taken from previous sections of this report which updated those dams to USACE criteria.

In the case of the wet dams, top of flood control and normal pool elevations are also provided. In the case of the dry dams, a 10-percent AEP storm (10 year) was routed over the full normal/conservation pool with the dam outlet functional. Storage elevations and each sites' elevation-storage curve were used to determine the 10-percent AEP storage elevation for a dry dam assuming some type of outlet operation. This methodology was used because a specific design for the reservoir outlet for the dry dams has not been completed. The methodology used was the following:

1. Routed the 10-percent AEP event into the reservoir with the conservation pool full to the outlet invert. The outlet was fully functional, allowing some of the 10-percent AEP event to exit the dam.
2. Determined the maximum elevation of the 10-percent AEP event and determined the storage at that elevation using the elevation-storage curve for the sites.
3. Subtracted the 10-percent AEP storage from the conservation storage to determine just the 10-percent AEP storm volume that produced the max pool.
4. Transposed the 10-percent AEP volume to the bottom of the dam and determined an elevation for just that event. This pool is lower than if just the 10-percent AEP had been routed into the empty dry dam with no outlet because some of its volume was lost to the outlet and routed downstream.

It was assumed for this analysis that real estate to the maximum PMF pool elevation would be obtained.

In addition, the real estate acquired for the four existing Papillion Creek Dams was investigated. It was determined that land was acquired (almost entirely in fee) for at least the top of flood control pool. Figure 45 shows the land acquisitions for the existing dams.

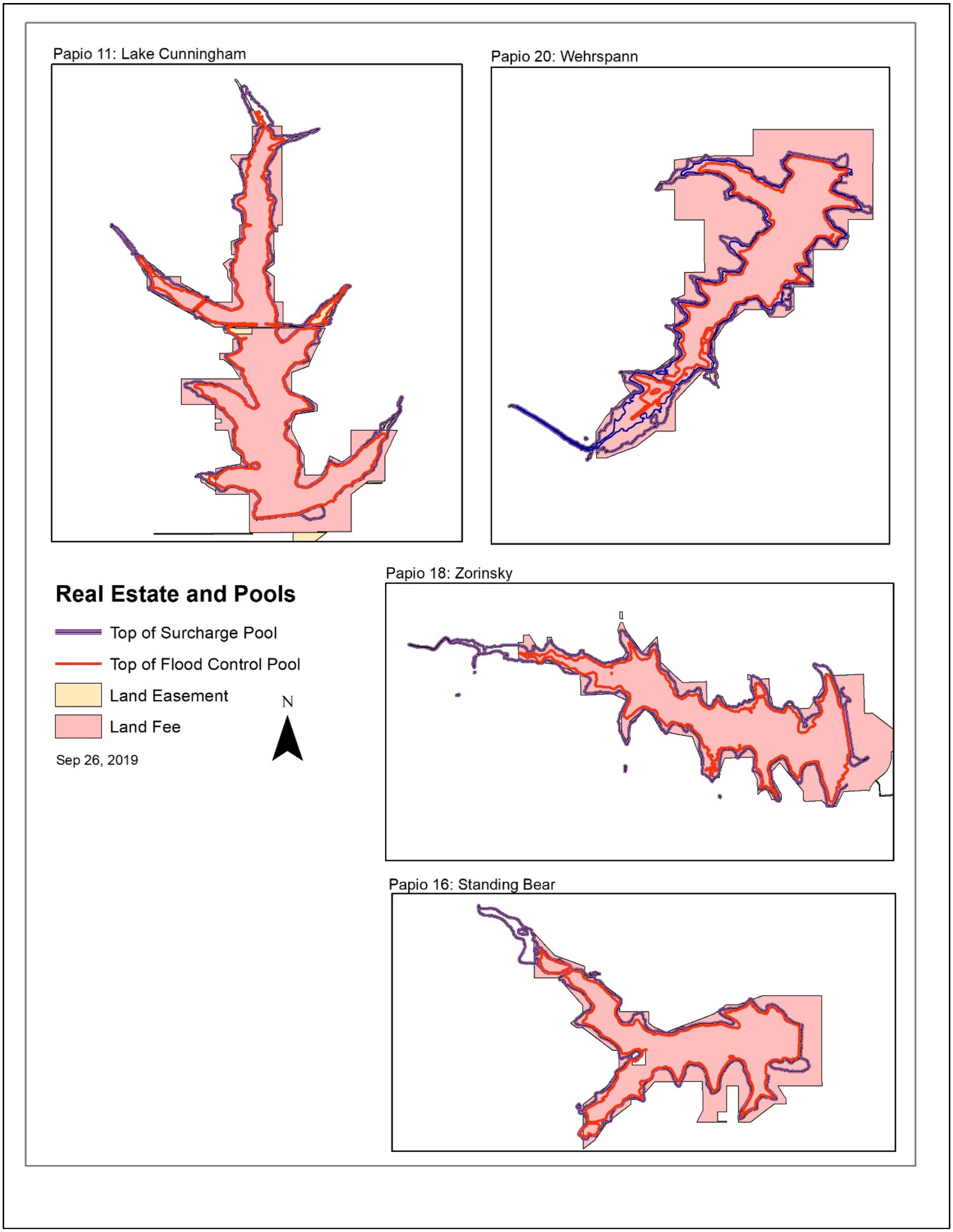


Figure 45. Existing Papillion Dam Land Acquisitions

15.1 TSP DS10 Wet and Dry Dam Results

Table 19 through Table 21 show the dry dam and wet dam results for DS10 at the time of TSP. Wet dam results are presented for both the updated PMF and the PMF found in the 1975 DM. At the time of TSP, it was assumed that the PMF maximum pool and 10-percent AEP pool elevations be used for permanent easement and fee calculations, respectively, in the case of the dry dam. This was decided upon by the project development team (PDT) leadership at the time.

It was decided in a meeting with the NWD Real Estate specialist in October 2019 that the top of PMF pool be used for permanent easement and the normal pool be used for fee in the case of the wet dam. These elevations, updated to the HMR 52 PMP, are in Table 20.

Note that finalized dry dam spillway and dam elevations are still needed with finalized outlet designs. Based on general guidance from engineers and planners who have experience with dry dams, design of the spillway crest elevation should consider costs and benefits with the goal of maximizing net benefits. Maximize the net flood risk benefits (annual benefits – annual costs = Net annual benefits). Design for the National Economic Development (NED) plan and if the residual risk is considered still too high, then a higher level of protection could be considered.

A datum conversion of NAVD88 = Project Datum + 0.243 was used for this site. This conversion was obtained from the Omaha District Dam Safety section. Note that some unit hydrograph peaking was included in the 10-percent AEP results for this site because the original DM unit hydrograph was peaked.

15.2 TSP DS19 Wet and Dry Dam Results

Table 22 through Table 24 show the dry dam and wet dam results for DS19. Wet dam results are presented for both the updated PMF and the PMF found in the HMR 2018 report using TR-60 design criteria. It is recommended that the PMF maximum pool be used for permanent easement in the case of the dry dam. This was decided upon by the project development team (PDT) leadership.

It was decided in a meeting with the NWD Real Estate specialist in October 2019 that the top of PMF pool be used for permanent easement and the normal pool be used for fee in the case of the wet dam. The dry dam does not have a fee pool. These updated values are in Table 23.

A datum conversion was not required in the case of these elevations because they were already in NAVD88. No unit hydrograph peaking was completed for the 10-percent AEP event.

Table 19. TSP DS10 Dry Dam Pools for Real Estate.

Table 20. TSP DS10 Wet Dam Pools for Real Estate.

Normal pool (1975 DM) =

Peak Flow Updated PMF = 35,000 cfs (HMR 52, Standing Bear)
Starting pool was top of flood control (1200.64 ft-NAVD88).

Table 21. TSP DS10 Design Memorandum Pools. Provided just for comparison.

DS10 (Wet Dam in 1975 DM)
PMF max pool =

Peak Flow 1975 PMF = 17,600 cfs (HMR 33)

Starting pool for PMF was 1/2 flood control pool storage (1195.54 ft-NAVD88)

Table 22. TSP DS19 Dry Dam Pools for Real Estate.

DS19 (Dry Dam)

10% AEP (10-year) =

Unit hydrographs were not peaked in the 10-year storm modeling
Starting pool for PMF was top of spillway crest determined from 500-year pool

Table 23. DS19 Wet Dam Pools for Real Estate.

DS19 (Wet Dam with Updated PMF & Starting Pool)	
	1164
Peak Flow Updated PMF = 27,900 cfs (HMR 52)	
Starting pool was top of flood control (1177 ft-NAVD88).	

Table 24. DS19 HDR Pools. Provided just for comparison.

DS19 (Wet Dam in HDR report)	
Spillway crest =	1177
Normal pool =	1164
Peak Flow HDR PMF = 18,261 cfs	

16 Road Closure Structures

An analysis of flood timing and the possibility of deploying road closure structures was considered. It was determined that the placement of HESCOs would most likely not work for the Papillion Creek watershed. Timing included the assumption that the fastest response would begin at the peak of the rainfall event creating the flood. Newspaper accounts of the June 1993 flood emphasize the rapid rise and fall of water in the Papillion Creek basin, supporting that the deployment of closure structures is likely unrealistic. The event was termed a "flash flood" (Omaha World-Herald, 2014).

It was concluded that a rapid deployment system would be needed and upstream gauges would need to be modified to trigger the deployment of barriers.

Flood timing was investigated using observed hydrograph peaks at stream gauges along the Little Papillion and Big Papillion. The timing of hypothetical events was also considered.

17 Risks at Time of TSP

This section describes the risks accepted in adopting results from existing models for this SMART planning project at the time of TSP. Risks were accepted for the screening-level analysis and will be addressed as needed as the project progresses past TSP. Additional risks associated with the proposed dam sites (DS10 and DS12) are documented in Appendices A-1 and A-2.

17.1 Storm Area

A difference in the storm area used by the 2010 USACE and 2018 FYRA studies to determine peak flows was identified at 42 of the 129 junctions requested by the Omaha District Hydraulics Section. Both studies used the same storm areas (10, 20, 30, 50, 70, 95, 120, 150, 200, 250, 300, 400 square miles) but assigned different storm areas to these identified junctions. The standard practice when frequency storm events are modeled is to assign a storm area equal to the contributing area above the junction where the alternative will be modeled. The FYRA model was reviewed and approved by FEMA so this risk is considered minimal.

17.2 Interpolation and Extrapolation of Additional Peak Flows

The models obtained from the project sponsor did not have the full set of eight events (50, 20, 10, 4, 2, 1, 0.5, and 0.2 percent AEP) needed for the economic analysis to produce a benefit-cost-ratio for project alternatives. For screening analysis, peak flows for the 50- and 20-percent AEP events were extrapolated and the 0.5-percent AEP was interpolated using a linear interpolation macro on log-transformed flows. These extrapolations and interpolations were checked using peak flow frequencies at a selection of the junctions.

17.3 RAS Unsteady Flow Model for Mud Creek and Lower Big Papillion Creek

The peak flow results presented in the October 2018 FYRA report were not only the peak flows produced by the FYRA HEC-HMS model but also those produced by an unsteady HEC-RAS model. HEC-RAS unsteady RAS model results were used for Mud Creek and the lower portion of the Big Papillion Creek. The existing condition unsteady HEC-RAS model results were plotted with the HEC-HMS model results for the dam alternatives and it was determined that they would not combine realistically. For this reason, only the HEC-HMS generated flows were provided to the Hydraulics Section for use in the steady HEC-RAS models. This means that results in the lower basin will not reflect what was approved by FEMA during the screening analysis.

17.4 Modified Puls Routing in HMS

In some reaches of the HEC-HMS model, channel routing is modeled using Modified Puls as opposed to Muskinghum Cunge 8-Point Creek Sections. It was assumed that this routing would remain applicable for all the alternatives simulated in the case of the peak flows.

17.5 Simplified Dam Site Alternatives Modeling

Proposed future dam sites were modeled in an extremely simplistic manner by removing their contributing drainage area from the downstream model through the use of sinks in HEC-HMS. This simple modeling assumed that the dams would be designed to control the full 0.2 percent AEP event (500-year event) and have no releases for all events modeled (2 through 500 year). In reality, all the dams will have an outlet which would release some flow. Actual flows through the dam will depend on outlet works design. However, existing dam outflows are insignificant and would continue to be insignificant in a new dam design.

17.6 Mannings Channel Roughness along Big Papillion Creek Reach

It was found that the Mannings channel roughness values for the Big Papillion Creek reach near the proposed dam sites 9A, 8A, and 7 seem too high in comparison with the HEC-RAS models and when compared with other reaches in the HEC-HMS model. The Big Papillion Creek channel roughness and overbank roughnesses were around 0.06. The channel roughness in the HEC-RAS model was 0.03 to 0.04 and its overbank roughness around 0.06. However, the 0.06 was also used in the 2010 USACE hydrology model. Discussion with the Chief of Hydraulics determined that having a higher Mannings Roughness in a hydrologic model compared with a hydraulic model is not unusual and should not be a significant concern given the other uncertainties in hydrologic routing models.

17.7 Channel Modifications on West Papillion Creek

Modifying the channel cross section on the West Papillion Creek for the channel modifications alternative resulted is a 19 percent change in peak flow at a junction near the confluence of West Papillion and South Papillion. This change was due to the channel modifications changing the shape and timing of the hydrographs. This resulted in a larger increase in peak flows near the confluence as the hydrograph flows added together.

It was decided to maintain the peak flows in the HEC-RAS model and not provide updates form HEC-HMS and enter into iterative modeling. This was decided because this is a SMART planning project with more acceptance of risk and because additional time-consuming iterative modeling may not produce more realistic results for a screening-level analysis. In addition, the HEC-RAS modeling will be updated after the tentatively selected plan (TSP) to unsteady modeling so spending additional time on the current modeling will not carry through to the later stages of the project.

17.8 Dam Site 10 Modeling

While the reproduced PMF results for DS10 are acceptable, the documented unit hydrograph itself could not be well reproduced. This might be an issue with the original 1975 analysis. The unit hydrograph could be improved by using HMS version 4.3 and a user-defined time-area curve. This might be implemented if DS10 is included in the tentatively selected plan (TSP).

17.9 Dam Elevation-Storage Curves

It was assumed that the elevation-storage curves in the 2004 HDR analysis, the NRD models, and the original Design Memorandums (DM) for the dams were accurate. Investigations for DS10 showed that the elevation-storage curves used for DS10 were not comparable between the 2004 HDR and the original 1975 DM. The 2004 HDR study estimated storage using a 30-meter DEM while the 1975 DM used quad maps. There is about a 15 foot difference in elevation near the top of dam for these curves assuming the same storage below TOD. It is recommended that elevation-storage curves be updated with the best available data if any of the dams are adopted after TSP. It's important to note that the elevation-storage curves were not used in the dam analysis screening using the NRD/FYRA models and do not affect the screening results.

17.10 Dry Dam Modeling

Additional modeling is required for the dry dam sites past screening analysis. Finalized spillway and dam elevations are still needed with finalized outlet designs. Design of the spillway crest elevation should consider costs and benefits with the goal of maximizing net benefits. Maximize the net flood risk benefits (annual benefits – annual costs = Net annual benefits). Design for the NED and if the residual risk is considered still too high, then a higher level of protection could be considered.

18 Unsteady Flow Modeling After TSP

The same HMS model used to produce peak flows for the steady-state analysis before TSP was used to produce runoff hydrographs as input to the unsteady hydraulic modeling. Runoff hydrographs were created and provided as DSS flow files for each sub basin within the Papillion Watershed for an array of different storm sizes. During the steady-state analysis, the storm size used to produce the flow at each junction of the RAS model was determined based on the cumulative drainage area to that specific inflow point. However, when an alternative like a levee is sized, all sub basins to that point in the channel should have the same storm area which produces a consistent intensity of rainfall over the full contributing drainage area to the proposed levee. To appropriately size the alternatives while still being able to compare with- and without-project results consistently, changes were made to the sub basin storm sizes as is discussed further in Appendix B Hydraulics.

19 Climate Change Analysis Summary

A climate change analysis was conducted with Engineering Construction Bulletin No. 2018-14 and Engineering Technical Letter 1100-2-3. Both observed and projected future trends were analyzed through a literature review and USACE tools. While observed, historic regional trends show increases in temperature, precipitation, and stream flow, the projected, future trends are not as strong for increases in stream flow in the future. For example, future precipitation is projected to continue to increase for the spring season but results for other seasons lack consensus between sources. Site-specific analysis of stream gauges and precipitation and temperature gauges at or near the site did not have statistically significant increasing trends (p-value < 0.05 for statistical significance).

Future, Without Project Conditions could be significantly impacted by changes in climate at some indeterminate point in the future. However, at present there is no evidence within streamflow records observed at the project-site scale indicating climate change is causing flood peaks to increase.

Based on the literature review, it was found that while regional, observed precipitation and stream flow datasets show increasing trends, the projected, future trends in precipitation and stream flow are less clear.

Because there is some evidence of potential increases to flood risk in the future based on projected datasets and basin conditions, it is suggested that flood risk continue to be monitored to see if a trend of increasing flow magnitudes begins to materialize within the gauged record. If such a trend should begin to emerge, resilience measures could be reconsidered. In addition to monitoring, the point where increases to flood risk would begin to critically undermine project performance should be identified, as well as how much lead time it would take to add resilience measures to the project (including time for planning, funding acquisition etc.).

See Appendix AD for the full climate change analysis and more detailed conclusions.

20 Equivalent Years of Record

An estimate of equivalent years of record for the Papillion Creek watershed was estimated in accordance with EM 1110-2-1619, *Risk-based Analysis for Flood Damage Reduction Studies* (USACE, 1996). Equivalent years of record are important because it helps to quantify the uncertainty in the analysis when the economics are calculated.

Peak flows used in the study have the following characteristics based on the FYRA 2018 report:

- Flows were produced by a rainfall-runoff model with parameters estimated from site-specific data.
- Site-specific GIS data were used to develop the model (not just handbook or textbook parameters).
- The model was calibrated to several events (14-Jun-2013, 3-Jun-2014, and 21-Jun-2014) at several different locations in the watershed. These events were not the major floods or even moderate floods with bankful stages. The reason for not using these larger events in calibration is that watershed and channel conditions have changed significantly in the past fifty years. Table 26 and Figure 45 show the difference in the calibration and historic events for reference.
- Big Papillion Creek, Little Papillion Creek, and West Papillion Creek were calibrated to all three calibration events.
- Only Little Papillion Creek used the 11-June-2008 verification event. The other creeks calibrations do not appear to have been verified.
- The model was not calibrated or verified to statistical gauge analysis like a peak flow frequency at the Fort Crook stream gauge.

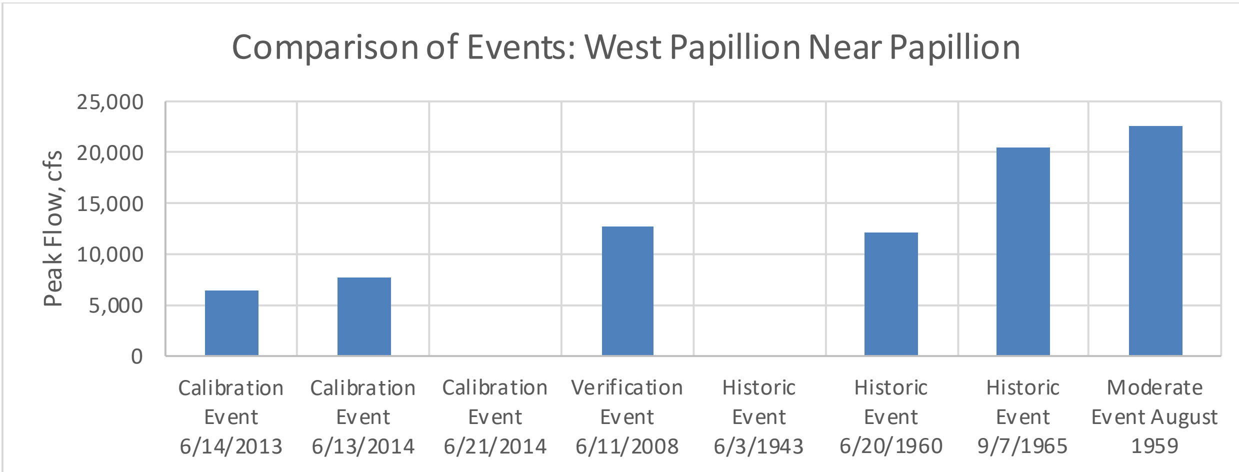
Based on reference to Table 4-5 in EM 1110-2-1619, the equivalent years of record for a rainfall-runoff model calibrated to several events recorded at a short-interval gauge is the watershed is somewhere between 20-30 years.

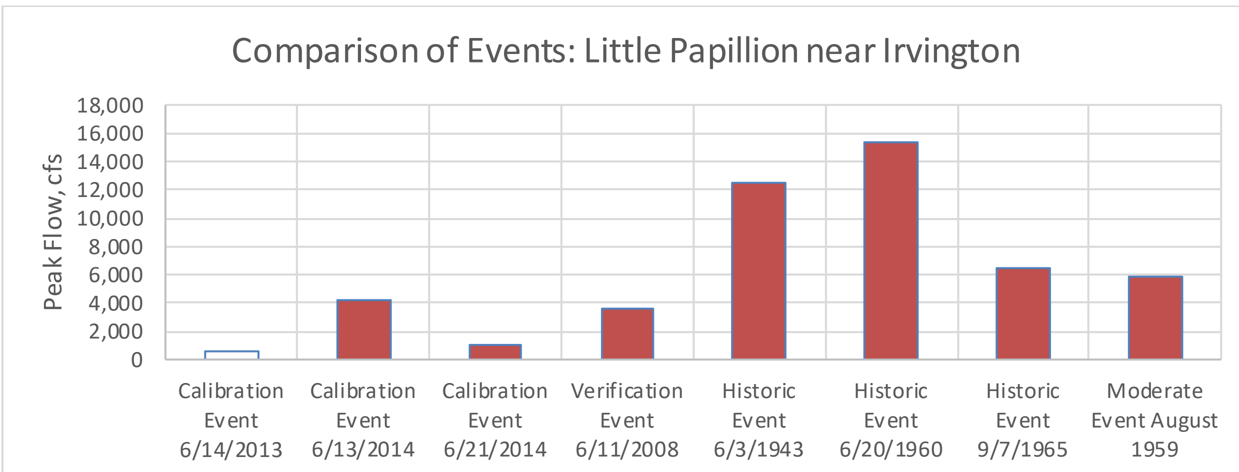
The recommended equivalent years of record for the Papillion Creek GRR project is 23 years. Several locations were used in the calibration of the model but the events used were small in comparison with the historic and moderate events of record (except in the Papillion Creek at Fort Crook location). In addition, the model was calibrated to events and not peak flow frequencies. Calibration or verification to the peak flow frequency at stream gauge would have decreased uncertainty in model results and resulted in a longer equivalent record.

The estimate of 23 year of equivalent years of record was used for both the existing and future conditions. Future conditions (2040) are not that far in the future so an assumption of 23 years (the same uncertainty in data) was considered reasonable.

Table 25. Comparison of Modeled and Historic Events

Event & Date	Peak Flow Location		
	West Papillion Near Papillion	Little Papillion near Irvington	Papillion Creek at Fort Crook
Calibration Event 6/14/2013	6,470	578	-
Calibration Event 6/13/2014	7,710	4,170	19,600
Calibration Event 6/21/2014	-	1,060	32,800
Verification Event 6/11/2008	12,622	3,566	24,800
Historic Event 6/3/1943	-	12,500	-
Historic Event 6/20/1960	12,000	15,300	9,200
Historic Event 9/7/1965	20,400	6,500	15,600
Moderate Event August 1959	22,500	5,900	-





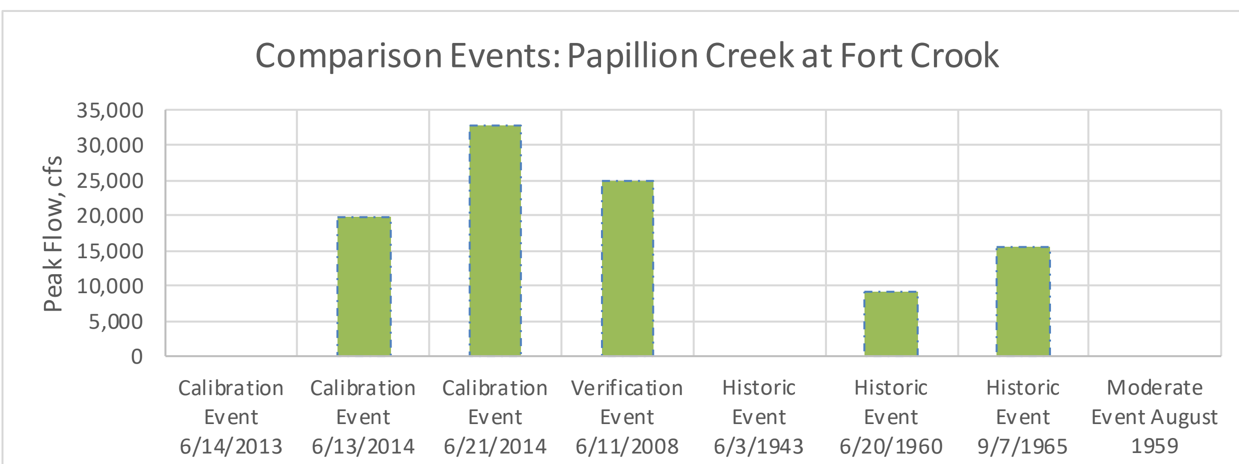


Figure 46. Comparison of Modeled Events and Historic

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Appendix AA. Existing Conditions Peak Flow Results

Table AA1. Existing Conditions Peak Flows - South Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Existing Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-072	2.69	10	670	1122	1470	1960	2380	2840	3334	4050
WP-JCT-073	4.32	10	1119	1882	2470	3300	4010	4770	5592	6780
WP-JCT-077	7.04	10	1923	3212	4200	5590	6770	8050	9425	11410
WP-JCT-081	10.16	20	2551	4270	5590	7450	9040	10740	12607	15310
WP-JCT-084	11.61	20	2828	4746	6220	8300	10070	11990	14074	17090
WP-JCT-085	12.76	20	3082	5167	6770	9030	10960	13050	15336	18650
WP-JCT-087	13.74	20	3379	5624	7340	9750	11830	14070	16532	20100
WP-JCT-088	15.41	20	3642	6000	7790	10290	12520	14950	17634	21540
WP-JCT-089	15.41	20	3626	5982	7770	10270	12500	14930	17606	21500
WP-JCT-104	28.58	30	3564	5880	7640	10100	12270	14660	17291	21120
WP-JCT-105	30.5	30	4056	6654	8620	11360	13800	16480	19437	23740
WP-JCT-106	30.5	30	4065	6660	8620	11350	13790	16480	19433	23730
WP-JCT-107	32.75	30	4347	7051	9080	11890	14530	17330	20486	25090
WP-JCT-112	37.92	50	4158	6752	8700	11400	13900	16550	19586	24020
WP-JCT-113	39.43	50	4296	6839	8720	11300	13800	16480	19526	23980

Table AA2. Existing Conditions Peak Flows – Big Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Existing Conditions Peak Flows (cfs) 50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4545	8131	11020	15240	18980	23210	28073	35350
BP-JCT-066	85.65	120	4546	8218	11200	15580	19480	23960	29126	36900
BP-JCT-073	96.06	120	4479	8258	11370	15990	20060	24730	30102	38200
BP-JCT-074	97.52	120	5171	8959	11940	16220	20090	24780	30175	38310
BP-JCT-076	102.14	120	5033	8768	11720	15970	20030	24660	30073	38250
BP-JCT-077	103.62	120	4742	8509	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4717	8546	11660	16240	20400	25160	30706	39090
BP-JCT-081	107.92	120	4261	8071	11270	16090	20310	25080	30617	38990
BP-JCT-084	110.96	120	4169	7992	11230	16140	20400	25230	30803	39230
BP-JCT-086	112.98	120	4066	7905	11190	16210	20500	25390	31005	39500
BP-JCT-087	115.2	150	3828	7481	10620	15430	19530	24230	29605	37740
BP-JCT-089	116.04	150	3787	7441	10590	15430	19550	24280	29667	37820
BP-JCT-090	117.05	150	3767	7418	10570	15420	19540	24260	29650	37810
BP-JCT-091	119.09	150	3940	7523	10550	15130	19360	24110	29507	37690
BP-JCT-092	121.32	150	4080	7595	10510	14860	19060	23820	29227	37450
BP-JCT-094	127.28	150	4131	7651	10560	14890	19100	23860	29310	37610
BP-JCT-095	129.08	150	4124	7642	10550	14880	19080	23840	29244	37460
BP-JCT-096	131.56	150	4217	7744	10640	14930	19160	23960	29381	37620
BP-JCT-103	136.39	200	5059	8264	10680	14040	17960	22590	27712	35500
BP-JCT-105	138.54	200	5145	8393	10840	14240	18150	22790	27942	35770
BP-JCT-106	139.76	200	5216	8478	10930	14330	18160	22790	27924	35720
BP-JCT-107	141.06	200	5247	8542	11020	14460	18210	22860	28000	35800
BP-JCT-110	143.54	200	5323	8666	11180	14670	18280	22960	28095	35880
BP-JCT-111	144.98	200	5391	8755	11280	14780	18270	22940	28067	35840
BP-JCT-115	147.17	250	5267	8528	10970	14350	17320	21620	26478	33850
BP-JCT-116	148.73	250	5328	8607	11060	14450	17410	21630	26495	33880
BP-JCT-119	152.29	250	5475	8817	11310	14750	17700	21700	26595	34030
BP-JCT-125	156.68	250	5636	9074	11640	15180	18130	21920	26852	34340
BP-JCT-127-G08-Q_ST	216.53	300	5304	10056	14050	20070	26460	32300	39508	50430
BP-JCT-129	218.71	300	5737	10437	14270	19920	24700	29800	37327	49040
BP-JCT-130	220.79	300	5964	10659	14440	19960	24320	29220	37046	49390
BP-JCT-132	224.06	300	7423	11642	14730	18930	22180	25730	32995	44600
BP-JCT-133	224.61	300	7787	11856	14770	18670	21740	25200	31327	40780
BP-JCT-135	227.91	300	8438	12323	15020	18550	21240	24630	29821	37600
BP-JCT-136	228.82	300	9507	12849	15040	17790	20270	23420	28125	35110
BP-JCT-138	230.65	300	8939	12058	14100	16660	18900	21960	26652	33700
BP-JCT-142	232.44	300	9109	12187	14190	16690	18910	21960	26662	33730
PA-JCT-01	367.26	400	11708	18999	24470	32050	36370	40980	45360	51300
PA-JCT-02	368.7	400	11719	19051	24560	32200	36570	41220	45665	51700
PA-JCT-12	379.54	400	12048	19647	25370	33320	38380	43470	48380	55080
PA-JCT-16	384.3	400	12128	19890	25760	33940	39190	44440	49583	56620
PA-JCT-17-G19-CAPEHART	384.3	400	11960	19623	25420	33500	38950	44250	49392	56430
PA-JCT-18	384.3	400	11878	19486	25240	33260	38780	44110	49255	56300
PA-JCT-20	386.32	400	11915	19537	25300	33330	38980	44440	49722	56970
PA-JCT-24	390.43	400	11856	19610	25510	33770	39600	45250	50810	58470
PA-JCT-27	391.97	400	11735	19095	24630	32310	38150	43890	49411	57040
PA-JCT-29	395.86	400	11739	19088	24610	32270	38190	44100	49830	57780
PA-JCT-30	395.86	400	11702	18914	24310	31770	37590	43470	49233	57250

Table AA3. Existing Conditions Peak Flows – Little Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Existing Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-19	17.82	20	82	117	140	170	200	260	333	450
LP-JCT-20	19.12	20	281	502	680	940	1170	1430	1716	2140
LP-JCT-21	20.97	20	649	1159	1570	2170	2680	3240	3859	4770
LP-JCT-29-G10-LP-Irvington	31.77	30	2079	3762	5130	7140	8950	10940	13094	16280
LP-JCT-30	33.81	50	2217	3978	5400	7480	9380	11500	13799	17210
LP-JCT-31	35.61	50	2419	4330	5870	8120	10190	12490	15001	18730
LP-JCT-32	37.62	50	2717	4838	6540	9020	11260	13810	16452	20340
LP-JCT-33	38.54	50	2778	4986	6770	9380	11710	14360	17056	21010
LP-JCT-34	0.86	10	120	219	300	420	530	650	783	980
LP-JCT-35	2.09	10	245	460	640	910	1150	1400	1685	2110
LP-JCT-37	3.24	10	365	674	930	1310	1650	2020	2430	3040
LP-JCT-38	4.14	10	423	802	1120	1600	2020	2480	2993	3760
LP-JCT-39	5.18	10	542	1020	1420	2020	2560	3140	3783	4740
LP-JCT-40-G11-Cole	6.1	10	668	1253	1740	2470	3130	3840	4623	5790
LP-JCT-41	6.68	10	674	1271	1770	2520	3180	3920	4738	5960
LP-JCT-42	45.22	50	3320	6050	8280	11570	14470	17780	21183	26190
LP-JCT-44	46.55	50	3368	6238	8610	12140	15130	18630	22271	27650
LP-JCT-47	48.43	70	3304	6249	8720	12440	15580	19170	23076	28890
LP-JCT-48-G12-LP-Aksarben	50.2	70	3238	6239	8790	12670	16000	19600	23608	29580
LP-JCT-49	51.33	70	3330	6416	9040	13030	16470	20280	24229	30060
LP-JCT-54	56.58	70	3384	6912	10040	14950	19310	24030	28779	35810
LP-JCT-55	57.62	70	3410	6952	10090	15010	19410	24240	28837	35590
LP-JCT-56	58.88	70	3626	7366	10670	15840	20500	25540	30464	37720
LP-JCT-57	59.85	70	3512	7069	10190	15050	19920	22460	25800	30520

Table AA4. Existing Conditions Peak Flows – West Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Existing Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-015	1.07	10	146	273	380	540	670	820	981	1220
WP-JCT-016	1.07	10	146	273	380	540	670	820	978	1210
WP-JCT-017	2.58	10	425	784	1080	1520	1880	2280	2717	3360
WP-JCT-018	3.4	10	622	1109	1500	2070	2580	3100	3698	4580
WP-JCT-019	5.15	10	994	1749	2350	3220	4010	4860	5717	6960
WP-JCT-022	7.14	10	1382	2443	3290	4520	5600	6710	7912	9660
WP-JCT-023	8.3	10	1614	2827	3790	5180	6400	7650	9037	11060
WP-JCT-026	10.32	10	1673	2941	3950	5410	6630	7890	9285	11310
WP-JCT-027	11.91	20	1885	3225	4270	5760	7100	8450	9995	12250
WP-JCT-030	13.94	20	1992	3447	4590	6230	7670	9130	10823	13300
WP-JCT-033	15.78	20	2367	4048	5360	7230	8880	10550	12521	15410
WP-JCT-034	17.58	20	2696	4624	6130	8280	10160	12100	14341	17620
WP-JCT-035	33.1	50	3207	5705	7710	10630	13040	15600	18509	22770
WP-JCT-036	33.1	50	3128	5598	7590	10500	12930	15500	18389	22620
WP-JCT-037	34.8	50	3260	5844	7930	10980	13540	16220	19254	23700
WP-JCT-039	36.55	50	3322	6037	8250	11510	14280	17140	20355	25070
WP-JCT-040	36.55	50	3315	6028	8240	11500	14270	17130	20345	25060
WP-JCT-041	38.2	50	3383	6191	8490	11890	14840	17850	21232	26200
WP-JCT-059	54.53	70	3119	5814	8050	11390	13900	16870	20172	25050
WP-JCT-061	55.57	70	3378	6028	8160	11270	13840	16960	20365	25420
WP-JCT-062	57.81	70	3761	6189	8030	10600	12950	16220	19588	24620
WP-JCT-063	59.32	70	3920	6211	7900	10210	12290	15510	18816	23780
WP-JCT-064	59.32	70	3727	6033	7760	10150	11820	14780	18033	22950
WP-JCT-065	61.42	95	3339	5731	7600	10270	11720	14160	17405	22350
WP-JCT-066	63.11	95	3249	5687	7620	10410	11450	13300	16529	21510
WP-JCT-115	108.2	150	5698	10215	13860	19190	23120	26580	30372	35700
WP-JCT-117	109.32	150	5940	10436	14010	19180	23200	26720	30544	35920
WP-JCT-118	110.38	150	6100	10580	14110	19180	23220	26780	30621	36020
WP-JCT-124	114.05	150	6261	10829	14420	19570	23680	27310	31198	36660
WP-JCT-130	118.41	150	6279	10840	14420	19550	23740	27400	31297	36770
WP-JCT-131	119.4	150	6423	10979	14530	19590	23790	27490	31400	36890
WP-JCT-132	121.21	150	6694	11236	14730	19660	23880	27670	31616	37160
WP-JCT-133	121.21	150	6662	11203	14700	19640	23860	27650	31588	37120
WP-JCT-144	124.91	200	6087	10454	13870	18750	23140	27090	30995	36490
WP-JCT-145	127.08	200	6199	10664	14160	19160	23570	27630	31637	37280
WP-JCT-146	127.08	200	6169	10626	14120	19120	23500	27590	31589	37220
WP-JCT-147	129.11	200	6244	10784	14350	19460	23850	28040	32132	37900
WP-JCT-148	129.11	200	6197	10737	14310	19440	23800	28010	32094	37850
WP-JCT-149	130.33	200	6193	10784	14410	19630	23980	28260	32401	38240
WP-JCT-156	134.09	200	6310	11084	14880	20370	24720	29230	33569	39700
WP-JCT-157	134.81	200	6350	11157	14980	20510	24860	29420	33796	39980
WP-JCT-158	134.81	200	6334	11143	14970	20510	24860	29410	33790	39980

Table AA5. Existing Conditions Peak Flows – Saddle Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Existing Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-50	1.7	10	434	741	980	1320	1620	1940	2290	2800
LP-JCT-51	3.03	10	849	1446	1910	2570	3160	3780	4453	5430
LP-JCT-52	3.86	10	1079	1874	2500	3400	4170	5000	5889	7180

Table AA6. Existing Conditions Peak Flows – Thomas Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Existing Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-23	4.06	10	892	1619	2210	3080	3820	4620	5477	6730
LP-JCT-24-G09-Thomas	4.92	10	1002	1846	2540	3570	4430	5380	6408	7920
LP-JCT-25	6.59	10	1294	2388	3290	4630	5770	7020	8367	10350
LP-JCT-26	8.3	10	1592	2940	4050	5700	7130	8580	10208	12600
LP-JCT-27	9.45	20	1421	2678	3730	5310	6620	8070	9645	11970
LP-JCT-28	10.8	20	1440	2724	3800	5420	6780	8260	9900	12330

Appendix AB. Build-Out Conditions Peak Flows

Table AB1. Build-Out Conditions Peak Flows – South Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Build-Out/Future Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-072	2.69	10	790	1260	1620	2110	2530	2990	3490	4200
WP-JCT-073	4.32	10	1300	2100	2700	3530	4240	5000	5820	7000
WP-JCT-077	7.04	10	2200	3540	4550	5940	7120	8400	9780	11750
WP-JCT-081	10.16	20	2900	4700	6040	7900	9480	11180	13050	15750
WP-JCT-084	11.61	20	3220	5230	6730	8810	10580	12500	14590	17590
WP-JCT-085	12.76	20	3490	5670	7300	9560	11500	13590	15880	19170
WP-JCT-087	13.74	20	3770	6110	7860	10290	12370	14620	17090	20660
WP-JCT-088	15.41	20	3960	6430	8280	10850	13080	15520	18210	22100
WP-JCT-089	15.41	20	3960	6420	8270	10830	13060	15490	18180	22060
WP-JCT-104	28.58	30	3920	6340	8150	10650	12830	15230	17870	21700
WP-JCT-105	30.5	30	4420	7130	9150	11940	14390	17100	20070	24360
WP-JCT-106	30.5	30	4400	7110	9140	11940	14380	17090	20060	24350
WP-JCT-107	32.75	30	4660	7510	9640	12580	15200	18050	21210	25800
WP-JCT-112	37.92	50	4550	7280	9310	12100	14600	17260	20310	24730
WP-JCT-113	39.43	50	4730	7400	9350	12000	14590	17270	20350	24830

Table AB2. Build-Out Conditions: Big Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Build-Out/Future Conditions (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	5230	8980	11910	16100	20010	24270	29180	36480
BP-JCT-066	85.65	120	5130	9050	12180	16720	20680	25230	30460	38280
BP-JCT-073	96.06	120	5070	9110	12390	17190	21300	26060	31500	39640
BP-JCT-074	97.52	120	5760	9750	12840	17220	21350	26130	31600	39790
BP-JCT-076	102.14	120	5520	9520	12660	17160	21320	26010	31530	39820
BP-JCT-077	103.62	120	5370	9420	12630	17270	21470	26210	31780	40130
BP-JCT-080	106.23	120	5490	9590	12840	17530	21800	26630	32290	40780
BP-JCT-081	107.92	120	5050	9160	12510	17440	21720	26550	32200	40680
BP-JCT-084	110.96	120	5010	9150	12540	17540	21860	26740	32440	40990
BP-JCT-086	112.98	120	4990	9160	12580	17650	22020	26950	32700	41330
BP-JCT-087	115.2	150	4760	8750	12030	16890	21070	25790	31320	39630
BP-JCT-089	116.04	150	4710	8700	12000	16900	21120	25870	31410	39740
BP-JCT-090	117.05	150	4680	8680	11980	16900	21110	25860	31400	39730
BP-JCT-091	119.09	150	4770	8710	11930	16690	20950	25720	31260	39610
BP-JCT-092	121.32	150	4890	8740	11850	16390	20670	25510	31040	39380
BP-JCT-094	127.28	150	4910	8780	11890	16430	20710	25560	31130	39530
BP-JCT-095	129.08	150	4910	8770	11880	16420	20690	25450	31010	39400
BP-JCT-096	131.56	150	5160	9010	12070	16480	20780	25500	31110	39590
BP-JCT-103	136.39	200	5280	8830	11540	15360	19510	24240	29510	37450
BP-JCT-105	138.54	200	5410	8990	11720	15550	19710	24440	29740	37730
BP-JCT-106	139.76	200	5480	9070	11800	15620	19710	24460	29740	37690
BP-JCT-107	141.06	200	5590	9200	11940	15760	19780	24550	29830	37770
BP-JCT-110	143.54	200	5730	9370	12120	15940	19850	24650	29930	37870
BP-JCT-111	144.98	200	5870	9510	12240	16020	19840	24630	29910	37840
BP-JCT-115	147.17	250	6110	9530	12020	15400	18780	23340	28330	35840
BP-JCT-116	148.73	250	6210	9630	12120	15480	18820	23360	28360	35880
BP-JCT-119	152.29	250	6730	10180	12,650	15,940	19,320	23,540	28570	36,130
BP-JCT-125	156.68	250	6770	10270	12780	16130	19490	23710	28760	36350
BP-JCT-127-G08-Q ST	216.53	300	6150	11790	16580	23840	29600	35900	42690	52650
BP-JCT-129	218.71	300	7650	12840	16830	22460	27410	32450	39930	51350
BP-JCT-130	220.79	300	8220	13260	17030	22230	26900	32200	39890	51710
BP-JCT-132	224.06	300	10690	14660	17290	20620	23960	27580	35880	49340
BP-JCT-133	224.61	300	11470	15050	17350	20190	23470	27000	34120	45310
BP-JCT-135	227.91	300	11770	15100	17210	19780	22910	26630	32340	40920
BP-JCT-136	228.82	300	11140	14380	16430	18940	21770	25670	30640	37960
BP-JCT-138	230.65	300	9960	13140	15190	17730	20100	24090	29000	36320
BP-JCT-142	232.44	300	10120	13260	15270	17750	20110	24090	29010	36350
PA-JCT-01	367.26	400	17460	24100	28530	34150	38550	42880	47220	53070
PA-JCT-02	368.7	400	17440	24160	28650	34360	38770	43160	47570	53520
PA-JCT-12	379.54	400	17320	24490	29360	35620	40650	45460	50340	56950
PA-JCT-16	384.3	400	17340	24730	29780	36300	41480	46480	51580	58520
PA-JCT-17-G19-CAPEHART	384.3	400	16880	24270	29350	35940	41280	46300	51400	58340
PA-JCT-18	384.3	400	16650	24040	29120	35730	41130	46190	51280	58210
PA-JCT-20	386.32	400	16500	23960	29120	35850	41400	46550	51780	58910
PA-JCT-24	390.43	400	16480	24140	29470	36460	42180	47550	53080	60650
PA-JCT-27	391.97	400	15620	23040	28220	35040	40840	46270	51740	59250
PA-JCT-29	395.86	400	15520	23010	28270	35210	41130	46770	52450	60270
PA-JCT-30	395.86	400	15400	22750	27890	34660	40540	46190	51880	59730

Table AB3. Build-Out Conditions: Little Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Build-Out/Future Conditions (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-19	17.82	20	100	140	160	190	220	340	390	450
LP-JCT-20	19.12	20	360	610	800	1070	1310	1590	1870	2270
LP-JCT-21	20.97	20	800	1360	1780	2380	2900	3470	4090	5000
LP-JCT-29-G10-LP-Irvington	31.77	30	2870	4840	6360	8510	10320	12340	14570	17810
LP-JCT-30	33.81	50	2910	4970	6570	8850	10770	12910	15250	18650
LP-JCT-31	35.61	50	3110	5330	7060	9530	11620	13940	16490	20200
LP-JCT-32	37.62	50	3430	5840	7710	10370	12690	15280	17870	21610
LP-JCT-33	38.54	50	3570	6060	7980	10710	13130	15840	18420	22110
LP-JCT-34	0.86	10	130	230	320	450	560	680	810	1010
LP-JCT-35	2.09	10	270	490	670	940	1180	1440	1720	2140
LP-JCT-37	3.24	10	380	700	960	1350	1690	2060	2470	3080
LP-JCT-38	4.14	10	490	880	1210	1690	2110	2580	3100	3860
LP-JCT-39	5.18	10	610	1100	1510	2110	2650	3240	3880	4840
LP-JCT-40-G11-Cole	6.1	10	730	1340	1830	2560	3230	3930	4720	5890
LP-JCT-41	6.68	10	740	1360	1860	2600	3280	4010	4830	6060
LP-JCT-42	45.22	50	4160	7190	9570	12980	15980	19350	22610	27300
LP-JCT-44	46.55	50	4320	7470	9940	13480	16620	20200	23630	28580
LP-JCT-47	48.43	70	4420	7630	10150	13760	17040	20740	24450	29840
LP-JCT-48-G12-LP-Aksarben	50.2	70	4410	7700	10300	14050	17380	21080	24970	30650
LP-JCT-49	51.33	70	4490	7870	10560	14440	17890	21740	25550	31080
LP-JCT-54	56.58	70	4680	8610	11850	16650	20850	25500	30210	37090
LP-JCT-55	57.62	70	4680	8660	11940	16820	21120	25840	30220	36540
LP-JCT-56	58.88	70	4850	9040	12520	17710	22230	27230	31790	38350
LP-JCT-57	59.85	70	4180	8210	11680	17010	21690	22980	26600	31760

Table AB4. Build-Out Conditions: West Papillion Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	50% AEP	20% AEP	Build-Out/Future Conditions 10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-015	1.07	10	200	350	460	620	750	900	1060	1300
WP-JCT-016	1.07	10	210	350	460	610	750	900	1060	1290
WP-JCT-017	2.58	10	560	960	1270	1710	2070	2480	2910	3530
WP-JCT-018	3.4	10	750	1290	1710	2310	2790	3350	3930	4760
WP-JCT-019	5.15	10	1110	1930	2580	3510	4300	5130	5950	7120
WP-JCT-022	7.14	10	1550	2690	3590	4880	5940	7060	8230	9920
WP-JCT-023	8.3	10	1850	3140	4150	5580	6780	8050	9410	11370
WP-JCT-026	10.32	10	1970	3320	4350	5810	7020	8290	9660	11630
WP-JCT-027	11.91	20	2230	3660	4740	6250	7580	8930	10480	12730
WP-JCT-030	13.94	20	2370	3930	5120	6790	8210	9740	11420	13860
WP-JCT-033	15.78	20	2780	4580	5950	7860	9510	11220	13180	16030
WP-JCT-034	17.58	20	3210	5270	6830	9000	10890	12850	15080	18320
WP-JCT-035	33.1	50	3980	6610	8620	11440	13880	16500	19410	23640
WP-JCT-036	33.1	50	3860	6480	8490	11330	13780	16380	19280	23480
WP-JCT-037	34.8	50	4010	6750	8850	11820	14380	17100	20140	24570
WP-JCT-039	36.55	50	4100	6990	9230	12420	15180	18070	21300	26000
WP-JCT-040	36.55	50	4080	6960	9210	12410	15160	18060	21290	25990
WP-JCT-041	38.2	50	4110	7110	9470	12860	15770	18810	22210	27160
WP-JCT-059	54.53	70	3980	6820	9040	12210	14790	17810	21150	26050
WP-JCT-061	55.57	70	4270	7050	9160	12110	14840	17940	21390	26480
WP-JCT-062	57.81	70	4810	7280	9030	11370	14100	17210	20630	25690
WP-JCT-063	59.32	70	5110	7350	8890	10890	13360	16520	19880	24880
WP-JCT-064	59.32	70	5020	7220	8740	10710	12750	15830	19110	24020
WP-JCT-065	61.42	95	4540	6890	8570	10810	12390	15230	18510	23450
WP-JCT-066	63.11	95	4580	6920	8590	10810	11920	14310	17590	22590
WP-JCT-115	108.2	150	6370	11260	15170	20840	24270	27740	31550	36870
WP-JCT-117	109.32	150	6670	11530	15360	20850	24370	27900	31740	37110
WP-JCT-118	110.38	150	6880	11740	15510	20880	24420	27990	31840	37230
WP-JCT-124	114.05	150	7270	12210	16010	21370	24970	28620	32520	37960
WP-JCT-130	118.41	150	7360	12300	16090	21420	25080	28740	32650	38100
WP-JCT-131	119.4	150	7570	12490	16230	21460	25140	28840	32760	38240
WP-JCT-132	121.21	150	7950	12830	16470	21500	25250	29050	33000	38510
WP-JCT-133	121.21	150	7960	12830	16460	21470	25230	29030	32980	38490
WP-JCT-144	124.91	200	7590	12280	15790	20650	24740	28570	32490	37970
WP-JCT-145	127.08	200	7770	12540	16100	21020	25190	29130	33150	38780
WP-JCT-146	127.08	200	7760	12510	16060	20960	25140	29100	33110	38710
WP-JCT-147	129.11	200	7890	12720	16320	21290	25530	29610	33710	39450
WP-JCT-148	129.11	200	7870	12690	16290	21260	25500	29580	33670	39400
WP-JCT-149	130.33	200	7910	12780	16420	21450	25720	29890	34040	39840
WP-JCT-156	134.09	200	8190	13220	16980	22170	26540	30990	35330	41420
WP-JCT-157	134.81	200	8230	13300	17090	22330	26690	31190	35570	41710
WP-JCT-158	134.81	200	8220	13290	17080	22320	26680	31190	35570	41710

Table AB5. Build-Out Conditions: Saddle Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	50% AEP	20% AEP	Build-Out/Future Conditions Peak Flows (cfs) 10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-50	1.7	10	430	740	980	1320	1620	1940	2290	2800
LP-JCT-51	3.03	10	850	1450	1910	2570	3160	3780	4450	5430
LP-JCT-52	3.86	10	1080	1870	2500	3400	4170	5000	5890	7180

Table AB6. Build-Out Conditions: Thomas Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Build-Out/Future Conditions Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-23	4.06	10	1047	1810	2410	3270	4010	4810	5670	6920
LP-JCT-24-G09-Thomas	4.92	10	1197	2097	2810	3840	4710	5650	6697	8230
LP-JCT-25	6.59	10	1685	2899	3850	5210	6350	7590	8958	10950
LP-JCT-26	8.3	10	2205	3735	4920	6600	8000	9450	11111	13520
LP-JCT-27	9.45	20	2181	3626	4730	6280	7630	9090	10701	13040
LP-JCT-28	10.8	20	2253	3758	4910	6530	7910	9420	11143	13660

Appendix AC. Dam Site Alternatives

Table AC1. Alternative DS-3C (and DS-1) Washington County – Big Papillion Creek Peak Flows

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS-3C (with DS-1) Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	0	0	0	0	0	0	0	0
BP-JCT-076	102.14	120	0	0	0	0	40	90	150	280
BP-JCT-077	103.62	120	50	100	140	210	270	340	440	610
BP-JCT-080	106.23	120	130	250	360	530	680	850	1040	1330
BP-JCT-081	107.92	120	350	670	950	1370	1740	2150	2600	3260
BP-JCT-084	110.96	120	610	1160	1630	2340	2960	3640	4370	5450
BP-JCT-086	112.98	120	610	1170	1660	2400	3040	3750	4520	5660
BP-JCT-087	115.2	150	590	1160	1650	2400	3060	3790	4580	5750
BP-JCT-089	116.04	150	600	1170	1670	2430	3100	3850	4660	5860
BP-JCT-090	117.05	150	590	1230	1800	2700	3510	4390	5340	6780
BP-JCT-091	119.09	150	700	1530	2290	3530	4620	5820	7110	9050
BP-JCT-092	121.32	150	780	1750	2680	4220	5590	7100	8720	11180
BP-JCT-094	127.28	150	790	1780	2710	4250	5610	7130	8750	11200
BP-JCT-095	129.08	150	850	1940	2980	4720	6290	8040	9920	12810
BP-JCT-096	131.56	150	970	2180	3330	5230	6940	8850	10910	14050
BP-JCT-103	136.39	200	1090	2420	3670	5730	7580	9680	11930	15370
BP-JCT-105	138.54	200	1110	2470	3740	5830	7700	9820	12070	15490
BP-JCT-106	139.76	200	1180	2600	3920	6080	8030	10230	12570	16130
BP-JCT-107	141.06	200	1240	2710	4070	6280	8270	10500	12890	16540
BP-JCT-110	143.54	200	1370	2930	4370	6690	8770	11120	13650	17490
BP-JCT-111	144.98	200	1470	3120	4630	7050	9220	11660	14310	18340
BP-JCT-115	147.17	250	1460	3130	4660	7130	9400	11900	14650	18840
BP-JCT-116	148.73	250	1520	3270	4870	7450	9830	12450	15350	19770
BP-JCT-119	152.29	250	1730	3650	5400	8200	10780	13640	16800	21640
BP-JCT-125	156.68	250	1960	4090	6000	9040	11830	14910	18330	23540
BP-JCT-127-G08-Q_ST	216.53	300	3550	7740	11630	17960	23340	29140	35760	45820
BP-JCT-129	218.71	300	3660	7940	11900	18330	21860	26350	33350	44360
BP-JCT-130	220.79	300	3840	8160	12100	18410	21640	25800	33100	44780
BP-JCT-132	224.06	300	4720	8930	12470	17800	19710	22440	26580	32620
BP-JCT-133	224.61	300	4810	9020	12520	17770	19080	21350	25420	31400
BP-JCT-135	227.91	300	5370	9520	12840	17670	18750	20510	24120	29350
BP-JCT-136	228.82	300	6400	10130	12880	16640	17610	18870	21580	25390
BP-JCT-138	230.65	300	8710	11330	13000	15050	15940	16890	18600	20900
BP-JCT-142	232.44	300	8680	11360	13070	15180	16030	16960	18660	20950
PA-JCT-01	367.26	400	11360	18700	24270	32040	36360	40980	45360	51290
PA-JCT-02	368.7	400	11360	18740	24350	32190	36570	41210	45660	51700
PA-JCT-12	379.54	400	11650	19300	25130	33300	38370	43460	48370	55080
PA-JCT-16	384.3	400	11690	19510	25500	33930	39190	44430	49580	56620
PA-JCT-17-G19-CAPEHART	384.3	400	11390	19130	25080	33480	38940	44240	49390	56430
PA-JCT-18	384.3	400	11210	18900	24840	33240	38770	44100	49250	56300
PA-JCT-20	386.32	400	11030	18760	24770	33310	38980	44440	49720	56970
PA-JCT-24	390.43	400	10910	18770	24940	33760	39590	45240	50800	58460
PA-JCT-27	391.97	400	10070	17630	23630	32290	38140	43880	49400	57040
PA-JCT-29	395.86	400	9610	17200	23310	32240	38180	44090	49820	57780
PA-JCT-30	395.86	400	9180	16660	22760	31740	37580	43460	49230	57250

Table AC2. Alternative All Dams but DS-3C (and DS-1) – South Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative All Dams but DS-3C Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-072	2.69	10	670	1120	1470	1960	2380	2840	3330	4050
WP-JCT-073	4.32	10	0	0	0	0	0	0	0	0
WP-JCT-077	7.04	10	830	1370	1780	2350	2830	3350	3920	4740
WP-JCT-081	10.16	20	1550	2560	3330	4410	5330	6320	7400	8960
WP-JCT-084	11.61	20	1830	3040	3970	5270	6390	7580	8890	10780
WP-JCT-085	12.76	20	2160	3560	4620	6100	7390	8760	10270	12440
WP-JCT-087	13.74	20	2530	4110	5300	6950	8390	9930	11620	14070
WP-JCT-088	15.41	20	2940	4740	6080	7930	9520	11280	13220	16020
WP-JCT-089	15.41	20	2930	4720	6060	7910	9490	11250	13180	15980
WP-JCT-104	28.58	30	2840	4610	5940	7780	9340	11080	12980	15730
WP-JCT-105	30.5	30	3340	5430	7000	9180	11010	13050	15290	18520
WP-JCT-106	30.5	30	3350	5430	7000	9170	11010	13050	15280	18510
WP-JCT-107	32.75	30	3810	6000	7610	9800	11720	14000	16410	19900
WP-JCT-112	37.92	50	3680	5770	7310	9400	11200	13440	15750	19080
WP-JCT-113	39.43	50	4070	6120	7570	9500	11150	13420	15750	19120

Table AC3. Alternative All Dams but DS-3C (and DS-1) – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative All Dams but DS-3C Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4590	8360	11440	15980	20120	24800	30260	38500
BP-JCT-081	107.92	120	4100	7860	11040	15870	20030	24720	30160	38380
BP-JCT-084	110.96	120	4050	7800	10980	15820	19960	24670	30100	38300
BP-JCT-086	112.98	120	3950	7690	10880	15760	19900	24610	30040	38240
BP-JCT-087	115.2	150	3800	7360	10390	15010	18980	23510	28700	36540
BP-JCT-089	116.04	150	3740	7290	10340	15000	18990	23550	28760	36630
BP-JCT-090	117.05	150	3740	7290	10330	14990	18980	23540	28740	36610
BP-JCT-091	119.09	150	3890	7370	10300	14710	18800	23380	28590	36480
BP-JCT-092	121.32	150	4060	7470	10270	14430	18500	23080	28310	36250
BP-JCT-094	127.28	150	4090	7510	10310	14460	18530	23120	28390	36410
BP-JCT-095	129.08	150	4080	7500	10300	14450	18520	23100	28320	36260
BP-JCT-096	131.56	150	4120	7540	10350	14500	18590	23220	28460	36410
BP-JCT-103	136.39	200	4890	8000	10350	13620	17400	21920	26860	34360
BP-JCT-105	138.54	200	4960	8120	10500	13820	17600	22120	27090	34630
BP-JCT-106	139.76	200	5000	8180	10580	13920	17600	22120	27080	34590
BP-JCT-107	141.06	200	5010	8230	10660	14050	17660	22200	27150	34660
BP-JCT-110	143.54	200	5070	8340	10810	14260	17730	22290	27250	34760
BP-JCT-111	144.98	200	5120	8410	10900	14370	17710	22270	27220	34720
BP-JCT-115	147.17	250	4850	8060	10500	13930	16730	20970	25640	32710
BP-JCT-116	148.73	250	4920	8140	10590	14020	16730	20980	25660	32740
BP-JCT-119	152.29	250	5060	8340	10830	14310	16870	21050	25760	32890
BP-JCT-125	156.68	250	5230	8600	11160	14730	17310	21220	25980	33200
BP-JCT-127-G08-Q_ST	216.53	300	4960	9230	12760	18030	24550	30360	37710	49040
BP-JCT-129	218.71	300	5020	9370	12980	18380	22960	27890	35360	47130
BP-JCT-130	220.79	300	5220	9570	13140	18420	22720	27300	35040	47420
BP-JCT-132	224.06	300	5970	10160	13420	18050	21100	24240	29600	37720
BP-JCT-133	224.61	300	6120	10270	13460	17960	20720	23820	28550	35560
BP-JCT-135	227.91	300	6480	10600	13710	18040	20350	23400	27820	34320
BP-JCT-136	228.82	300	7250	11020	13730	17350	19520	22400	26740	33140
BP-JCT-138	230.65	300	8680	11730	13720	16220	18370	20800	25220	31840
BP-JCT-142	232.44	300	8840	11850	13810	16260	18380	20810	25230	31860
PA-JCT-01	367.26	400	10470	17590	23070	30810	35470	39900	44410	50560
PA-JCT-02	368.7	400	10480	17640	23160	30960	35680	40190	44770	51030
PA-JCT-12	379.54	400	10880	18260	23930	31930	37020	41990	46900	53630
PA-JCT-16	384.3	400	10980	18510	24320	32540	37850	43080	48250	55360
PA-JCT-17-G19-CAPEHART	384.3	400	10790	18210	23930	32030	37300	42650	47770	54810
PA-JCT-18	384.3	400	10650	18010	23700	31760	37010	42400	47520	54550
PA-JCT-20	386.32	400	10590	17980	23710	31850	37180	42800	48090	55380
PA-JCT-24	390.43	400	10500	18020	23910	32320	37880	43760	49380	57160
PA-JCT-27	391.97	400	10020	17210	22840	30880	36230	41970	47510	55210
PA-JCT-29	395.86	400	10070	17260	22870	30880	36280	42050	47780	55780
PA-JCT-30	395.86	400	10030	17100	22610	30450	35700	41350	47070	55070

Table AC4. Alternative All Dams but DS-3C (and DS-1) – West Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative All Dams but DS-3C Peak Flows (cfs)							
			50% ACE	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-015	1.07	10	150	270	380	540	670	820	980	1220
WP-JCT-016	1.07	10	150	270	380	540	670	820	980	1210
WP-JCT-017	2.58	10	0	0	0	0	0	0	0	0
WP-JCT-018	3.4	10	230	390	510	680	840	1010	1190	1450
WP-JCT-019	5.15	10	650	1120	1500	2040	2500	3000	3540	4330
WP-JCT-022	7.14	10	1040	1810	2430	3320	4090	4880	5770	7070
WP-JCT-023	8.3	10	1290	2240	2990	4070	5000	5940	7030	8610
WP-JCT-026	10.32	10	1310	2320	3130	4300	5230	6180	7270	8850
WP-JCT-027	11.91	20	1500	2630	3540	4850	5910	6970	8220	10030
WP-JCT-030	13.94	20	1610	2870	3880	5360	6530	7710	9110	11160
WP-JCT-033	15.78	20	1950	3480	4700	6480	7900	9320	11010	13480
WP-JCT-034	17.58	20	2290	4080	5510	7600	9290	10980	12970	15860
WP-JCT-035	33.1	50	2940	5300	7210	10010	12340	14730	17410	21320
WP-JCT-036	33.1	50	2890	5220	7110	9880	12220	14600	17260	21150
WP-JCT-037	34.8	50	3030	5470	7450	10360	12830	15330	18130	22220
WP-JCT-039	36.55	50	3110	5680	7780	10880	13560	16290	19280	23650
WP-JCT-040	36.55	50	3110	5670	7770	10870	13550	16280	19270	23630
WP-JCT-041	38.2	50	3120	5790	7990	11270	14120	17020	20160	24750
WP-JCT-059	54.53	70	2920	5460	7580	10750	13230	15930	19050	23650
WP-JCT-061	55.57	70	3140	5670	7710	10710	13140	16030	19260	24050
WP-JCT-062	57.81	70	3420	5770	7580	10140	12250	15230	18410	23170
WP-JCT-063	59.32	70	3510	5760	7460	9830	11620	14500	17620	22300
WP-JCT-064	59.32	70	3340	5600	7330	9770	11260	13710	16770	21420
WP-JCT-065	61.42	95	3010	5340	7220	9950	11340	13270	16290	20890
WP-JCT-066	63.11	95	2970	5340	7260	10070	11210	12570	15540	20090
WP-JCT-115	108.2	150	5570	9520	12610	17010	20760	23930	27190	31740
WP-JCT-117	109.32	150	5550	9600	12770	17320	20860	24130	27420	32020
WP-JCT-118	110.38	150	5550	9650	12890	17550	20930	24220	27540	32170
WP-JCT-124	114.05	150	5610	9840	13200	18060	21430	24980	28270	32850
WP-JCT-130	118.41	150	5540	9800	13210	18160	21650	25360	28650	33210
WP-JCT-131	119.4	150	5530	9860	13340	18410	22060	25960	29470	34360
WP-JCT-132	121.21	150	5530	9970	13560	18830	22750	26880	30690	36050
WP-JCT-133	121.21	150	5520	9950	13540	18810	22700	26820	30600	35910
WP-JCT-144	124.91	200	4990	9250	12760	17990	21970	26000	29820	35200
WP-JCT-145	127.08	200	5110	9460	13060	18410	22490	26630	30560	36120
WP-JCT-146	127.08	200	5100	9440	13020	18350	22410	26530	30430	35920
WP-JCT-147	129.11	200	5160	9580	13240	18690	22840	27070	31070	36730
WP-JCT-148	129.11	200	5150	9560	13200	18630	22780	26990	30960	36570
WP-JCT-149	130.33	200	5190	9630	13310	18790	23010	27260	31290	36970
WP-JCT-156	134.09	200	5340	9960	13790	19510	23980	28470	32770	38850
WP-JCT-157	134.81	200	5380	10030	13890	19660	24170	28710	33060	39220
WP-JCT-158	134.81	200	5370	10020	13880	19650	24160	28700	33040	39200

Table AC5. Alternative All Dams but DS-3C (and DS-1) – Little Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative All Dams but DS-3C Peak Flows (cfs)							
			50% ACE	20% ACE	10% ACE	4% ACE	2% ACE	1% ACE	0.5% ACE	0.2% ACE
LP-JCT-19	17.82	20	80	120	140	170	200	260	330	450
LP-JCT-20	19.12	20	280	500	680	940	1170	1430	1720	2140
LP-JCT-21	20.97	20	650	1160	1570	2170	2680	3240	3860	4770
LP-JCT-29-G10-LP-Irvington	31.77	30	1680	3060	4180	5830	7050	8390	9960	12260
LP-JCT-30	33.81	50	1730	3220	4450	6290	7680	9190	10920	13460
LP-JCT-31	35.61	50	1910	3560	4930	6980	8550	10250	12200	15060
LP-JCT-32	37.62	50	2190	4110	5710	8110	10010	12010	14280	17610
LP-JCT-33	38.54	50	2300	4310	5990	8510	10540	12680	15080	18610
LP-JCT-34	0.86	10	120	220	300	420	530	650	780	980
LP-JCT-35	2.09	10	240	460	640	910	1150	1400	1690	2110
LP-JCT-37	3.24	10	360	670	930	1310	1650	2020	2430	3040
LP-JCT-38	4.14	10	420	800	1120	1600	2020	2480	2990	3760
LP-JCT-39	5.18	10	540	1020	1420	2020	2560	3140	3780	4740
LP-JCT-40-G11-Cole	6.1	10	670	1250	1740	2470	3130	3840	4620	5790
LP-JCT-41	6.68	10	670	1270	1770	2520	3180	3920	4740	5960
LP-JCT-42	45.22	50	2830	5360	7490	10700	13300	16110	19240	23860
LP-JCT-44	46.55	50	2930	5610	7880	11320	14130	17170	20530	25490
LP-JCT-47	48.43	70	2980	5740	8080	11640	14720	17940	21510	26790
LP-JCT-48-G12-LP-Aksarben	50.2	70	2960	5800	8230	11960	15260	18690	22370	27810
LP-JCT-49	51.33	70	3080	6010	8510	12340	15700	19340	23070	28560
LP-JCT-54	56.58	70	3480	6920	9910	14540	18740	23310	27910	34730
LP-JCT-55	57.62	70	3470	6930	9950	14630	18900	23560	28230	35160
LP-JCT-56	58.88	70	3740	7410	10600	15520	20000	24910	29910	37330
LP-JCT-57	59.85	70	3670	7110	10050	14530	19420	22360	25230	29210

Table AC6. Alternative All Dams but DS-3C (and DS-1) – Thomas Creek

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative All Dams but DS-3C Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-23	4.06	10	890	1620	2210	3080	3820	4620	5480	6730
LP-JCT-24-G09-Thomas	4.92	10	0	0	0	0	0	0	0	0
LP-JCT-25	6.59	10	350	620	850	1180	1460	1770	2100	2580
LP-JCT-26	8.3	10	710	1270	1730	2400	2970	3590	4260	5250
LP-JCT-27	9.45	20	900	1610	2180	3010	3690	4440	5300	6560
LP-JCT-28	10.8	20	1250	2190	2930	4000	4760	5630	6660	8160

Table AC7. Alternative DS19 – South Papillion

Junction	DA (mi2)	FYR A Storm Area (mi2)	Alternative with DS19 Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-072	2.69	10	670	1120	1470	1960	2380	2840	3330	4050
WP-JCT-073	4.32	10	0	0	0	0	0	0	0	0
WP-JCT-077	7.04	10	830	1370	1780	2350	2830	3350	3920	4740
WP-JCT-081	10.16	20	1550	2560	3330	4410	5330	6320	7400	8960
WP-JCT-084	11.61	20	1830	3040	3970	5270	6390	7580	8890	10780
WP-JCT-085	12.76	20	2160	3560	4620	6100	7390	8760	10270	12440
WP-JCT-087	13.74	20	2530	4110	5300	6950	8390	9930	11620	14070
WP-JCT-088	15.41	20	2940	4740	6080	7930	9520	11280	13220	16020
WP-JCT-089	15.41	20	2930	4720	6060	7910	9490	11250	13180	15980
WP-JCT-104	28.58	30	2840	4610	5940	7780	9340	11080	12980	15730
WP-JCT-105	30.5	30	3340	5430	7000	9180	11010	13050	15290	18520
WP-JCT-106	30.5	30	3350	5430	7000	9170	11010	13050	15280	18510
WP-JCT-107	32.75	30	3810	6000	7610	9800	11720	14000	16410	19900
WP-JCT-112	37.92	50	3680	5770	7310	9400	11200	13440	15750	19080
WP-JCT-113	39.43	50	4070	6120	7570	9500	11150	13420	15750	19120

Table AC8. Alternative DS19 – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative with DS19 Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4720	8550	11660	16240	20400	25160	30710	39090
BP-JCT-081	107.92	120	4260	8070	11270	16090	20310	25080	30620	38990
BP-JCT-084	110.96	120	4170	7990	11230	16140	20400	25230	30800	39230
BP-JCT-086	112.98	120	4070	7900	11190	16210	20500	25390	31010	39500
BP-JCT-087	115.2	150	3830	7480	10620	15430	19530	24230	29600	37740
BP-JCT-089	116.04	150	3790	7440	10590	15430	19550	24280	29670	37820
BP-JCT-090	117.05	150	3770	7420	10570	15420	19540	24260	29650	37810
BP-JCT-091	119.09	150	3940	7520	10550	15130	19360	24110	29510	37690
BP-JCT-092	121.32	150	4080	7600	10510	14860	19060	23820	29230	37450
BP-JCT-094	127.28	150	4130	7650	10560	14890	19100	23860	29310	37610
BP-JCT-095	129.08	150	4120	7640	10550	14880	19080	23840	29240	37460
BP-JCT-096	131.56	150	4220	7740	10640	14930	19160	23960	29380	37620
BP-JCT-103	136.39	200	5060	8260	10680	14040	17960	22590	27710	35500
BP-JCT-105	138.54	200	5140	8390	10840	14240	18150	22790	27940	35770
BP-JCT-106	139.76	200	5220	8480	10930	14330	18160	22790	27920	35720
BP-JCT-107	141.06	200	5250	8540	11020	14460	18210	22860	28000	35800
BP-JCT-110	143.54	200	5320	8670	11180	14670	18280	22960	28090	35880
BP-JCT-111	144.98	200	5390	8750	11280	14780	18270	22940	28070	35840
BP-JCT-115	147.17	250	5270	8530	10970	14350	17320	21620	26480	33850
BP-JCT-116	148.73	250	5330	8610	11060	14450	17410	21630	26500	33880
BP-JCT-119	152.29	250	5480	8820	11310	14750	17700	21700	26600	34030
BP-JCT-125	156.68	250	5640	9070	11640	15180	18130	21920	26850	34340
BP-JCT-127-G08-Q ST	216.53	300	5300	10060	14050	20070	26460	32300	39510	50430
BP-JCT-129	218.71	300	5740	10440	14270	19920	24700	29800	37330	49040
BP-JCT-130	220.79	300	5960	10660	14440	19960	24320	29220	37050	49390
BP-JCT-132	224.06	300	7420	11640	14730	18930	22180	25730	32990	44600
BP-JCT-133	224.61	300	7790	11860	14770	18670	21740	25200	31330	40780
BP-JCT-135	227.91	300	8440	12320	15020	18550	21240	24630	29820	37600
BP-JCT-136	228.82	300	9510	12850	15040	17790	20270	23420	28120	35110
BP-JCT-138	230.65	300	8940	12060	14100	16660	18900	21960	26650	33700
BP-JCT-142	232.44	300	9110	12190	14190	16690	18910	21960	26660	33730
PA-JCT-01	367.26	400	11010	18060	23400	30840	35490	39930	44430	50570
PA-JCT-02	368.7	400	11000	18100	23480	30990	35700	40220	44790	51040
PA-JCT-12	379.54	400	11550	18840	24330	31960	37050	42050	46950	53650
PA-JCT-16	384.3	400	11660	19110	24740	32580	37880	43130	48290	55370
PA-JCT-17-G19-CAPEHART	384.3	400	11620	18930	24430	32070	37350	42720	47820	54830
PA-JCT-18	384.3	400	11630	18860	24290	31810	37070	42470	47560	54560
PA-JCT-20	386.32	400	11740	18990	24410	31910	37250	42870	48140	55400
PA-JCT-24	390.43	400	11680	19070	24640	32380	37960	43820	49420	57180
PA-JCT-27	391.97	400	11730	18710	23880	30980	36340	42040	47560	55230
PA-JCT-29	395.86	400	11690	18690	23880	31020	36430	42120	47840	55810
PA-JCT-30	395.86	400	11630	18520	23620	30610	35870	41420	47130	55110

Table AC9. Alternative DS19 – West Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative with DS19 Peak Flows (cfs) 50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-015	1.07	10	150	270	380	540	670	820	980	1220
WP-JCT-016	1.07	10	150	270	380	540	670	820	980	1210
WP-JCT-017	2.58	10	420	780	1080	1520	1880	2280	2720	3360
WP-JCT-018	3.4	10	620	1110	1500	2070	2580	3100	3700	4580
WP-JCT-019	5.15	10	990	1750	2350	3220	4010	4860	5720	6960
WP-JCT-022	7.14	10	1380	2440	3290	4520	5600	6710	7910	9660
WP-JCT-023	8.3	10	1610	2830	3790	5180	6400	7650	9040	11060
WP-JCT-026	10.32	10	1670	2940	3950	5410	6630	7890	9280	11310
WP-JCT-027	11.91	20	1890	3220	4270	5760	7100	8450	9990	12250
WP-JCT-030	13.94	20	1990	3450	4590	6230	7670	9130	10820	13300
WP-JCT-033	15.78	20	2370	4050	5360	7230	8880	10550	12520	15410
WP-JCT-034	17.58	20	2700	4620	6130	8280	10160	12100	14340	17620
WP-JCT-035	33.1	50	3210	5710	7710	10630	13040	15600	18510	22770
WP-JCT-036	33.1	50	3130	5600	7590	10500	12930	15500	18390	22620
WP-JCT-037	34.8	50	3260	5840	7930	10980	13540	16220	19250	23700
WP-JCT-039	36.55	50	3320	6040	8250	11510	14280	17140	20360	25070
WP-JCT-040	36.55	50	3310	6030	8240	11500	14270	17130	20340	25060
WP-JCT-041	38.2	50	3380	6190	8490	11890	14840	17850	21230	26200
WP-JCT-059	54.53	70	3120	5810	8050	11390	13900	16870	20170	25050
WP-JCT-061	55.57	70	3380	6030	8160	11270	13840	16960	20360	25420
WP-JCT-062	57.81	70	3760	6190	8030	10600	12950	16220	19590	24620
WP-JCT-063	59.32	70	3920	6210	7900	10210	12290	15510	18820	23780
WP-JCT-064	59.32	70	3730	6030	7760	10150	11820	14780	18030	22950
WP-JCT-065	61.42	95	3340	5730	7600	10270	11720	14160	17410	22350
WP-JCT-066	63.11	95	3250	5690	7620	10410	11450	13300	16530	21510
WP-JCT-115	108.2	150	5590	9550	12630	17020	20850	23970	27220	31760
WP-JCT-117	109.32	150	5580	9620	12790	17330	20970	24170	27460	32040
WP-JCT-118	110.38	150	5560	9670	12910	17570	21040	24270	27570	32180
WP-JCT-124	114.05	150	5630	9860	13220	18070	21510	25020	28300	32860
WP-JCT-130	118.41	150	5560	9830	13230	18170	21670	25400	28670	33200
WP-JCT-131	119.4	150	5560	9890	13360	18420	22080	25990	29490	34360
WP-JCT-132	121.21	150	5540	9990	13580	18850	22760	26920	30720	36040
WP-JCT-133	121.21	150	5540	9970	13560	18820	22710	26860	30630	35910
WP-JCT-144	124.91	200	4990	9250	12770	18010	21990	26030	29840	35210
WP-JCT-145	127.08	200	5100	9460	13060	18430	22520	26670	30590	36130
WP-JCT-146	127.08	200	5080	9420	13020	18380	22440	26560	30450	35930
WP-JCT-147	129.11	200	5160	9590	13250	18710	22870	27100	31100	36740
WP-JCT-148	129.11	200	5140	9560	13210	18660	22810	27020	30990	36580
WP-JCT-149	130.33	200	5170	9620	13310	18820	23040	27300	31320	36980
WP-JCT-156	134.09	200	5330	9950	13790	19530	24010	28510	32790	38850
WP-JCT-157	134.81	200	5360	10020	13890	19680	24200	28750	33090	39230
WP-JCT-158	134.81	200	5370	10020	13890	19670	24190	28740	33070	39210

Table AC10. Alternative DS10 – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS10 Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4720	8550	11660	16240	20400	25160	30710	39090
BP-JCT-081	107.92	120	4260	8070	11270	16090	20310	25080	30620	38990
BP-JCT-084	110.96	120	4170	7990	11230	16140	20400	25230	30800	39230
BP-JCT-086	112.98	120	4070	7900	11190	16210	20500	25390	31010	39500
BP-JCT-087	115.2	150	3830	7480	10620	15430	19530	24230	29600	37740
BP-JCT-089	116.04	150	3790	7440	10590	15430	19550	24280	29670	37820
BP-JCT-090	117.05	150	3770	7420	10570	15420	19540	24260	29650	37810
BP-JCT-091	119.09	150	3940	7520	10550	15130	19360	24110	29510	37690
BP-JCT-092	121.32	150	4080	7600	10510	14860	19060	23820	29230	37450
BP-JCT-094	127.28	150	4130	7650	10560	14890	19100	23860	29310	37610
BP-JCT-095	129.08	150	4120	7640	10550	14880	19080	23840	29240	37460
BP-JCT-096	131.56	150	4220	7740	10640	14930	19160	23960	29380	37620
BP-JCT-103	136.39	200	5060	8260	10680	14040	17960	22590	27710	35500
BP-JCT-105	138.54	200	5140	8390	10840	14240	18150	22790	27940	35770
BP-JCT-106	139.76	200	5220	8480	10930	14330	18160	22790	27920	35720
BP-JCT-107	141.06	200	5250	8540	11020	14460	18210	22860	28000	35800
BP-JCT-110	143.54	200	5320	8670	11180	14670	18280	22960	28090	35880
BP-JCT-111	144.98	200	5390	8750	11280	14780	18270	22940	28070	35840
BP-JCT-115	147.17	250	5270	8530	10970	14350	17320	21620	26480	33850
BP-JCT-116	148.73	250	5330	8610	11060	14450	17410	21630	26500	33880
BP-JCT-119	152.29	250	5480	8820	11310	14750	17700	21700	26600	34030
BP-JCT-125	156.68	250	5640	9070	11640	15180	18130	21920	26850	34340
BP-JCT-127-G08-Q ST	216.53	300	5530	9840	13300	18340	25120	31030	38340	49530
BP-JCT-129	218.71	300	5570	9970	13520	18700	23330	28380	35860	47610
BP-JCT-130	220.79	300	5760	10170	13690	18800	23070	27750	35520	47910
BP-JCT-132	224.06	300	6710	10870	13980	18290	21380	24670	30580	39660
BP-JCT-133	224.61	300	6910	10990	14010	18150	21020	24260	29370	37030
BP-JCT-135	227.91	300	7340	11360	14260	18180	20650	23840	28540	35490
BP-JCT-136	228.82	300	8180	11790	14280	17510	19810	22820	27410	34220
BP-JCT-138	230.65	300	8690	11800	13840	16410	18600	21310	25930	32900
BP-JCT-142	232.44	300	8840	11920	13930	16450	18610	21310	25940	32920
PA-JCT-01	367.26	400	11180	18550	24170	32050	36360	40980	45360	51290
PA-JCT-02	368.7	400	11160	18570	24240	32200	36570	41220	45670	51700
PA-JCT-12	379.54	400	11430	19120	25010	33310	38370	43470	48380	55080
PA-JCT-16	384.3	400	11490	19340	25390	33940	39190	44440	49580	56620
PA-JCT-17-G19-CAPEHART	384.3	400	11210	18980	24980	33490	38940	44250	49390	56430
PA-JCT-18	384.3	400	11070	18780	24760	33250	38780	44110	49250	56300
PA-JCT-20	386.32	400	10990	18740	24760	33330	38980	44440	49720	56970
PA-JCT-24	390.43	400	10930	18800	24960	33770	39600	45250	50810	58460
PA-JCT-27	391.97	400	10680	18180	24010	32300	38150	43890	49410	57040
PA-JCT-29	395.86	400	10760	18250	24040	32260	38180	44100	49830	57780
PA-JCT-30	395.86	400	10750	18100	23760	31760	37580	43470	49230	57250

Table AC11. Alternative DS10 – Little Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS10 Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
LP-JCT-19	17.82	20	80	120	140	170	200	260	330	450
LP-JCT-20	19.12	20	280	500	680	940	1170	1430	1720	2140
LP-JCT-21	20.97	20	650	1160	1570	2170	2680	3240	3860	4770
LP-JCT-29-G10-LP-Irvington	31.77	30	1680	3060	4180	5830	7050	8390	9960	12260
LP-JCT-30	33.81	50	1730	3220	4450	6290	7680	9190	10920	13460
LP-JCT-31	35.61	50	1910	3560	4930	6980	8550	10250	12200	15060
LP-JCT-32	37.62	50	2190	4110	5710	8110	10010	12010	14280	17610
LP-JCT-33	38.54	50	2300	4310	5990	8510	10540	12680	15080	18610
LP-JCT-34	0.86	10	120	220	300	420	530	650	780	980
LP-JCT-35	2.09	10	240	460	640	910	1150	1400	1690	2110
LP-JCT-37	3.24	10	360	670	930	1310	1650	2020	2430	3040
LP-JCT-38	4.14	10	420	800	1120	1600	2020	2480	2990	3760
LP-JCT-39	5.18	10	540	1020	1420	2020	2560	3140	3780	4740
LP-JCT-40-G11-Cole	6.1	10	670	1250	1740	2470	3130	3840	4620	5790
LP-JCT-41	6.68	10	670	1270	1770	2520	3180	3920	4740	5960
LP-JCT-42	45.22	50	2830	5360	7490	10700	13300	16110	19240	23860
LP-JCT-44	46.55	50	2930	5610	7880	11320	14130	17170	20530	25490
LP-JCT-47	48.43	70	2980	5740	8080	11640	14720	17940	21510	26790
LP-JCT-48-G12-LP-Aksarben	50.2	70	2960	5800	8230	11960	15260	18690	22370	27810
LP-JCT-49	51.33	70	3080	6010	8510	12340	15700	19340	23070	28560
LP-JCT-54	56.58	70	3480	6920	9910	14540	18740	23310	27910	34730
LP-JCT-55	57.62	70	3470	6930	9950	14630	18900	23560	28230	35160
LP-JCT-56	58.88	70	3740	7410	10600	15520	20000	24910	29910	37330
LP-JCT-57	59.85	70	3670	7110	10050	14530	19420	22360	25230	29210

Table AC12. Alternative DS-12 – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS-12 Peak Flows (cfs) 50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4720	8550	11660	16240	20400	25160	30710	39090
BP-JCT-081	107.92	120	4260	8070	11270	16090	20310	25080	30620	38990
BP-JCT-084	110.96	120	4170	7990	11230	16140	20400	25230	30800	39230
BP-JCT-086	112.98	120	4070	7900	11190	16210	20500	25390	31010	39500
BP-JCT-087	115.2	150	3830	7480	10620	15430	19530	24230	29600	37740
BP-JCT-089	116.04	150	3790	7440	10590	15430	19550	24280	29670	37820
BP-JCT-090	117.05	150	3770	7420	10570	15420	19540	24260	29650	37810
BP-JCT-091	119.09	150	3940	7520	10550	15130	19360	24110	29510	37690
BP-JCT-092	121.32	150	4080	7600	10510	14860	19060	23820	29230	37450
BP-JCT-094	127.28	150	4130	7650	10560	14890	19100	23860	29310	37610
BP-JCT-095	129.08	150	4120	7640	10550	14880	19080	23840	29240	37460
BP-JCT-096	131.56	150	4220	7740	10640	14930	19160	23960	29380	37620
BP-JCT-103	136.39	200	5060	8260	10680	14040	17960	22590	27710	35500
BP-JCT-105	138.54	200	5140	8390	10840	14240	18150	22790	27940	35770
BP-JCT-106	139.76	200	5220	8480	10930	14330	18160	22790	27920	35720
BP-JCT-107	141.06	200	5250	8540	11020	14460	18210	22860	28000	35800
BP-JCT-110	143.54	200	5320	8670	11180	14670	18280	22960	28090	35880
BP-JCT-111	144.98	200	5390	8750	11280	14780	18270	22940	28070	35840
BP-JCT-115	147.17	250	5270	8530	10970	14350	17320	21620	26480	33850
BP-JCT-116	148.73	250	5330	8610	11060	14450	17410	21630	26500	33880
BP-JCT-119	152.29	250	5480	8820	11310	14750	17700	21700	26600	34030
BP-JCT-125	156.68	250	5640	9070	11640	15180	18130	21920	26850	34340
BP-JCT-127-G08-Q ST	216.53	300	5300	10060	14050	20070	26460	32300	39510	50430
BP-JCT-129	218.71	300	5740	10440	14270	19920	24700	29800	37330	49040
BP-JCT-130	220.79	300	5960	10660	14440	19960	24320	29220	37050	49390
BP-JCT-132	224.06	300	7420	11640	14730	18930	22180	25730	32990	44600
BP-JCT-133	224.61	300	7790	11860	14770	18670	21740	25200	31330	40780
BP-JCT-135	227.91	300	8440	12320	15020	18550	21240	24630	29820	37600
BP-JCT-136	228.82	300	9510	12850	15040	17790	20270	23420	28120	35110
BP-JCT-138	230.65	300	8940	12060	14100	16660	18900	21960	26650	33700
BP-JCT-142	232.44	300	9110	12190	14190	16690	18910	21960	26660	33730
PA-JCT-01	367.26	400	11720	19000	24460	32020	36240	40870	45280	51260
PA-JCT-02	368.7	400	11710	19040	24540	32170	36460	41110	45590	51670
PA-JCT-12	379.54	400	12060	19650	25350	33270	38250	43360	48300	55050
PA-JCT-16	384.3	400	12130	19880	25740	33900	39080	44340	49510	56590
PA-JCT-17-G19-CAPEHART	384.3	400	11970	19610	25390	33440	38810	44150	49320	56400
PA-JCT-18	384.3	400	11880	19470	25210	33200	38640	44010	49180	56270
PA-JCT-20	386.32	400	11910	19520	25260	33260	38840	44350	49660	56950
PA-JCT-24	390.43	400	11840	19580	25470	33710	39470	45160	50740	58440
PA-JCT-27	391.97	400	11690	19030	24550	32210	37990	43800	49340	57010
PA-JCT-29	395.86	400	11690	19010	24510	32140	38020	44010	49760	57740
PA-JCT-30	395.86	400	11640	18820	24190	31620	37400	43380	49160	57210

Table AC13. Alternative DS-12 – West Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS-12 Peak Flows (cfs) 50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
WP-JCT-015	1.07	10	150	270	380	540	670	820	980	1220
WP-JCT-016	1.07	10	150	270	380	540	670	820	980	1210
WP-JCT-017	2.58	10	0	0	0	0	0	0	0	0
WP-JCT-018	3.4	10	230	390	510	680	840	1010	1190	1450
WP-JCT-019	5.15	10	650	1120	1500	2040	2500	3000	3540	4330
WP-JCT-022	7.14	10	1040	1810	2430	3320	4090	4880	5770	7070
WP-JCT-023	8.3	10	1290	2240	2990	4070	5000	5940	7030	8610
WP-JCT-026	10.32	10	1310	2320	3130	4300	5230	6180	7270	8850
WP-JCT-027	11.91	20	1500	2630	3540	4850	5910	6970	8220	10030
WP-JCT-030	13.94	20	1610	2870	3880	5360	6530	7710	9110	11160
WP-JCT-033	15.78	20	1950	3480	4700	6480	7900	9320	11010	13480
WP-JCT-034	17.58	20	2290	4080	5510	7600	9290	10980	12970	15860
WP-JCT-035	33.1	50	2940	5300	7210	10010	12340	14730	17410	21320
WP-JCT-036	33.1	50	2890	5220	7110	9880	12220	14600	17260	21150
WP-JCT-037	34.8	50	3030	5470	7450	10360	12830	15330	18130	22220
WP-JCT-039	36.55	50	3110	5680	7780	10880	13560	16290	19280	23650
WP-JCT-040	36.55	50	3110	5670	7770	10870	13550	16280	19270	23630
WP-JCT-041	38.2	50	3120	5790	7990	11270	14120	17020	20160	24750
WP-JCT-059	54.53	70	2920	5460	7580	10750	13230	15930	19050	23650
WP-JCT-061	55.57	70	3140	5670	7710	10710	13140	16030	19260	24050
WP-JCT-062	57.81	70	3420	5770	7580	10140	12250	15230	18410	23170
WP-JCT-063	59.32	70	3510	5760	7460	9830	11620	14500	17620	22300
WP-JCT-064	59.32	70	3340	5600	7330	9770	11260	13710	16770	21420
WP-JCT-065	61.42	95	3010	5340	7220	9950	11340	13270	16290	20890
WP-JCT-066	63.11	95	2970	5340	7260	10070	11210	12570	15540	20090
WP-JCT-115	108.2	150	5870	10310	13840	18940	23030	26530	30330	35670
WP-JCT-117	109.32	150	6110	10530	13990	18950	23100	26680	30510	35890
WP-JCT-118	110.38	150	6270	10670	14090	18950	23130	26740	30580	35990
WP-JCT-124	114.05	150	6420	10920	14400	19350	23580	27270	31170	36640
WP-JCT-130	118.41	150	6420	10910	14400	19360	23650	27360	31260	36740
WP-JCT-131	119.4	150	6550	11050	14510	19410	23690	27440	31360	36870
WP-JCT-132	121.21	150	6830	11300	14710	19480	23780	27620	31570	37130
WP-JCT-133	121.21	150	6800	11270	14680	19460	23760	27610	31550	37090
WP-JCT-144	124.91	200	6100	10460	13860	18720	22990	27040	30950	36460
WP-JCT-145	127.08	200	6210	10660	14150	19130	23420	27570	31590	37250
WP-JCT-146	127.08	200	6200	10640	14120	19090	23360	27530	31540	37190
WP-JCT-147	129.11	200	6250	10790	14340	19430	23710	27980	32080	37870
WP-JCT-148	129.11	200	6220	10740	14300	19400	23660	27950	32050	37820
WP-JCT-149	130.33	200	6210	10790	14400	19590	23850	28210	32360	38210
WP-JCT-156	134.09	200	6330	11090	14870	20330	24590	29170	33520	39680
WP-JCT-157	134.81	200	6370	11160	14970	20470	24730	29360	33750	39960
WP-JCT-158	134.81	200	6350	11150	14960	20470	24730	29350	33740	39950

Table AC14. Alternative DS-8A – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS-8A Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4720	8550	11660	16240	20400	25160	30710	39090
BP-JCT-081	107.92	120	4260	8070	11270	16090	20310	25080	30620	38990
BP-JCT-084	110.96	120	4090	7890	11120	16030	20250	25030	30550	38900
BP-JCT-086	112.98	120	4050	7860	11120	16090	20360	25190	30760	39180
BP-JCT-087	115.2	150	3810	7440	10560	15330	19380	24050	29370	37430
BP-JCT-089	116.04	150	3750	7380	10510	15320	19400	24090	29430	37510
BP-JCT-090	117.05	150	3760	7390	10510	15310	19390	24080	29420	37500
BP-JCT-091	119.09	150	3920	7480	10480	15020	19210	23920	29270	37370
BP-JCT-092	121.32	150	4060	7550	10440	14750	18910	23630	28990	37130
BP-JCT-094	127.28	150	4110	7610	10490	14780	18950	23680	29080	37290
BP-JCT-095	129.08	150	4100	7600	10480	14770	18930	23660	29010	37140
BP-JCT-096	131.56	150	4130	7630	10520	14820	19010	23770	29140	37300
BP-JCT-103	136.39	200	4950	8130	10530	13880	17810	22410	27490	35210
BP-JCT-105	138.54	200	5050	8260	10690	14070	18010	22620	27730	35480
BP-JCT-106	139.76	200	5080	8320	10760	14160	18010	22620	27710	35440
BP-JCT-107	141.06	200	5100	8380	10850	14300	18070	22690	27780	35500
BP-JCT-110	143.54	200	5170	8490	11000	14500	18140	22790	27880	35590
BP-JCT-111	144.98	200	5220	8560	11090	14610	18130	22770	27850	35550
BP-JCT-115	147.17	250	4980	8230	10710	14180	17110	21450	26260	33560
BP-JCT-116	148.73	250	5050	8320	10800	14270	17110	21470	26290	33590
BP-JCT-119	152.29	250	5200	8530	11050	14560	17370	21530	26380	33740
BP-JCT-125	156.68	250	5370	8790	11380	14980	17800	21700	26600	34050
BP-JCT-127-G08-Q_ST	216.53	300	5100	9750	13680	19630	25950	31740	38990	50030
BP-JCT-129	218.71	300	5370	10030	13900	19690	24340	29370	36890	48620
BP-JCT-130	220.79	300	5580	10240	14060	19720	24010	28830	36630	48970
BP-JCT-132	224.06	300	6910	11170	14350	18750	21970	25430	32440	43570
BP-JCT-133	224.61	300	7220	11360	14390	18520	21530	24910	30780	39770
BP-JCT-135	227.91	300	7790	11790	14640	18440	21050	24370	29360	36790
BP-JCT-136	228.82	300	8780	12300	14670	17700	20110	23210	27800	34590
BP-JCT-138	230.65	300	8750	11900	13970	16580	18780	21710	26330	33270
BP-JCT-142	232.44	300	8920	12030	14060	16610	18790	21710	26340	33290
PA-JCT-01	367.26	400	11650	18950	24440	32050	36370	40980	45360	51300
PA-JCT-02	368.7	400	11650	18990	24520	32200	36570	41220	45670	51700
PA-JCT-12	379.54	400	11980	19590	25330	33320	38380	43470	48380	55080
PA-JCT-16	384.3	400	12040	19820	25710	33940	39190	44440	49580	56620
PA-JCT-17-G19-CAPEHART	384.3	400	11800	19490	25330	33500	38950	44250	49390	56430
PA-JCT-18	384.3	400	11690	19320	25130	33260	38780	44110	49250	56300
PA-JCT-20	386.32	400	11640	19300	25140	33330	38980	44440	49720	56970
PA-JCT-24	390.43	400	11580	19370	25350	33770	39600	45250	50810	58470
PA-JCT-27	391.97	400	11350	18770	24410	32310	38150	43890	49410	57040
PA-JCT-29	395.86	400	11390	18790	24410	32270	38190	44100	49830	57780
PA-JCT-30	395.86	400	11360	18630	24120	31770	37590	43470	49230	57250

Table AC15. Alternative DS-7 – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS-7 Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4590	8360	11440	15980	20120	24800	30260	38500
BP-JCT-081	107.92	120	4100	7860	11040	15870	20030	24720	30160	38380
BP-JCT-084	110.96	120	4070	7840	11050	15930	20110	24870	30350	38630
BP-JCT-086	112.98	120	4010	7800	11040	15990	20220	25030	30550	38900
BP-JCT-087	115.2	150	3840	7450	10530	15230	19270	23890	29180	37170
BP-JCT-089	116.04	150	3780	7390	10480	15220	19290	23930	29230	37250
BP-JCT-090	117.05	150	3790	7390	10480	15210	19280	23920	29220	37240
BP-JCT-091	119.09	150	3940	7480	10450	14930	19100	23760	29070	37110
BP-JCT-092	121.32	150	4090	7560	10410	14650	18800	23460	28780	36880
BP-JCT-094	127.28	150	4130	7600	10450	14680	18840	23510	28870	37040
BP-JCT-095	129.08	150	4140	7600	10450	14670	18820	23490	28810	36900
BP-JCT-096	131.56	150	4220	7690	10530	14720	18900	23610	28940	37040
BP-JCT-103	136.39	200	5130	8280	10630	13880	17690	22270	27310	34960
BP-JCT-105	138.54	200	5220	8410	10790	14080	17880	22470	27540	35230
BP-JCT-106	139.76	200	5270	8480	10870	14170	17890	22470	27520	35190
BP-JCT-107	141.06	200	5290	8530	10960	14310	17940	22550	27600	35260
BP-JCT-110	143.54	200	5350	8640	11110	14520	18010	22640	27690	35350
BP-JCT-111	144.98	200	5400	8720	11200	14630	18000	22620	27670	35310
BP-JCT-115	147.17	250	5180	8420	10840	14200	16990	21300	26080	33320
BP-JCT-116	148.73	250	5250	8500	10930	14300	17080	21320	26100	33360
BP-JCT-119	152.29	250	5380	8700	11180	14610	17380	21390	26200	33500
BP-JCT-125	156.68	250	5550	8970	11520	15050	17810	21560	26420	33810
BP-JCT-127-G08-Q ST	216.53	300	5170	9910	13930	20030	26440	32280	39490	50420
BP-JCT-129	218.71	300	5590	10290	14160	19900	24690	29770	37300	49020
BP-JCT-130	220.79	300	5800	10500	14320	19930	24310	29190	37020	49370
BP-JCT-132	224.06	300	7240	11480	14610	18890	22150	25650	32890	44460
BP-JCT-133	224.61	300	7600	11690	14650	18630	21690	25100	31170	40530
BP-JCT-135	227.91	300	8240	12160	14900	18510	21170	24520	29620	37240
BP-JCT-136	228.82	300	9310	12690	14930	17750	20190	23300	27890	34680
BP-JCT-138	230.65	300	8920	12030	14060	16610	18820	21800	26400	33300
BP-JCT-142	232.44	300	9090	12150	14150	16640	18830	21800	26410	33330
PA-JCT-01	367.26	400	11710	19000	24470	32050	36370	40980	45360	51300
PA-JCT-02	368.7	400	11700	19040	24550	32200	36570	41220	45670	51700
PA-JCT-12	379.54	400	12050	19650	25370	33320	38380	43470	48380	55080
PA-JCT-16	384.3	400	12130	19890	25760	33940	39190	44440	49580	56620
PA-JCT-17-G19-CAPEHART	384.3	400	11920	19590	25400	33500	38950	44250	49390	56430
PA-JCT-18	384.3	400	11840	19460	25220	33260	38780	44110	49250	56300
PA-JCT-20	386.32	400	11860	19490	25270	33330	38980	44440	49720	56970
PA-JCT-24	390.43	400	11800	19570	25480	33770	39600	45250	50810	58470
PA-JCT-27	391.97	400	11680	19050	24600	32310	38150	43890	49410	57040
PA-JCT-29	395.86	400	11690	19040	24580	32270	38190	44100	49830	57780
PA-JCT-30	395.86	400	11650	18870	24280	31770	37590	43470	49230	57250

Table AC16. Alternative DS-9A – Big Papillion

Junction	DA (mi2)	FYRA Storm Area (mi2)	Alternative DS-9A Peak Flows (cfs)							
			50% AEP	20% AEP	10% AEP	4% AEP	2% AEP	1% AEP	0.5% AEP	0.2% AEP
BP-JCT-056	75.67	95	4550	8130	11020	15240	18980	23210	28070	35350
BP-JCT-066	85.65	120	4550	8220	11200	15580	19480	23960	29130	36900
BP-JCT-073	96.06	120	4480	8260	11370	15990	20060	24730	30100	38200
BP-JCT-074	97.52	120	5170	8960	11940	16220	20090	24780	30170	38310
BP-JCT-076	102.14	120	5030	8770	11720	15970	20030	24660	30070	38250
BP-JCT-077	103.62	120	4740	8510	11550	16000	20130	24810	30270	38520
BP-JCT-080	106.23	120	4720	8550	11660	16240	20400	25160	30710	39090
BP-JCT-081	107.92	120	4260	8070	11270	16090	20310	25080	30620	38990
BP-JCT-084	110.96	120	4170	7990	11230	16140	20400	25230	30800	39230
BP-JCT-086	112.98	120	4050	7850	11110	16080	20340	25180	30740	39160
BP-JCT-087	115.2	150	3820	7450	10560	15320	19380	24040	29360	37420
BP-JCT-089	116.04	150	3760	7390	10510	15310	19390	24080	29420	37500
BP-JCT-090	117.05	150	3750	7380	10500	15300	19380	24060	29400	37490
BP-JCT-091	119.09	150	3920	7480	10480	15020	19200	23910	29260	37360
BP-JCT-092	121.32	150	4070	7550	10440	14740	18900	23620	28980	37120
BP-JCT-094	127.28	150	4100	7600	10480	14770	18940	23660	29060	37280
BP-JCT-095	129.08	150	4090	7580	10470	14770	18930	23640	28990	37130
BP-JCT-096	131.56	150	4140	7640	10530	14820	19000	23760	29130	37290
BP-JCT-103	136.39	200	5050	8230	10620	13940	17800	22400	27480	35200
BP-JCT-105	138.54	200	5140	8360	10780	14140	18000	22600	27710	35470
BP-JCT-106	139.76	200	5210	8440	10870	14230	18000	22610	27700	35420
BP-JCT-107	141.06	200	5240	8510	10960	14360	18060	22680	27770	35480
BP-JCT-110	143.54	200	5320	8630	11120	14570	18130	22770	27860	35580
BP-JCT-111	144.98	200	5370	8710	11210	14680	18120	22750	27830	35540
BP-JCT-115	147.17	250	5220	8460	10890	14250	17150	21440	26250	33550
BP-JCT-116	148.73	250	5280	8540	10980	14350	17240	21460	26280	33580
BP-JCT-119	152.29	250	5430	8750	11230	14650	17530	21530	26380	33730
BP-JCT-125	156.68	250	5600	9020	11570	15090	17960	21700	26600	34040
BP-JCT-127-G08-Q_ST	216.53	300	5230	9970	13970	20020	26400	32250	39460	50390
BP-JCT-129	218.71	300	5660	10350	14200	19890	24660	29750	37280	49000
BP-JCT-130	220.79	300	5870	10560	14360	19920	24280	29170	36990	49340
BP-JCT-132	224.06	300	7330	11560	14660	18890	22140	25670	32900	44450
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BP-JCT-136	228.82	300	9390	12750	14970	17760	20210	23350	27980	34850
BP-JCT-138	230.65	300	8940	12050	14080	16630	18850	21860	26500	33460
BP-JCT-142	232.44	300	9080	12160	14160	16660	18860	21860	26510	33490
PA-JCT-01	367.26	400	11710	19000	24470	32050	36370	40980	45360	51300
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PA-JCT-16	384.3	400	12130	19890	25760	33940	39190	44440	49580	56620
PA-JCT-17-G19-CAPEHART	384.3	400	11940	19610	25410	33500	38950	44250	49390	56430
PA-JCT-18	384.3	400	11860	19470	25230	33260	38780	44110	49250	56300
PA-JCT-20	386.32	400	11880	19510	25280	33330	38980	44440	49720	56970
PA-JCT-24	390.43	400	11820	19580	25490	33770	39600	45250	50810	58470
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PA-JCT-29	395.86	400	11700	19060	24590	32270	38190	44100	49830	57780
PA-JCT-30	395.86	400	11670	18880	24290	31770	37590	43470	49230	57250

Appendix AD. Climate Change Assessment

A qualitative climate change analysis was undertaken in accordance with the USACE Engineering and Construction Bulletin No. 2018-14 (USACE, 2018) and Engineering Technical Letter 1100-2-3, *Guidance for Detection of Nonstationarities in Annual Maximum Discharges*. This analysis included both a literature review and analysis of USGS gauges near the project site. Only flood flows were considered because the Papillion Creek GRR project is a flood risk mitigation project with no environmental restoration component. While this assessment does not change the numerical results of the Papillion Creek alternatives, it helps to inform alternative selection by providing information on possible trends in flood flows with time.

AD1. Relevant Current Climate and Climate Change

AD1.1 Current Climate

Omaha, Nebraska has a hot-summer humid continental climate characterized by cold winters and hot summers. The average annual rainfall is 30.63 inches with May and June being the months of highest rainfall. However, precipitation is highly variable from year-to-year with the statewide average ranging as low as 13.36 inches in 2012 and as high as 35.5 inches in 1915 (NOAA, 2017). Flooding is typically caused by intense rainfall in the spring and summer months. The average annual snowfall is 26 inches with the majority falling in November through March (monthly average 3 to 6 inches). Figure 46 shows the monthly climate patterns for Omaha, Nebraska (U.S. Climate Data, 2018).

AD1.2 Mean Temperature

AD1.2.1 Observed Trends

The *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017) shows that mean annual temperatures within the study area have increased slightly over time. Present-day (1986-2016) annual mean temperatures have increased between 0.5 and 1°F in comparison with the first part of the last century (1901-1960). Observed winter temperatures have increased over 1.5°F for the Omaha area for the present-day (1986-2016) in comparison with the first part of the last century (1901-1960). Summer temperatures appear to have increased only slightly (0 to 0.5°F). These increases are shown in Figure 47 (USGCRP, 2017).

The USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Missouri River Region 10* (USACE, 2015) also supports a positive upward trend in temperature. A positive statistically significant increasing trend in observed temperature from 1950-2000 was determined for the Missouri River region including the study site (USACE, 2015). The strongest increase in temperature was in the winter (December-February) and spring (March-May).

At the State-scale, average temperatures in Nebraska have increased about 1 degree F since the early 20th century with warming observed in the winter and spring seasons. Summers have not warmed substantially in the state (NOAA, 2017).

AD1.2.2 Projected Trends

According to the *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017), the mean temperature in the Midwest is forecasted to increase between 4.21°F to 5.29°F between 2036-2065 and from 5.57°F to 9.49°F from 2071-2100 in comparison with the 1976-2005 average. Projected increases are dependent on the emissions scenario modeled. These trends are coarsely represented in Figure 48.

The 2015 USACE study also reports several studies predicting increases in temperature with time. Figure 49 shows projected changes in seasonal maximum air temperature for 2041-2070 compared with 1971-2000 by season. Summer seasonal maximum air temperature are forecasted to increase the most in the study area (~4-4.5 degrees C) followed by fall (~3-3.5 degrees C), winter (~2.5-3 degrees C), and spring (~2-2.5 degrees).

At the State-scale and assuming a higher emissions pathway where emissions continue to increase with time, historically unprecedented warming is projected by the end of the 21th century. Figure 50 shows projected increases in temperature with time (NOAA, 2017).

AD1.3 Mean Precipitation

AD1.3.1 Observed Trends

The *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017) shows mean annual precipitation within the study area has increased over time. In comparison with the first part of the last century (1901-1960), annual mean precipitation has increased by 10 to 15 percent in the Omaha area for the present-day (1986-2016). This increase is shown in Figure 51 (USGCRP, 2017). The largest increase has been in the spring for the project area.

The USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Missouri River Region 10* (USACE, 2015) notes that the lower portion of the Missouri River basin generally shows increasing trends for observed precipitation and extreme precipitation. Annual precipitation for the study area has increased between 5 to 10 percent from 1895-2009.

At the State-scale, the frequency of heavy rainfall events has increased but this increase is not the largest of record. Figure 52 shows that Nebraska is experiencing an above average number of 2-inch event over the last decade but this number of large events is smaller than what was observed in 1900 to 1904 (NOAA, 2017).

AD1.3.2 Projected Trends

Mean annual precipitation within the study area is projected to continue to increase with time for the spring season. Figure 53 shows the spring total precipitation is forecasted to increase between 10 to 30 percent for the 2070-2099 time frame relative to the 1976-2005 average for the highest emission scenario (representative concentration pathway 8.5 W/m^2, RCP8.5) (USGCRP, 2017). Results for other seasons are inconclusive or indicate changes small compared with natural variations (hatched areas).

The USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Missouri River Region 10* (USACE, 2015) reports possible increasing trends in seasonal precipitation for all months but summer (~0 to -15%) for 2055 in comparison to 1985. Largest increases were for spring (~15 to 30%), followed by fall (~0 to 30%) and winter (0-15%). Figure 54 shows these trends.

At the State-scale, projections of overall annual precipitation are uncertain but winter and spring precipitation is projected to increase across the state (NOAA, 2017).

AD1.4 Extreme Precipitation

Several studies forecast that extreme precipitation event intensity will likely increase at rates much larger than that of mean precipitation events. Pall et al. (2007) found that the Clausius-Clapeyron (CC) relationship is a better predictor of change in extreme events for the mid-latitude region of the Earth and that these extreme events' intensities are increasing at a much faster rate than the mean events' intensities. The Clausius-Clapeyron equation relates saturated water vapor pressure to instantaneous air temperature and it predicts an approximately 7 percent increase in precipitation intensity of extreme rainfall events per degree Celsius increase in air temperature mass (7 percent per °C). The CC relationship implies that atmospheric moisture would increase roughly exponentially with temperature (Pall et al. 2007).

It was determined in Ivancic & Shaw (2016) that the CC rate of increase is applicable to many regions of the United States but that the rate is constrained by the availability of air moisture and influenced by the type of storm (frontal or convective) producing the precipitation. They determined that the CC rate of increase for the United States was larger in the Midwest and Northeast due to these regions' moist continental climates than in the drier parts of the country (like Nevada) where it is limited by moisture availability.

Figure 55 from Ivancic & Shaw show that extreme precipitation intensity increases in the Omaha, Nebraska area are forecasted to increase at a rate higher than 7 percent per °C and are statistically significant.

In addition, the *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017) supports that observed heavy precipitation events will increase in the future for all regions of the United States even in regions where mean precipitation is projected to decrease. This report classifies extreme events as those exceeding the 20 percent annual exceedance probability (AEP) (average 5-year return period). For the high emission scenario, these events are expected to increase by two to three times the historical average for the region by the end of the 21th century.

AD1.5 Stream Flow

AD1.5.1 Observed Trends

A review of peer-reviewed literature on climate change indicates that the frequency of large floods are increasing over time even though the annual peak stream flows are not. Therefore, while the largest annual events do not appear to be becoming larger, the frequency of large flood events is increasing. Increases in flood frequency from 1962 to 2011 indicate increases in event frequency in all seasons but the winter. Flood magnitudes only increased in the autumn which is not the typical flood season for the project site (Mallakpour & Villarini, 2015).

The USGS publication *Trends in Annual, Seasonal, and Monthly Streamflow Characteristics at 227 Streamgages in the Missouri River Watershed, Water Years 1960-2011* (Norton et al, 2014) reports an upward trend in observed stream flow in the project area. These trends are shown in Figure 56.

The *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017) reports that statistically significant increases in flooding are well documented and are attributed to observed increases in precipitation.

The USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Missouri River Region 10* (USACE, 2015) indicates that there is a mild upward trend in mean stream flow in the Missouri River Region for the lower portion of the region including the Papillion Creek basins.

AD1.5.2 Projected Trends

The USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Missouri River Region 10* (USACE, 2015) reports that there is little consensus in the recent literature on the projected trend in stream flow over time. Trend direction is dependent on the selection of GCM models used for temperature and precipitation, the emission scenario, and the hydrologic model used. Uncertainty is large in the hydrologic models used.

AD1.6 Literature Review Summary

Based on the literature review above, important hydrologic variables for the Papillion Creek watershed which may be impacted by climate change include intensity, duration, and frequency of precipitation events as well as air temperatures. Perturbations in these variables could lead to changes in the duration and magnitude of peak runoff events. It is therefore appropriate to investigate the potential impacts of global climate change on the Papillion Creek watershed.

The literature review indicates that:

1. Mean, annual temperatures have increased and are forecasted to continue to increase with time. Historic, observed temperature show increases in spring and winter temperatures, but little warming for the summer months. Future, projections of mean annual temperature show increases in temperature for all seasons. The largest increases are projected to occur in summer and fall.
2. Mean, annual, observed precipitation has increased over time. The largest, observed increase was in spring for the region encompassing the study area. Future precipitation is projected to continue to increase for the spring season. Results for other seasons lack consensus between sources.
3. Extreme, precipitation intensity is forecasted to increase at a rate of 7 percent per °C.
4. The frequency of large floods have increased over time based on observed events for all seasons, but winter.
5. The literature is not clear on if stream flow in the study area will increase or decrease with time.

Figure 57 summarizes the observed and predicted trends for the Missouri River Basin, of which the Papillion watershed is a part, from the 2015 USACE study. In the case of all primary variables (temperature, temperature minimums, temperature maximums, precipitation, precipitation extremes, and stream flow) trends are increasing with time.

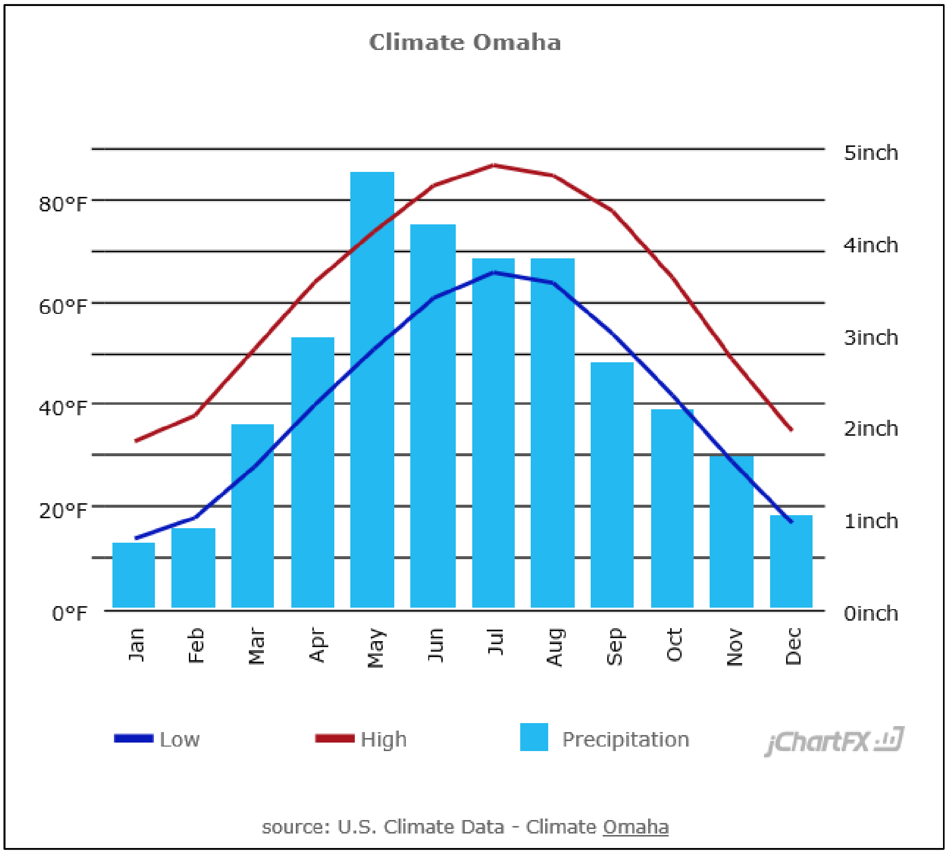


Figure 47. Climate in Omaha, Nebraska (US Climate Data, 2018)

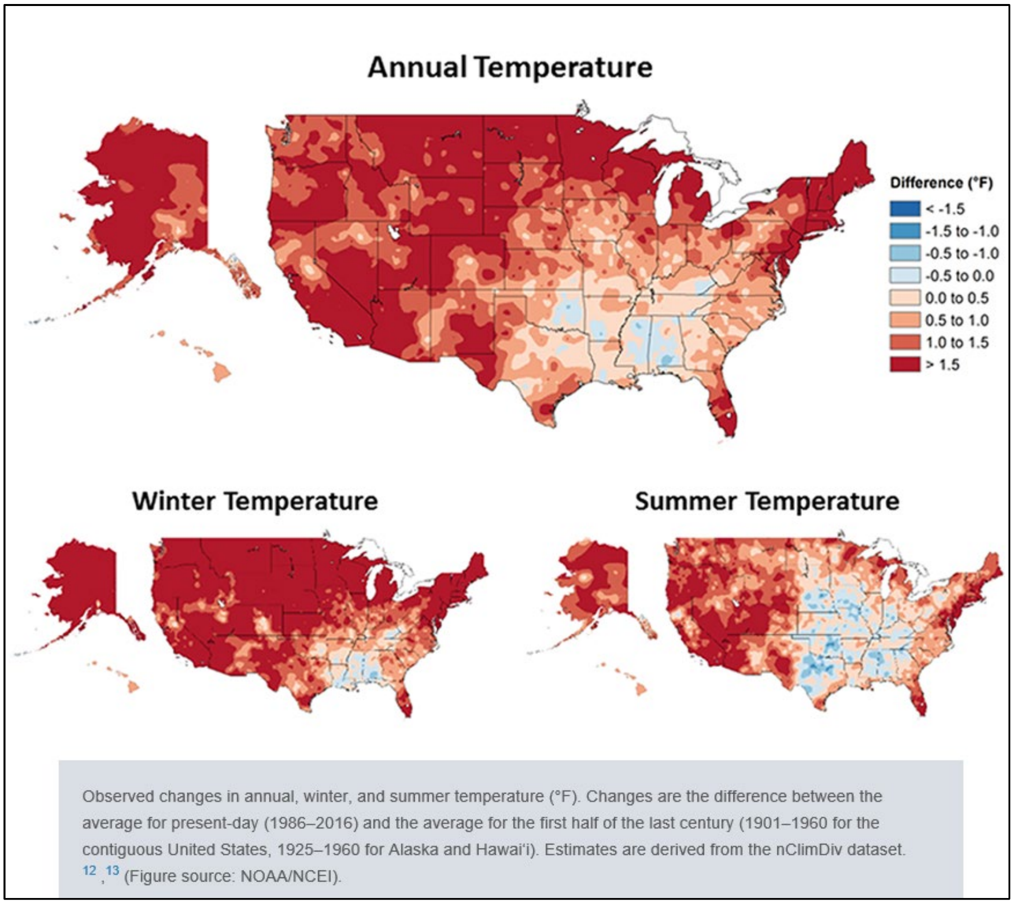
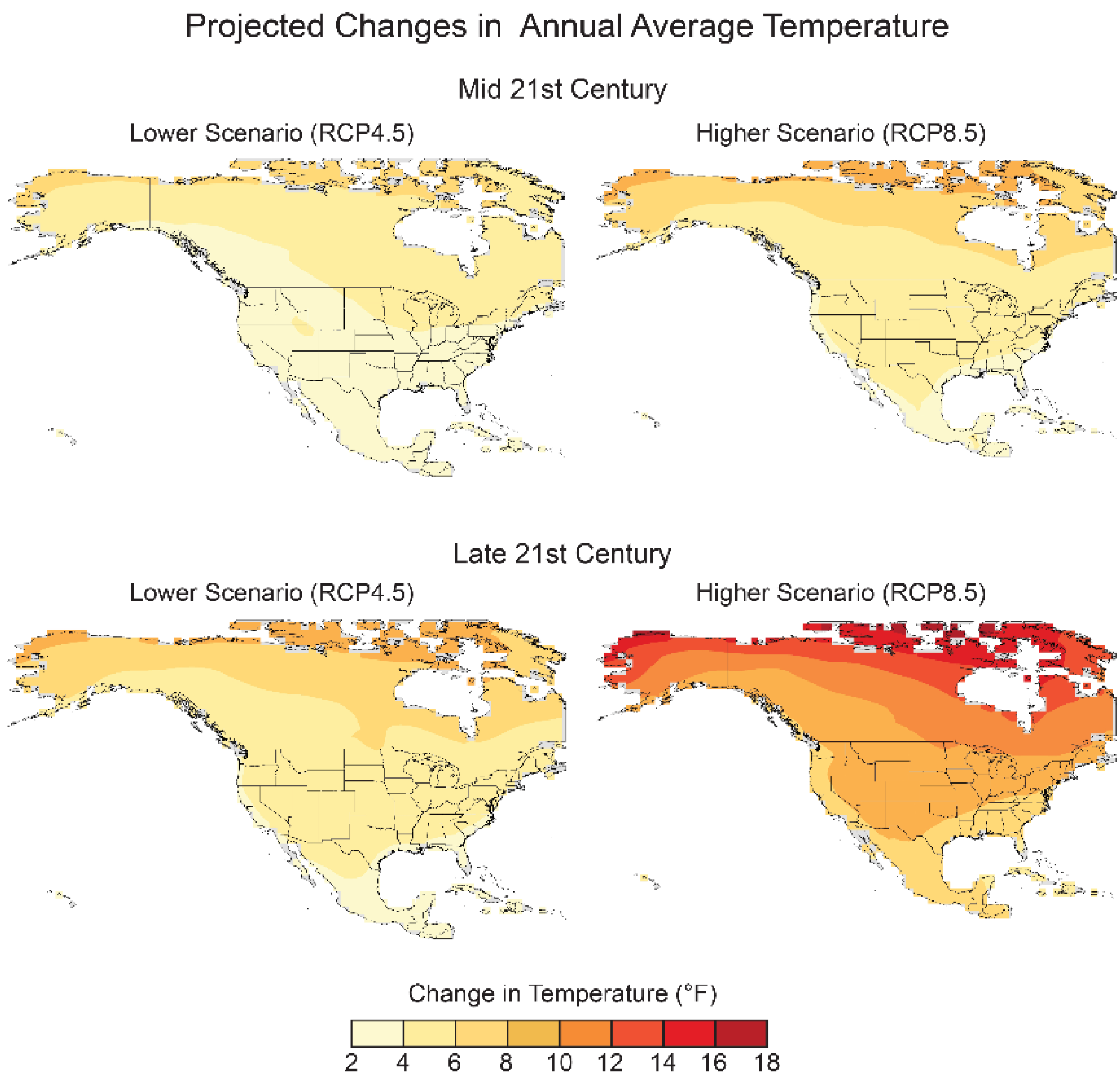


Figure 48. Observed Changes in Temperature. Between the first half of the last century (1901-1960) and present day (1986-2016).



Projected changes in annual average temperatures (°F). Changes are the difference between the average for mid-century (2036–2065; top) or late-century (2070-2099, bottom) and the average for near-present (1976–2005). Each map depicts the weighted multimodel mean. Increases are statistically significant in all areas (that is, more than 50% of the models show a statistically significant change, and more than 67% agree on the sign of the change[78]). (Figure source: CICS-NC and NOAA NCEI).

Figure 49. Projected Changes in Annual Average Temperature (USGCRP, 2018).

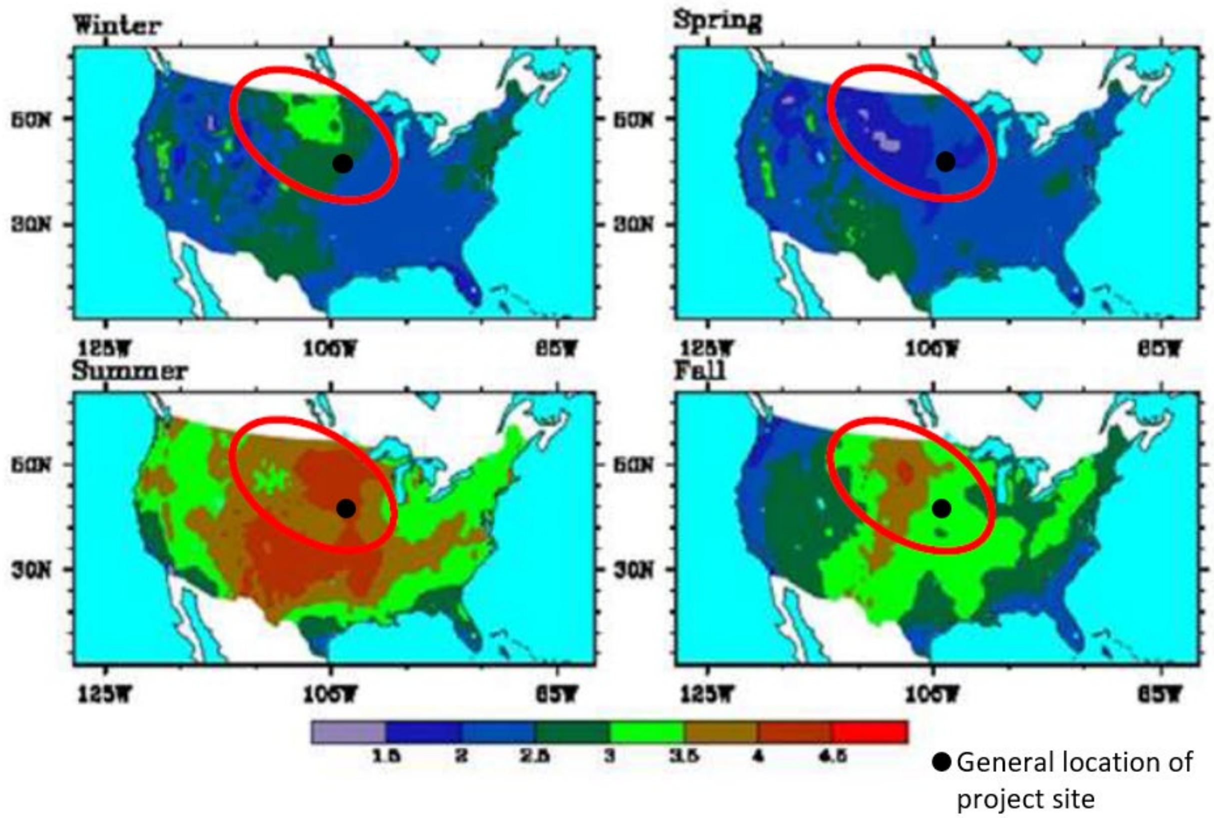


Figure 50. Projected Changes in Seasonal Maximum Air Temperature (degrees C), 2041-2070 vs 1971-2000 (USACE, 2015)

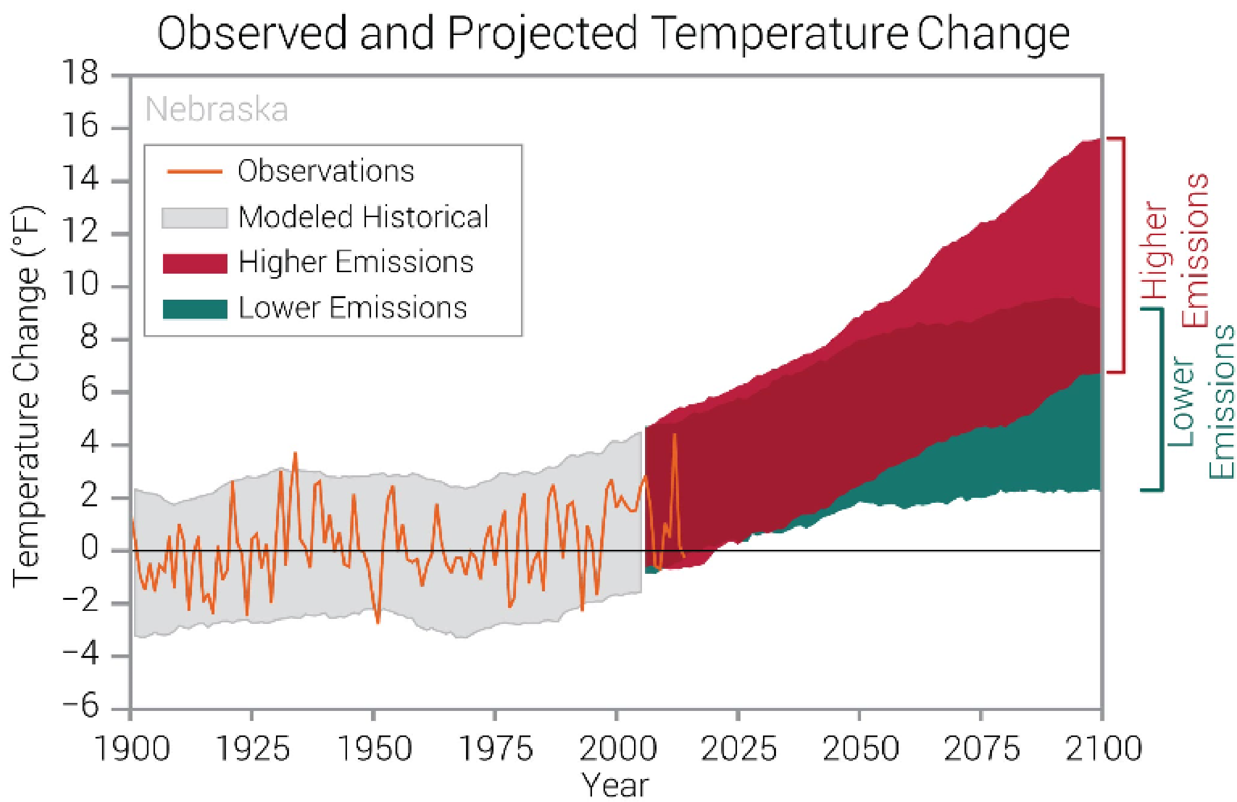
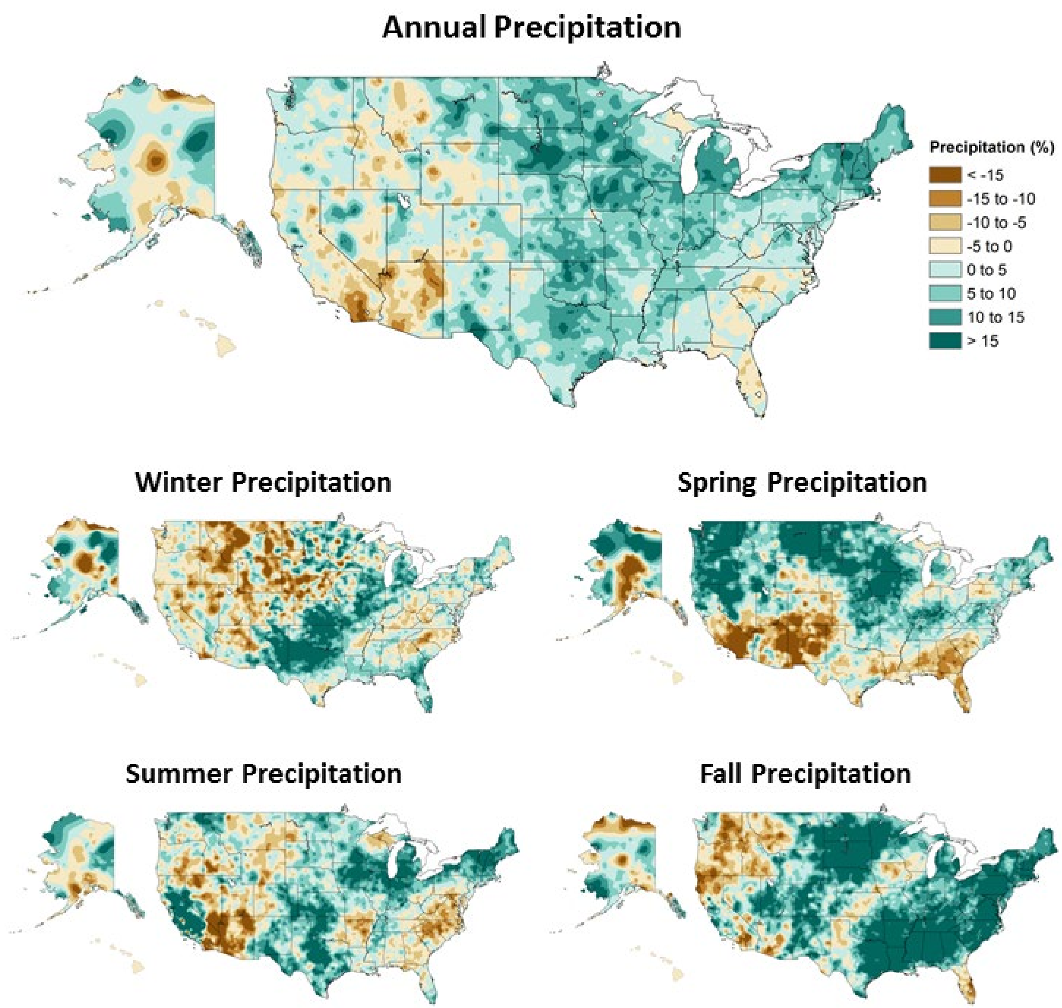


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Nebraska. Observed data are for 1900–2014. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse has emissions increase at a slower rate (lower emissions). Temperatures in Nebraska (orange line) have risen about 1°F since the beginning of the 20th century. Shading indicates the range of annual temperatures from the set of models. Observed temperatures are generally within the envelope of model simulations of the historical period (gray shading). Historically unprecedented warming is projected during the 21st century. Less warming is expected under a lower emissions future (the coldest years being about as warm as the warmest years in the historical record; green shading) and more warming under a higher emissions future (the hottest years being about 11°F warmer than the hottest year in the historical record; red shading). Source: CICS-NC/NOAA NCEI.

Figure 51. Observed and Projected Temperature Changes in Nebraska (NOAA, 2017)



Annual and seasonal changes in precipitation over the United States. Changes are the average for present-day (1986–2015) minus the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i) divided by the average for the first half of the century. (Figure source: [top panel] adapted from Peterson et al. 2013,[6] © American Meteorological Society. Used with permission; [bottom four panels] NOAA NCEI, data source: nCLIMDiv].

Figure 52. Changes in Observed Precipitation. Between the first half of the last century (1901-1960) and present day (1986-2016).

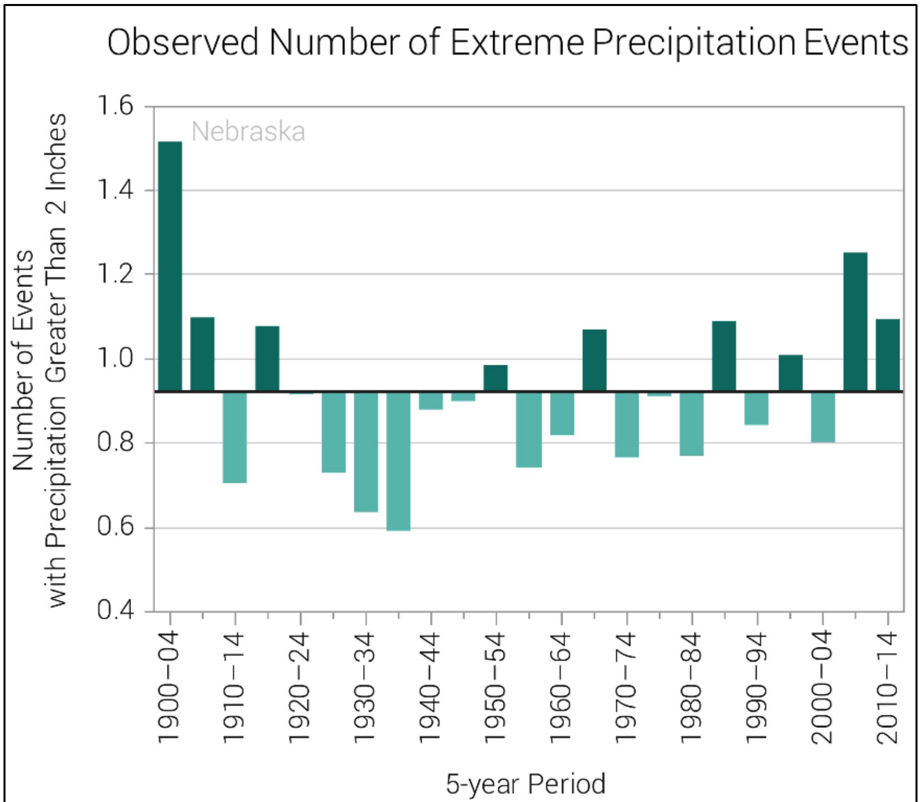
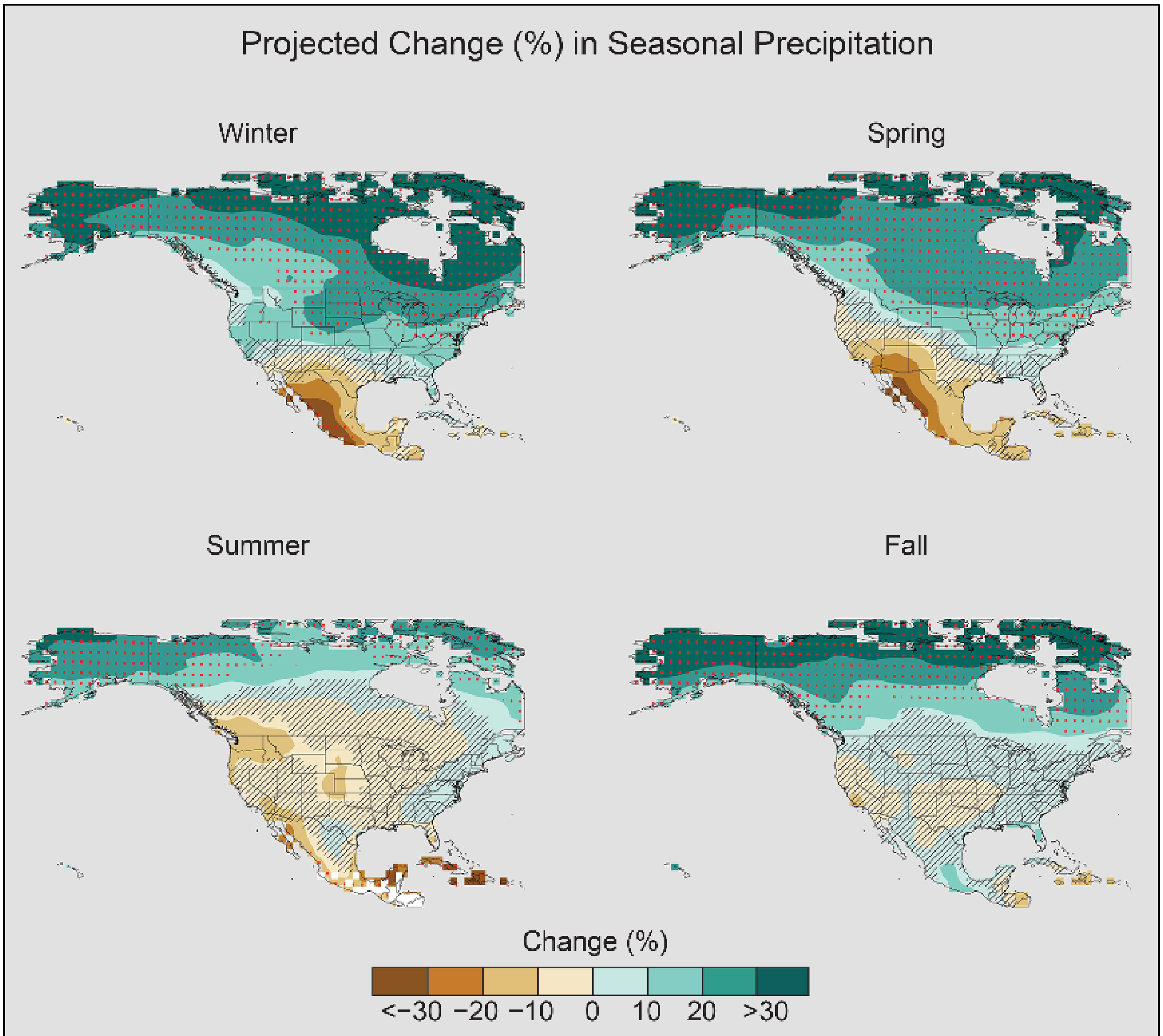


Figure 5: The observed number of extreme precipitation events (annual number of days with precipitation greater than 2 inches) for 1900–2014, averaged over 5-year periods; these values are averages from 60 long-term reporting stations. In the historical record, the largest number of heavy precipitation events occurred from 1900 to 1904, with an average of 1.5 events per year per station, followed by 2005–2009, with an average of 1.3 events annually. The dark horizontal line is the long-term average (1900–2014) of 0.9 days per year per station. Source: CICS-NC and NOAA NCEI.

Figure 53. Observed Number of Extreme Precipitation Events (greater than 2 inches) for 1900-2014



Projected change (%) in total seasonal precipitation from CMIP5 simulations for 2070–2099. The values are weighted multimodel means and expressed as the percent change relative to the 1976–2005 average. These are results for the higher scenario (RCP8.5). Stippling indicates that changes are assessed to be large compared to natural variations. Hatching indicates that changes are assessed to be small compared to natural variations. Blank regions (if any) are where projections are assessed to be inconclusive. Data source: World Climate Research Program's (WCRP's) Coupled Model Intercomparison Project. (Figure source: NOAA NCEI).

Figure 54. Projected Change in Precipitation. Years 2070 to 2099 compared with 1976-2005 average.

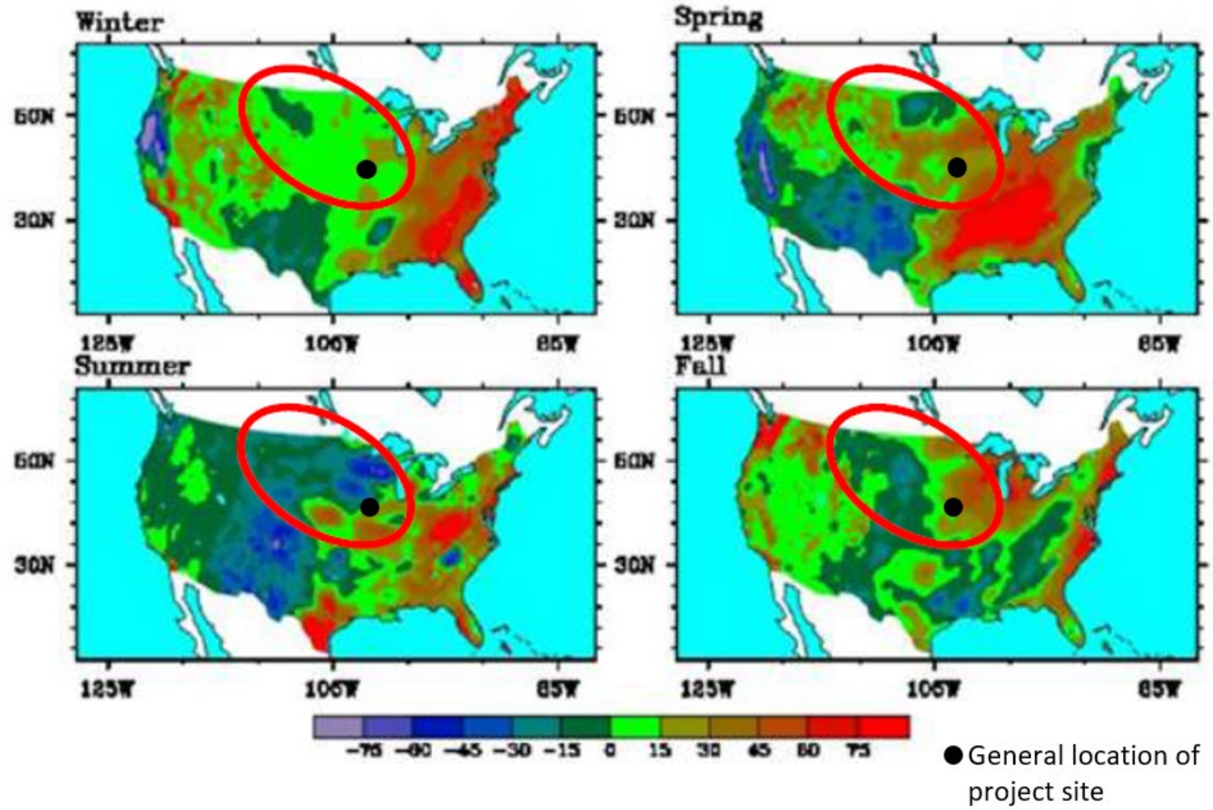


Figure 55. Projected Changes in Seasonal Precipitation (mm), 2055 vs 1985.

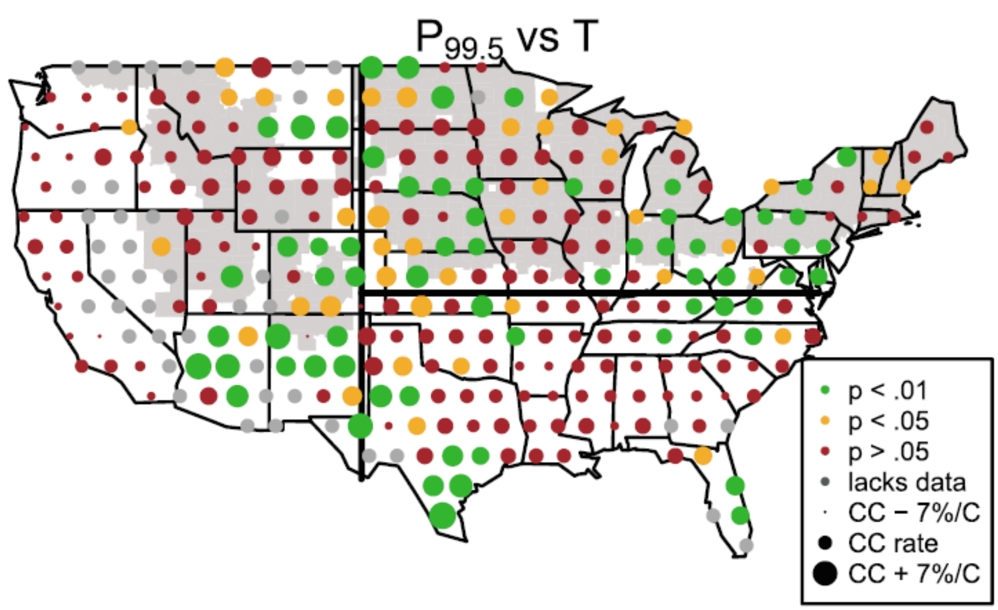


Figure 56. Precipitation Intensity vs. Temperature (Ivancic & Shaw 2016)

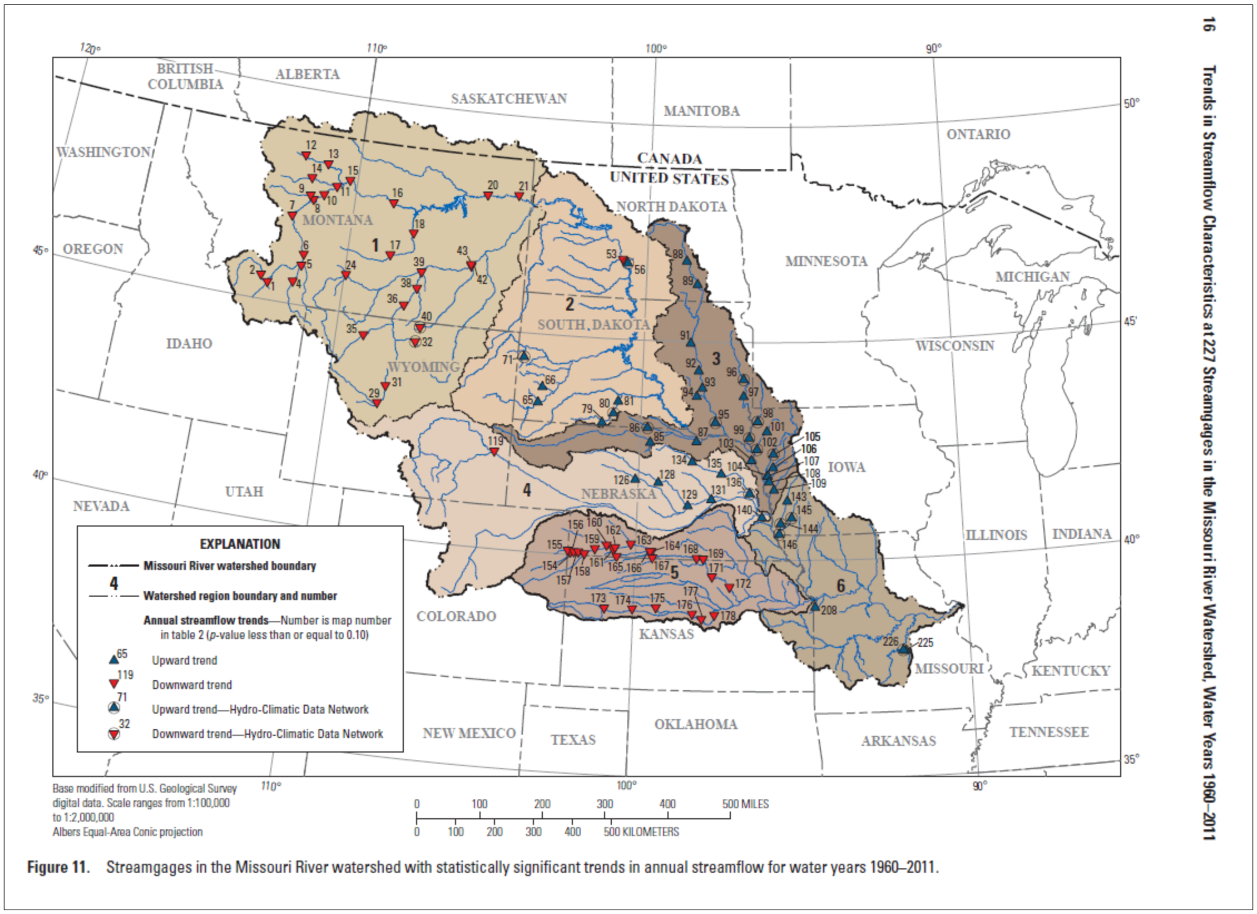


Figure 57. USGS Stream Gauges in the Missouri River Watershed with Statistically Significant Trends in Annual Stream Flow for Water Years 1960-2011 (Norton et al, 2014).

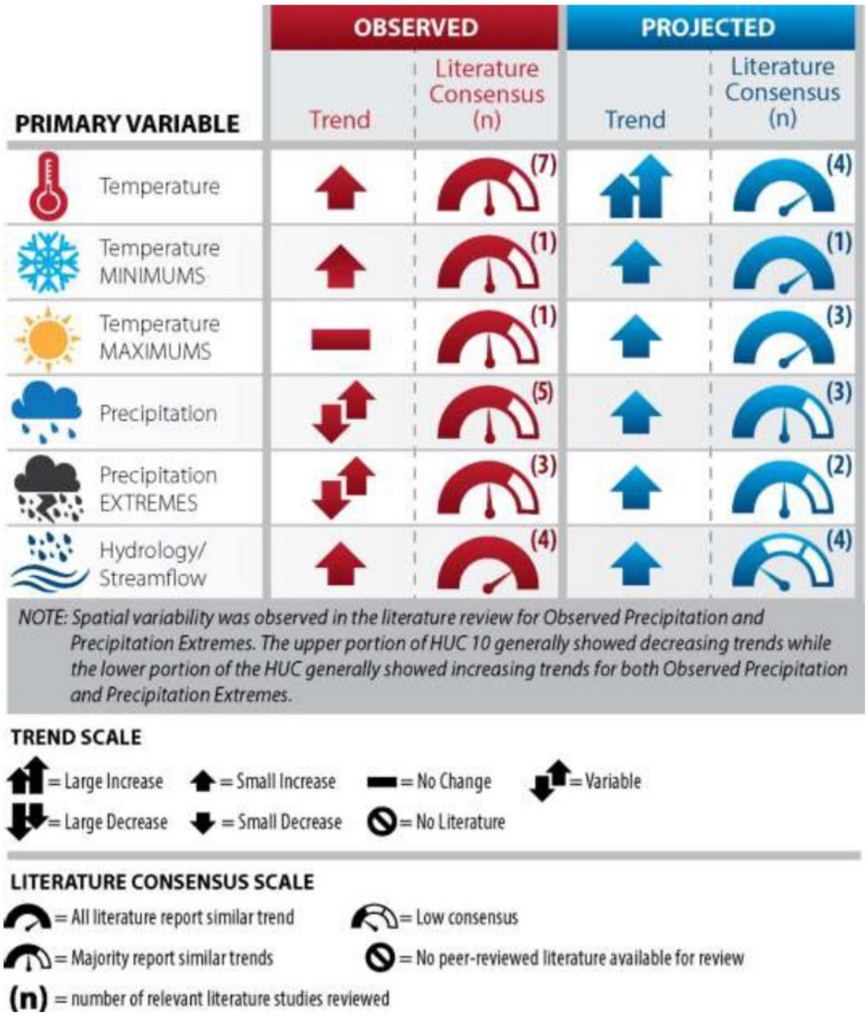


Figure 58. Summary Matrix of Observed and Projected Climate Trends and Literary Consensus (USACE, 2015)

AD2. Precipitation and Temperature at Project Site

At the project-site scale, daily precipitation at the Omaha Eppley Airfield from 1/1/1945 to 1/8/2020 was tested for trends for separate months in the spring and summer (March, April, May, June, and July) and for combined months (MAMJJ and AMJJ). While all these tests showed a slight increase in daily precipitation with time none were statistically significant (statistical significance set to p-value less than 0.05). This indicates that daily precipitation observed at the site is neither increasing nor decreasing with time.

At the project-site scale, daily maximum temperature at the Omaha Eppley Airfield from 1/1/1945 to 1/8/2020 was tested for trends for separate months in the spring and summer (March, April, May, June, and July) and for combined months (MAMJJ and AMJJ). While all these tests showed a slight increase in daily maximum temperature except for July with time, none were statistically significant (statistical significance set to p-value less than 0.05). This indicates that daily observed maximum temperatures at the site are neither increasing nor decreasing with time.

AD3. First Order Statistical Analysis of Streamflows—Papillion Creek & Vulnerability Assessment

This section of the climate change analysis used three USACE climate tools (USACE, 2019) and stream gauge records near the Papillion Creek watershed to see if flows have statistically significant trends and if the 1023 HUC (Missouri-Little Sioux), which includes the study site, is viewed as relatively vulnerable in the USACE flood risk reduction business line. Tools used include the Nonstationarity Detection Tool, the Climate Hydrology Assessment Tool, and the Watershed Vulnerability Assessment Tool.

AD3.1 Stream Gauges

All the stream gauges within the Papillion Creek watershed have periods of record less than 15 years and are therefore too short to use in a climate assessment where 30 years is required for some of the tools. Due to this limitation, stream gauges outside of the watershed but within the general area were selected. These gauges had 372 to 871 square miles of drainage area which is larger in the case of two of the selected watersheds but still fairly comparable to the Papillion Creek 400 square miles.

Gauges selected for this assessment are shown in Table 27 and Figure 58 below.

All these gauges are located in largely rural watersheds with significantly less urbanization than the Papillion Creek watershed. The Boyer River channel has been straightened over time and nonfederal levees have been constructed. Logan Creek appears to have been straightened over time. The Maple Creek channel appears very natural through most of its length with a large amount of sinuosity. No significantly large flood mitigation projects beyond local levees are known to exist above these three gauges.

Table 26. USGS Stream Gauges

Stream Gauge	Station ID	Upstream Area (sq mi)	Period of Record (POR)	Observed Years
Boyer River at Logan, IA	06609500	871	1918-2014	85
Logan Creek near Uehling, NE	06799500	831	1940-2012	73
Maple Creek near Nickerson, NE	06800000	372	1944, 1955-2014	61

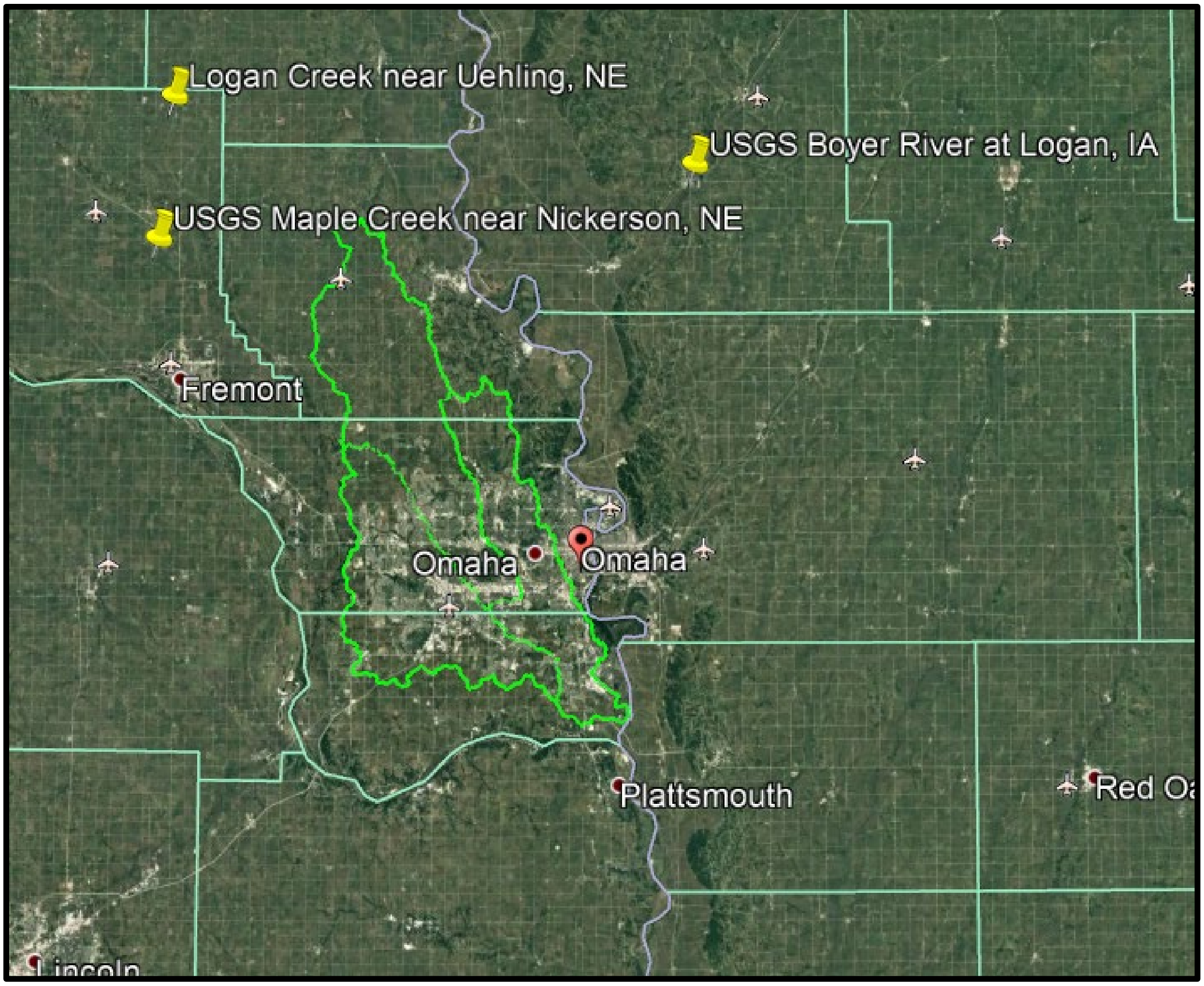


Figure 59. Project Site (green watershed) and Stream Gauges Used in Climate Change Analysis

AD3.2 Period of Record

The Nonstationarity Detection Tool was used to determine if the stream gauge records needed to be limited to a specific period to be considered homogeneous and stationary in the Papillion Creek GRR. This can be important in a study if it uses a Bulletin 17C analysis or calibration events that are not recent. Stationary assumes that the statistical characteristics of hydrologic time series data are constant through time; this is a fundamental assumption for many statistical processes in hydrology. However, recent scientific evidence shows that climate change and human modifications to some watersheds are undermining this assumption.

The Nonstationarity Detection Tool helps to identify if the record of annual peak stream flows are impacted by anthropogenic activities (e.g. dam construction, urbanization, etc.) and aids in reducing the record to a homogenous section for the rest of the analysis. For a nonstationarity to be considered strong, it must trigger two or more tests within a range of five years for the same statistic (distribution, mean, etc) to show consensus, it must trigger two or more tests within a range of five years for different statistics to show robustness, and it must show a significant change in the magnitude of the standard deviation and/or mean.

In the case of the Boyer River at Logan, a significant number of years of data (more than five years) were missing from the record so the period of record considered in the tool was shortened to consider just the continuous record (1938-2014). Five tests were triggered in this continuous record but they were spread out and not strong. In addition, no trend was determined by the Mann-Kendall and Spearman Tests.

In the case of the Logan Creek near Uehling gauge, the record was limited to the continuous period of record. No tests were triggered and the monotonic trend analysis with the Mann-Kendall and Spearman test showed no significant trends so the continuous period of record was adopted.

In the case of the Maple Creek at Nickerson gauge, the period of record was truncated to 1956 - 2014 to eliminate a large break in the record. No strong change points were observed with this shortened record. The monotonic trend analysis with the Mann-Kendall and Spearman test showed no significant trends for 1956 - 2014.

Table 28 summarizes the homogeneous, adopted period of records for the gauges tested. Figure 59 through Figure 64 show the Nonstationarity Detection Tool results for the adopted period of records and the Monotonic Trend Analysis results showing no trends.

The period of record determined in this analysis indicates that the full period of record of stream flow observations for the Papillion Creek stream gauges can be assumed to be homogenous. This means their full records can be used in statistical analysis and calibration. These records are relatively short with less than 15 years of data for peak flows which typically started to be collected in 2004. However, the stream gauges tested outside of the watershed have not undergone the changes in land use (urbanization) and construction of flood mitigation infrastructure (dams and levees) seen in the Papillion Creek watershed over time. It can be argued the analysis presented does not capture the urbanization and alternation of channels and flows within the Papillion Creek watershed. The most recent dam completed in the Papillion Creek watershed was Lake Flannagan in 2018 and several others are currently under construction. For this reason, the POR used in analysis should be considered with care. The hydrologic models used in this study were calibrated to 2013 and 2014 events and verified with a 2008 event.

Table 27. Adopted Period of Records

Stream Gauge	Station ID	Full POR	Adopted Period of Record	Adopted No. of Years	Nonstat. Detected	Record Adjustment Notes
Boyer River at Logan, IA	06609500	1918-2014	1938-2014	77	Five tests triggered but spread out	Record shortened due to missing data
Logan Creek near Uehling, NE	06799500	1940-2012	1940-2005	66	No tests triggered in continuous record	Record shortened due to missing data
Maple Creek near	06800000	1944, 1955-2014	1956-2014	59	Two tests triggered for 1989 after	Record was shorted due to missing data

Nickerson, NE					record shortened but not strong	

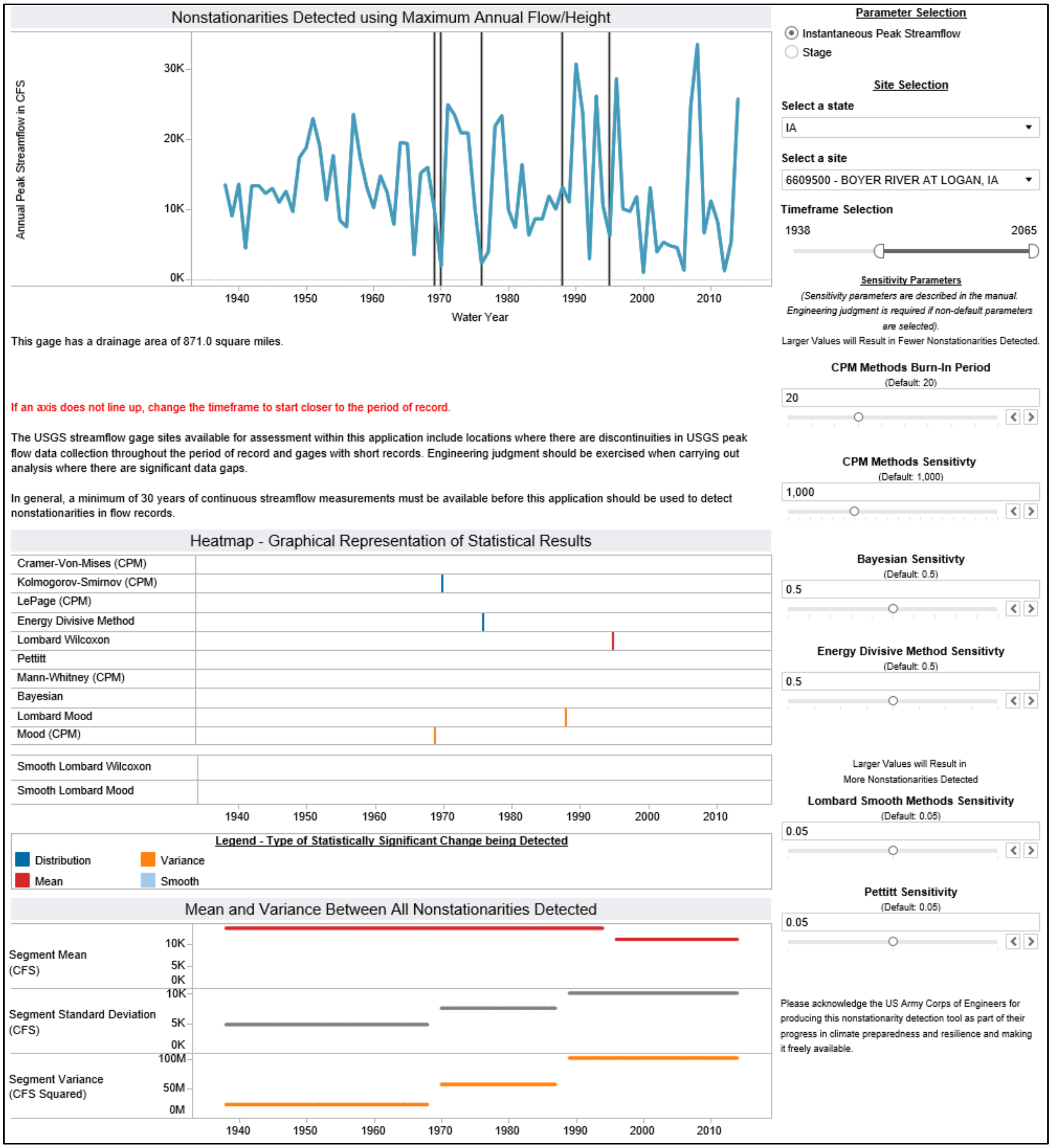
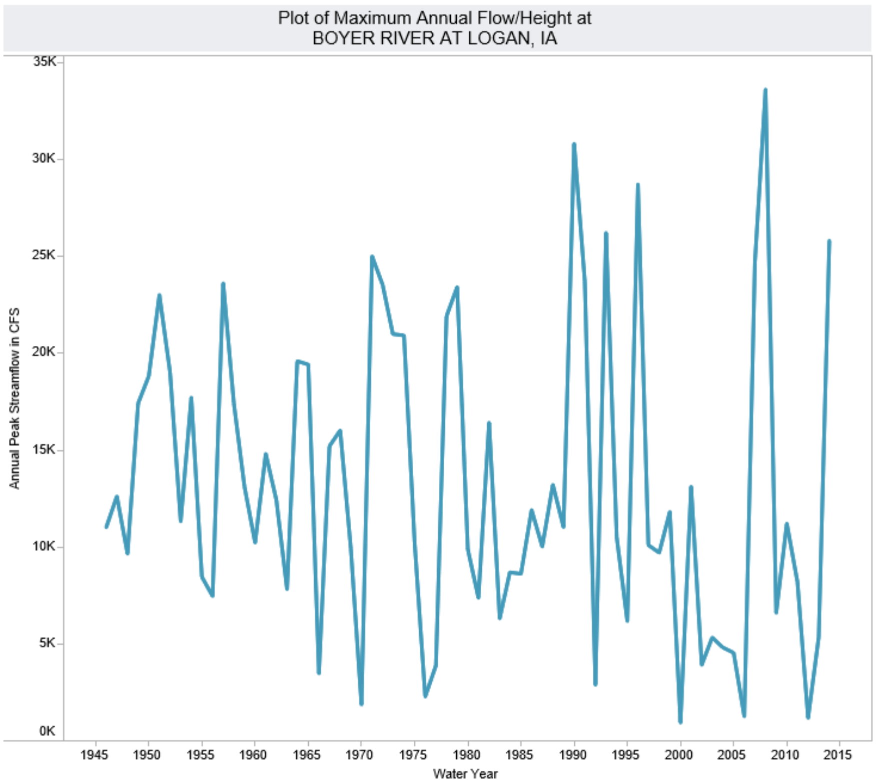


Figure 60. Nonstationarity Results for Boyer River at Logan, IA.



Timeframe Selection

1946 2065

Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.071.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was Null.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 61. Monotonic Trends for Boyer River at Logan. No trends detected.

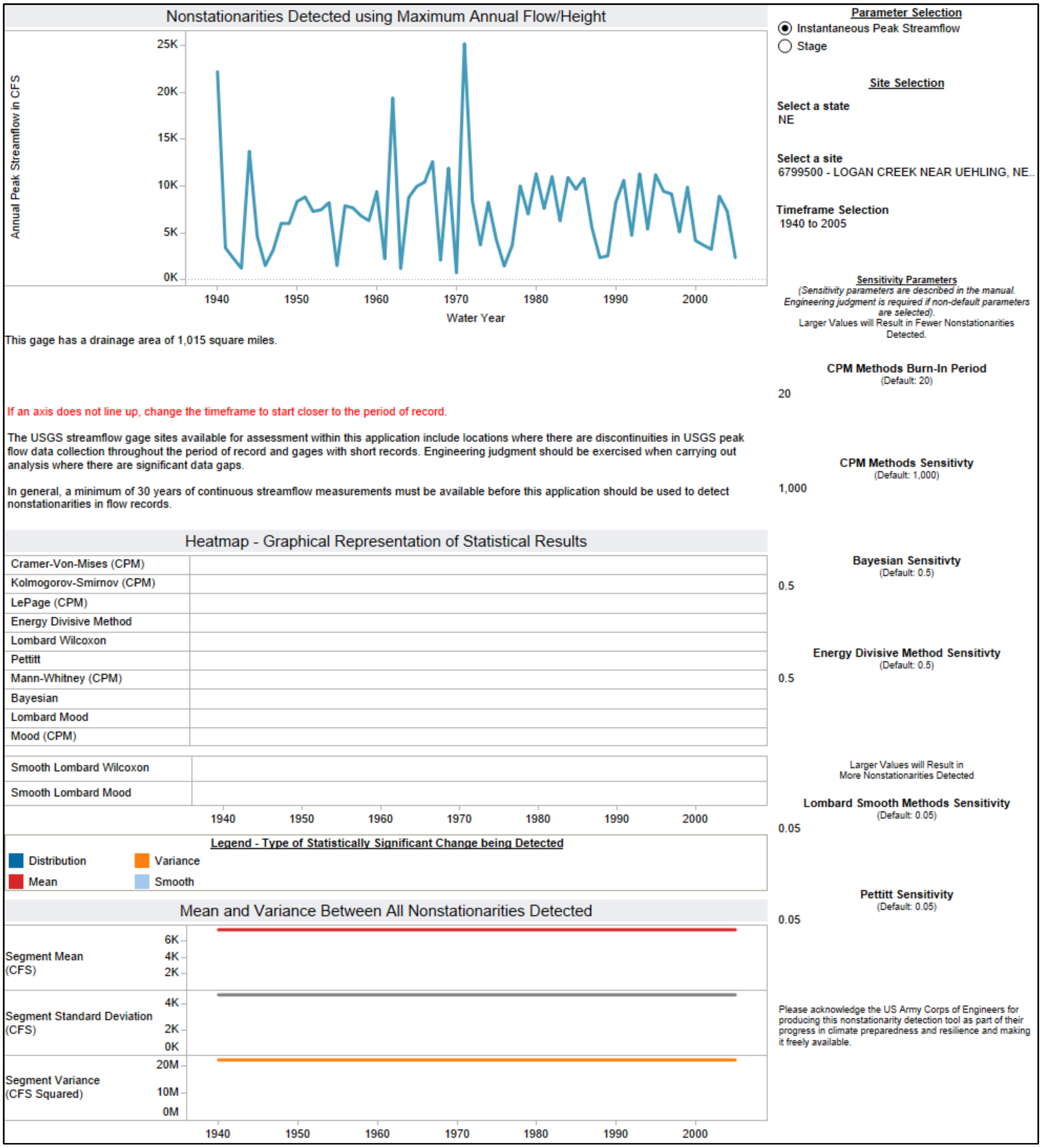
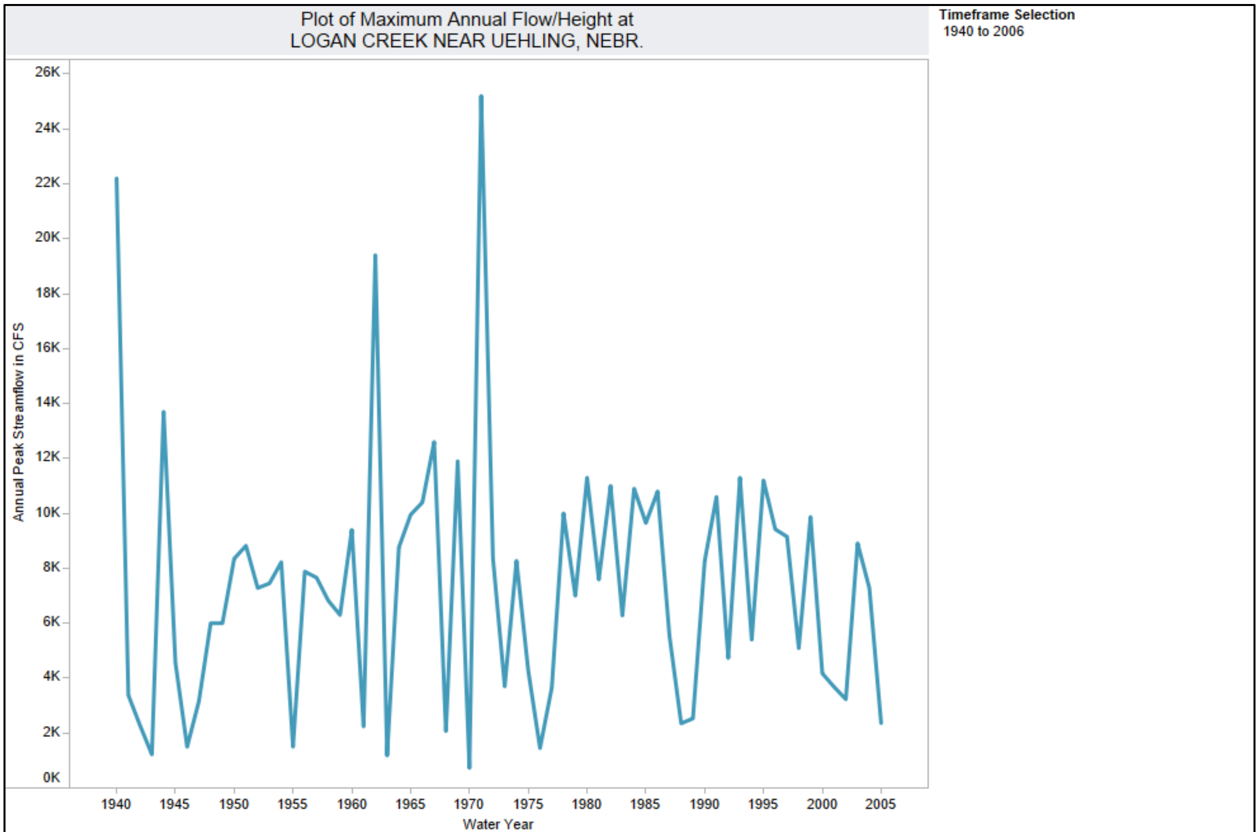


Figure 62. Nonstationarity Results for Period of Record (POR) for Logan Creek near Uehling, NE.



Monotonic Trend Analysis

Is there a statistically significant trend?
No, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.500.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.454.

What type of trend was detected?
Using parametric statistical methods, **no trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **no trend** was detected.

Please acknowledge the US Army Corps of Engineers for producing this nonstationarity detection tool as part of their progress in climate preparedness and resilience and making it freely available.

Figure 63. Monotonic Trends for Logan Creek near Uehling. No trends detected.

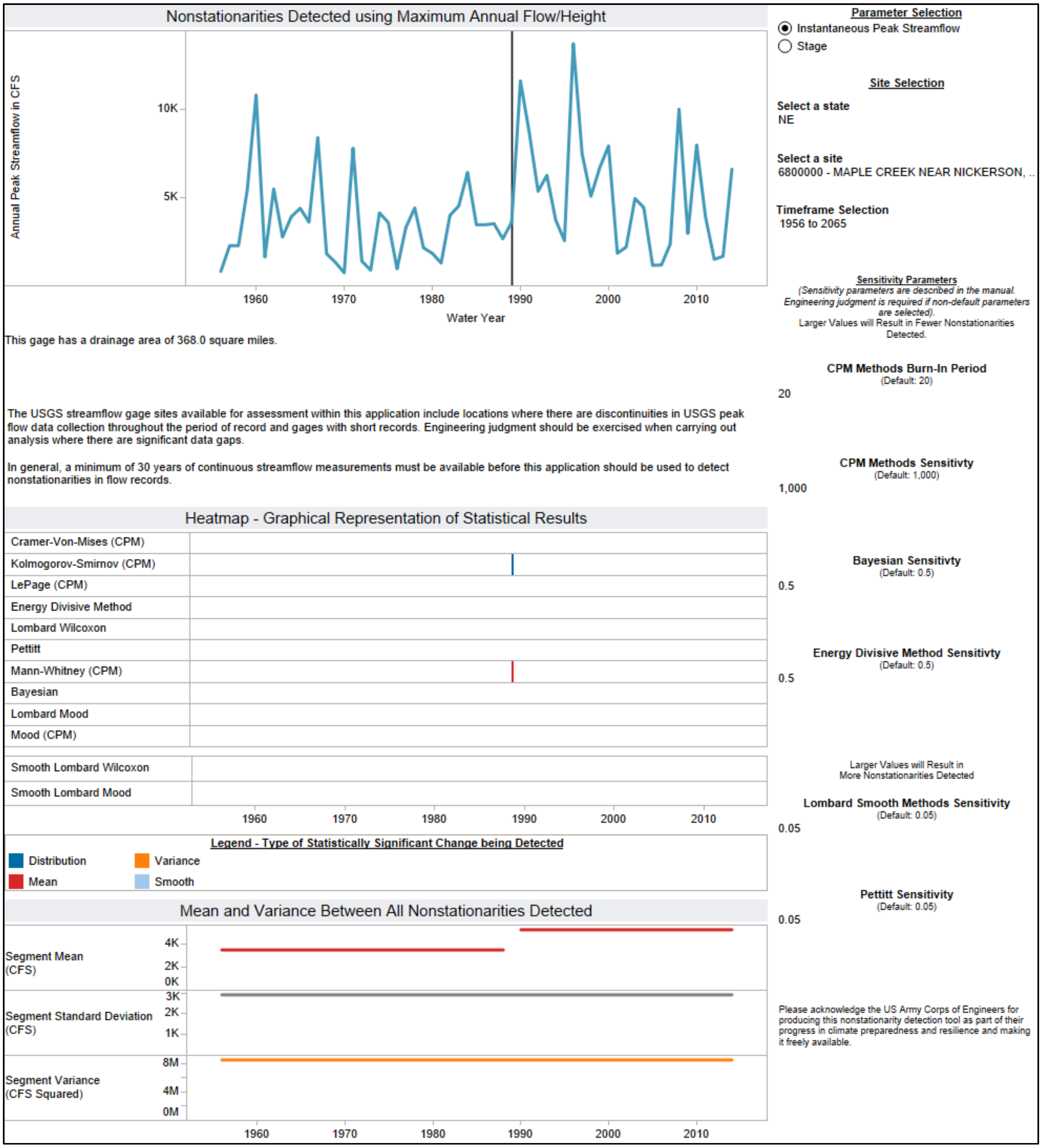


Figure 64. Nonstationarity Results for Maple Creek near Nickerson, NE. Record shortened.

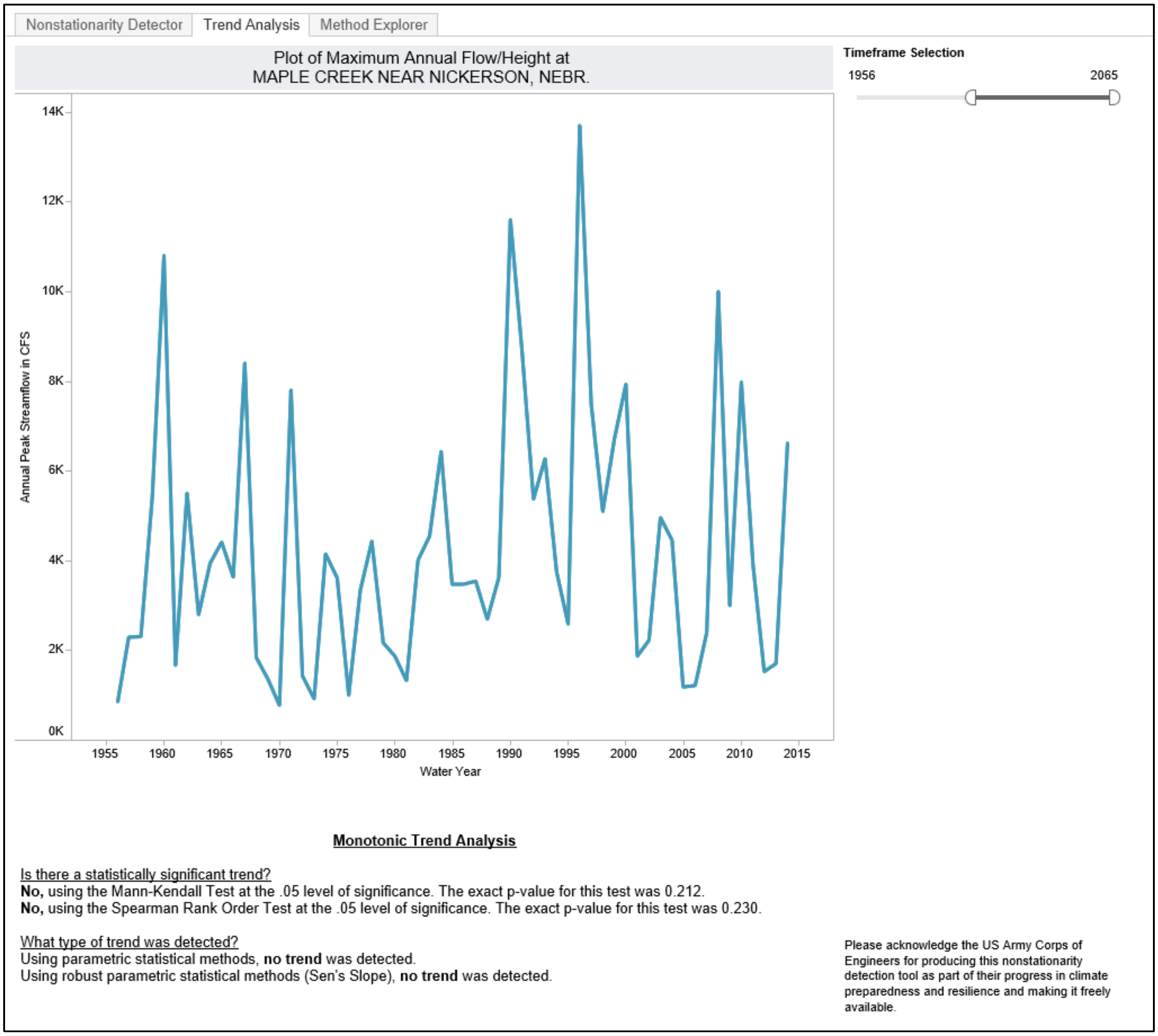


Figure 65. Monotonic Trend Analysis for Maple Creek near Nickerson. No trends detected for shortened record.

AD3.3 Stream Flow Trends

The Climate Hydrology Assessment tool (CHAT) was used to develop first-order trends for annual peak flows at gauges near the study site. Several Papillion Creek gauges were available in the tool but their periods of record were short and all showed no statistically significant trends. The gauges adopted for the nonstationarity detection tool analysis were used to see if gauges with longer records might have trends.

The periods of record used for each gauge in this analysis were determined with input from the nonstationarity detection tool and are summarized in Table 29 in the "Adopted Period of Record" column. The CHAT generates a p-value for the trend that can be used to help interpret if the trend is statistically significant. P-values less than 0.05 were assumed to be statistically significant.

Table 29 summaries the stream flow trends results. None of the results were statistically significant for the gauges tested. This means there is no strong evidence that stream flows are increasing or decreasing with time. Figure 65 through Figure 67 show the Climate Hydrology Assessment tool results.

While no trends were identified in the historic, observed annual instantaneous peaks at the stream gauges tested, the modeled annual maximum monthly stream flows for the HUC4 containing the project area is projected to increase with time. The p value associated with a positively sloped trendline fit to the projected streamflows for 2000-2099 is less than 0.0001 (threshold for significance <0.05). Modeled, projected, streamflow is generated using global climate models (GCM) outputs. This is shown in Figure 68 with the default year of 2000 separating where emissions were held constant (1950-1999) and where the projected pathway of emissions is being applied (2000-2099). The projected hydrology used in Figure 68 was produced from the Global Circulation Model (GCM) Coupled Model Intercomparison Project Phase 5 (CMIP-5) suite of model simulations of temperature and precipitation, downscaled from the global scale to the HUC-4 watershed scale using the Bias Correction and Spatial Downscaling (BCSD) method, based on 93 combinations of GCMs and Representative Concentration Pathway of Greenhouse Emissions (RCP) translated to a hydrologic response using the U.S. Bureau of Reclamation's CONUS wide Variable Infiltration Capacity (VIC) model.

It should be kept in mind that these projected stream flows have a large amount of uncertainty. This uncertainty is shown visually in the spread of flow results for the HUC4 presented in Figure 69. Uncertainty is introduced with each step of the dataset generation including the boundary conditions used in the GCMs used to produce projections of temperature and precipitation, the RCPs selected for the modeling, the downscaling method used to convert the global results to regional HUC 4 scale results, and the uncertainties in the hydrologic model used to generate the stream flow. The hydrologic model used in the case of these 93 stream flow projections was the U.S. Bureau of Reclamation's CONUS wide Variable Infiltration Capacity (VIC) model.

Table 28. Stream Flow Trends. No statistically significant trends.

Stream Gauge	Station ID	Adopted Period of Record	P-Value	General Trend	Statistically Significant?
Boyer River at Logan, IA	06609500	1938-2014	0.42	Downward	No
Logan Creek near Uehling, NE	06799500	1940-2005	0.89	Downward	No
Maple Creek near Nickerson, NE	06800000	1956-2014	0.241	Slight upward	No

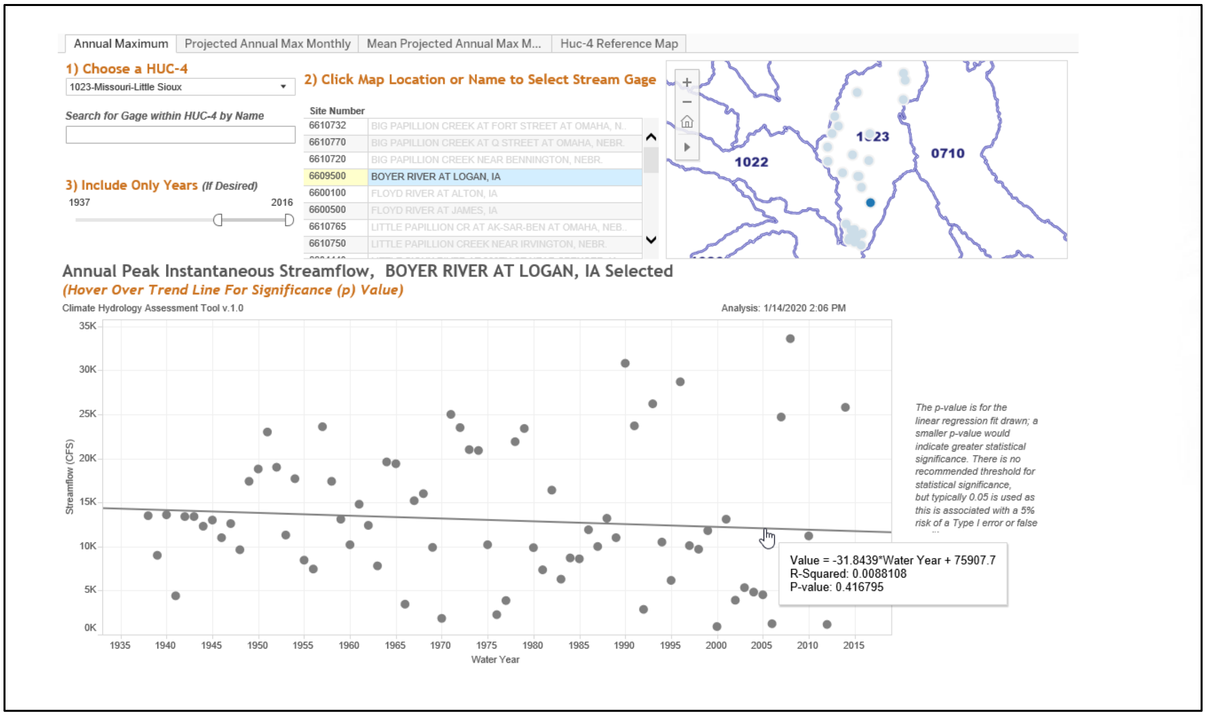


Figure 66. Stream Flow Trends for Boyer River at Logan

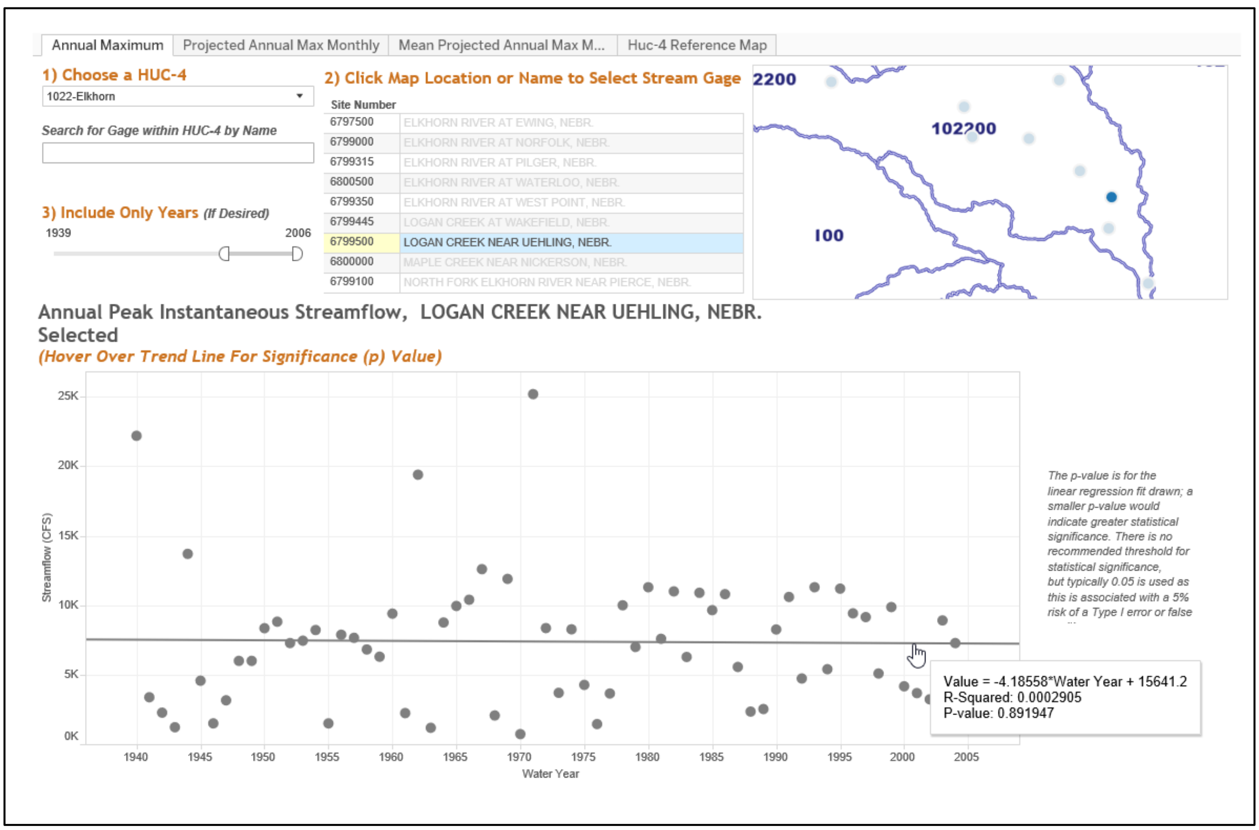


Figure 67. Stream Flow Trend for Logan Creek near Uehling

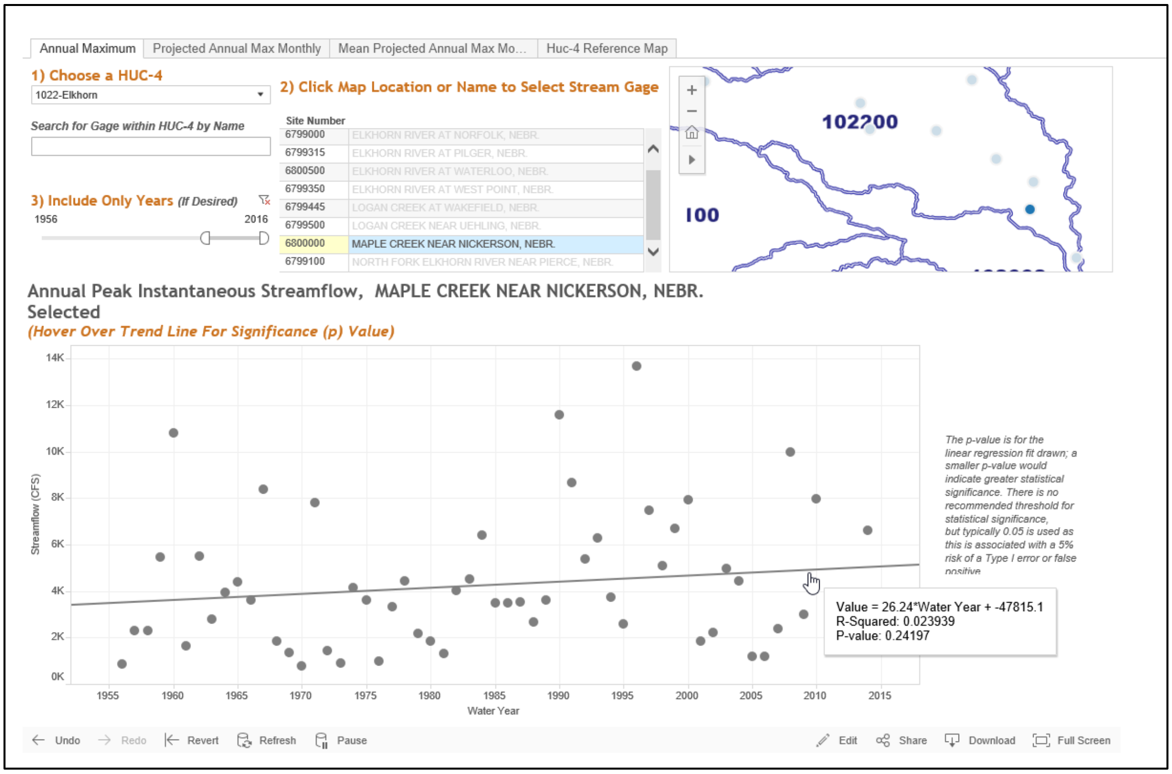


Figure 68. Stream Flow Trend for Maple Creek Near Nickerson

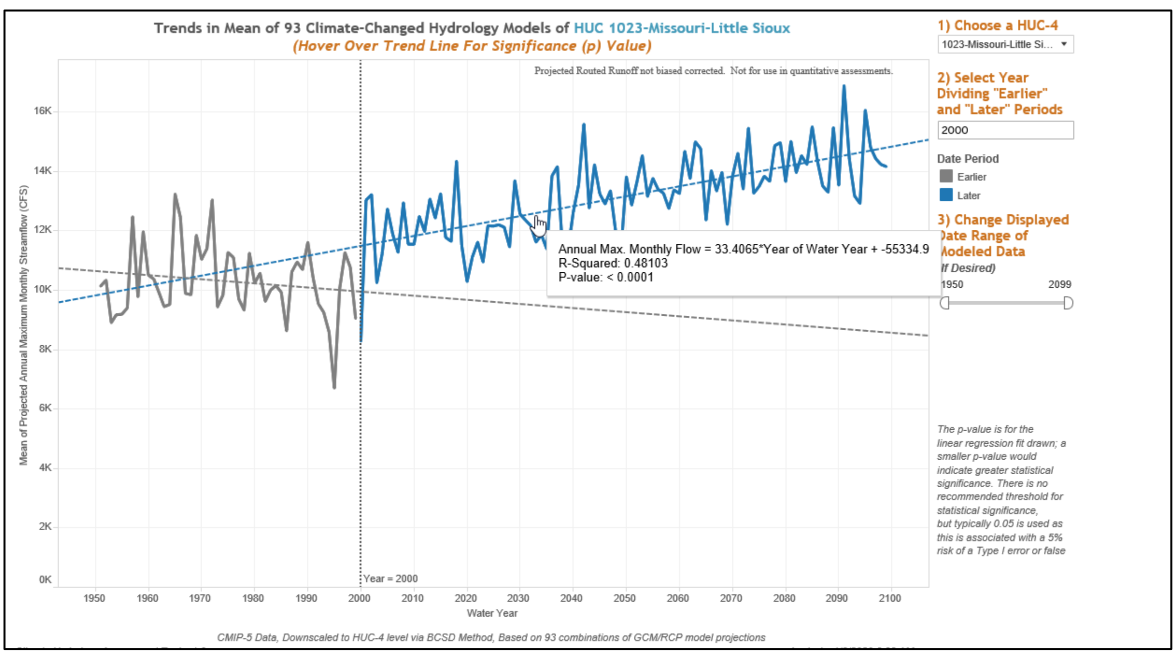


Figure 69. Stream Flow Trend for HUC 4. Statistically significant increases in stream flow projected from default 2000 onward.

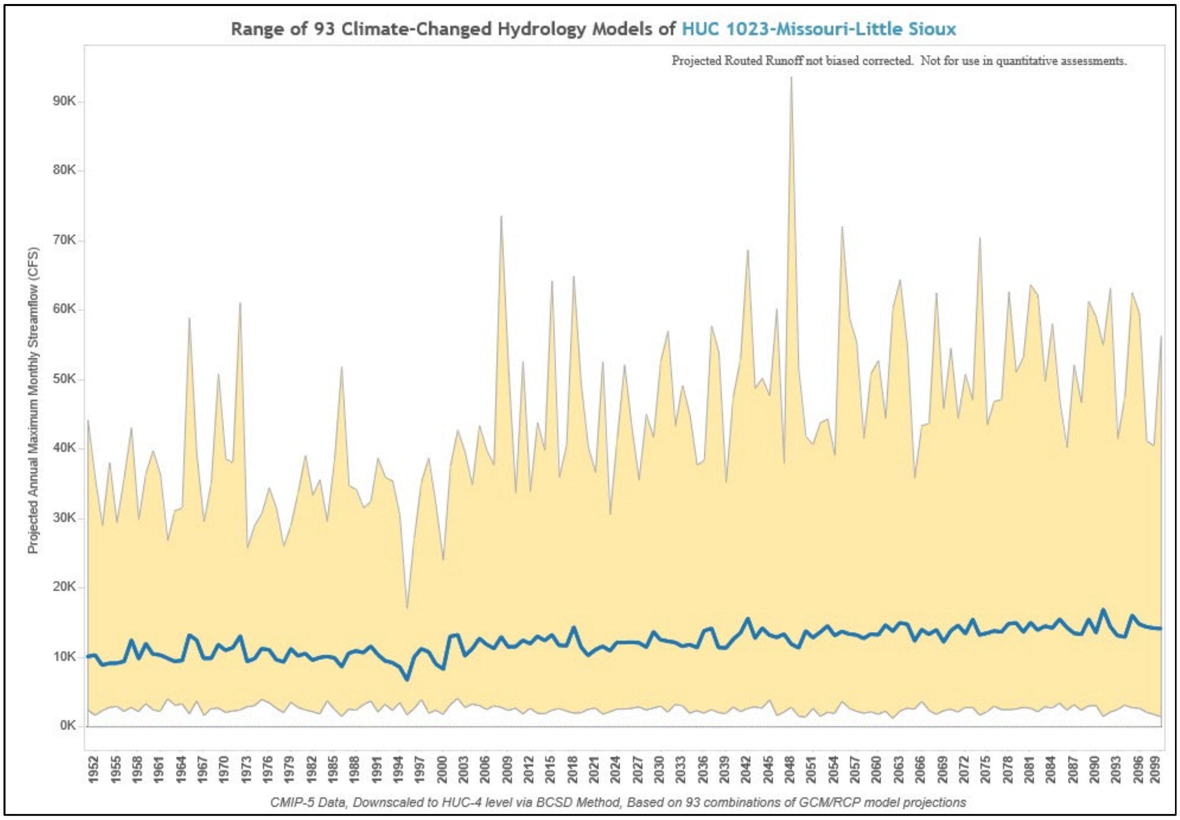


Figure 70. Spread in the Projected Stream Flows for HUC 4.

AD3.4 Vulnerability

The USACE Vulnerability Assessment (VA) Tool provides a nationwide, screening-level assessment of climate change vulnerability related to the USACE mission, operations, programs, and projects. The Vulnerability tool was used to help determine if the Papillion Creek watershed is considered vulnerable to climate change based on USACE standards. Only flood flows were considered (flood mitigation business lines) for this project because it does not have an ecosystem restoration component. Papillion Creek is part of the Missouri-Little Sioux HUC 4.

The USACE vulnerability assessment tool flags watersheds as being vulnerable to climate change across a specific USACE business line (flood risk reduction in the case of this study) if that watershed HUC 4 vulnerability score falls within the top 20% of vulnerability scores as compared to the other 201 HUC 4 watersheds in the contiguous United States (CONUS). The vulnerability score is calculated using a weighted order weighted area (WOWA) method based on a series of indicator variables. The tool uses climate changed hydrology determined using 100 traces of CMIP5 GCM based climate outputs converted to a hydrologic response using the U.S. Bureau of Reclamations CONUS wide Variable Infiltration Capacity (VIC) models. The uncertainty in the modeling is partially communicated by providing output for two epochs of time and for both the top 50% of traces of flow (WET scenario) and bottom 50% of traces (Dry scenario). The default national standard settings were used in the tool.

The flood risk reduction business line is vulnerable for both the 2050 and 2085 Epochs and for both dry and wet scenarios. The driving indicators to this vulnerability are: the urban population in the 500-year flood plain (590), flood magnification within and upstream of the HUC (568C), and the likelihood that small changes in precipitation will result in large increases in runoff (277). Results are shown in Table 30 and Table 31 and in Figure 70.

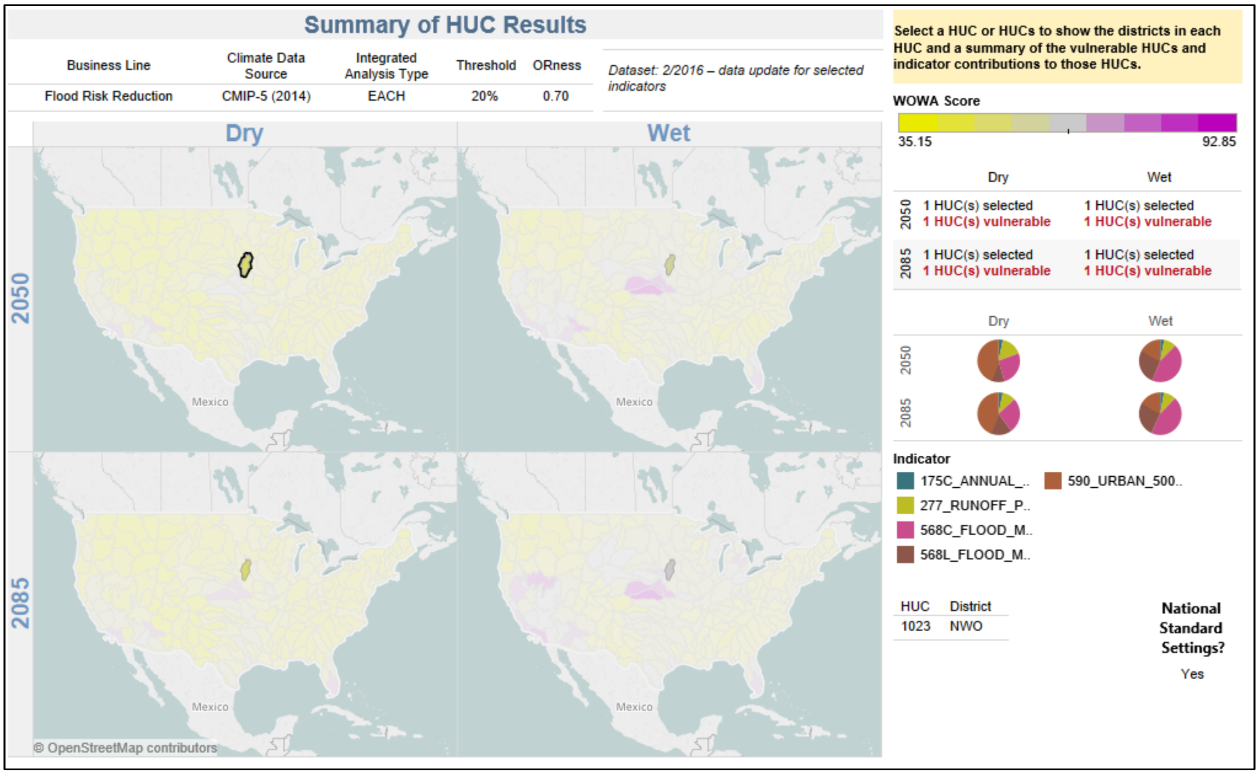


Figure 71. Vulnerability Results. HUC 1023 Flood Risk Reduction business line is vulnerable for both dry and wet future scenarios.

Table 29. Vulnerability Results and Indicators for 2050 Epoch

2050 Epoch	HUC 1023 – Vulnerable	
	Dry	Wet
Indicator	Contribution to WOWA Flood Risk Reduction Vulnerability Score	
590 Urban 500 YR Floodplain Area	44.4	16.9
568C Flood Magnification	26.3	43.7
277 Runoff Precipitation	16.1	9.5
568L Flood Magnification	10	27
175C Annual Cov	3.2	2.9

Total WOWA Vulnerability Score:	**53.17**	**53.17**

Table 30. Vulnerability Results and Indicators for 2085 Epoch

2085 Epoch	HUC 1023 - Vulnerable	
Indicator	Dry	Wet
	Contribution to WOWA Flood Risk Reduction Vulnerability Score	
590 Urban 500 YR Floodplain Area	43.6	16.3
568C Flood Magnification	26.8	44.9
277 Runoff Precipitation	10.2	9.4
568L Flood Magnification	16.3	26.7
175C Annual Cov	3.1	2.7
Total WOWA Vulnerability Score:	**53.17**	**53.17**

AD4. Climate Change Conclusions

Future, Without Project Conditions could be significantly impacted by changes in climate at some indeterminate point in the future. However, at present there is no evidence within streamflow records observed at the project-site scale indicating climate change is causing flood peaks to increase.

Because there is some evidence of potential increases to flood risk in the future based on projected datasets and basin conditions, it is suggested that flood risk continue to be monitored to see if a trend of increasing flow magnitudes begins to materialize within the gauged record. If such a trend should begin to emerge, resilience measures could be reconsidered. In addition to monitoring, the point where increases to flood risk would begin to critically undermine project performance should be identified, as well as how much lead time it would take to add resilience measures to the project (including time for planning, funding acquisition etc.).

If it is decided that adaptive measures to build resilience to climate change into the TSP project design are to be considered, such measures will be identified and discussed further in the next phase of study.

AD5. Residual Risk Due to Climate Change

Table 32 lists the different alternative measures being considered as part of this study and their associated qualitative risk due to climate. Risks are similar on all stream reaches so the table does not separate information out by reach. The qualitative likelihood for all measures considered is possible, but not very likely.

Table 31. Climate Change Risks

Measure	Trigger	Hazard	Harm	Qualitative Likelihood
Dam with Pool	Increased precipitation and runoff Increase in population at risk in the basin	Future flood volumes may be larger than present Large flood volumes may occur more frequently	Increased hydrologic loading. Larger risk to flooding of population downstream Recreation features may be inundated	Possible but not very likely
Dry Dam	Increased precipitation and runoff Increase in population at risk in the basin	Future flood volumes may be larger than present Large flood volumes may occur more frequently	Increased hydrologic loading. Larger risk to flooding of population downstream	Possible but not very likely
New Levee/Flood Wall and/or Levee Raise	Increased precipitation and runoff to channels	Future flood volumes may be larger than present Large flood volumes may occur more frequently	Flood waters may remain on the levee or flood wall for longer durations with more frequent loadings Flood frequency may increase and decrease the level of protection of the levee	Possible but not very likely
Channel Widening	Increased precipitation and runoff to channels	Future flood volumes may be larger than present Large flood volumes may occur more frequently	Increase in likelihood of flows getting out of bank and increasing risk to life and property	Possible but not very likely
Nonstructural	Increased precipitation and runoff to channels	Water stages may be higher than those used to determine designs	Property may be at risk again after a raise in first-floor elevation that was not high enough for future conditions	Possible but not very likely