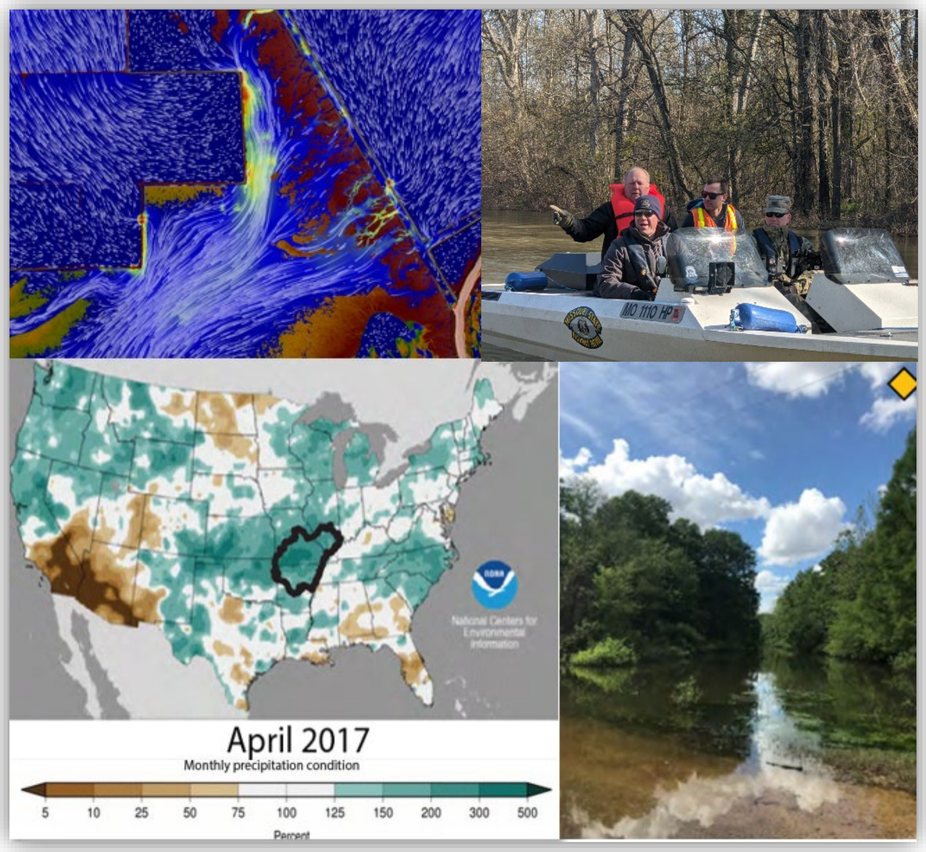
Hydrologic Analysis of the Black River in Southeast Missouri



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Executive Summary

A broadly scoped study was conducted to evaluate flooding issues in Butler Co, Missouri. It can be generally summarized that flooding issues occurring recently have been a product of increased precipitation. In the area of Poplar Bluff, Missouri, where the Mississippi River Delta gives way to the Ozark Mountains, statistically significant increasing trends in annual precipitation totals, the intensity of precipitation events, and the frequency of high intensity precipitation events were observed. In these same areas, statistically significant increasing trends in streamflows (including baseflow and run-off components of flow) were observed. In areas adjacent to levees along the Black River in Butler Co, Missouri, studies showed that groundwater has a significant impact on prolonging flooding conditions, that groundwater and streamflow in the Black River have a high degree of connectivity, and that the Black River in Butler Co, Missouri is a gaining stream (meaning that Black River baseflows increase as one moves downstream as a result of groundwater flowing into the Black River). A study conducted by the U.S. Geological Survey, in cooperation with the U.S. Army Corps of Engineers determined that no major changes in bed aggradation or degradation have occurred from data analyzed from 1948 to 2019. Therefore, it is most likely that increases in flooding occurring recently within the Black River watershed are a result of increased precipitation.

Based on suggestions from local stakeholders, the U.S. Army Corps of Engineers evaluated several Clearwater Dam operational scenarios in order to determine if it is feasible to change the water control plan for Clearwater Dam to help alleviate flooding in Butler Co, Missouri. Evaluations of reservoir operations at Clearwater Dam demonstrated that attempts to limit releases during the growing season increase the number of days of uncontrolled spillage at Clearwater Dam, increasing the number of days above which critical elevation and streamflow thresholds are exceeded and imposing serious risk to the safety of Clearwater Dam and increasing the frequency of higher peak releases.

A Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model was developed for an area adjacent to the Black River in the southern portion of Butler Co, Missouri. The model showed that adding slope to ditches in some areas, creating 2-stage ditches in some locations, and potentially adding tile drains has a significant impact on reducing flooding issues related to the interaction of surface water and groundwater in area evaluated. Two-stage ditches are considered a best management practice recommended for further analysis and are most applicable where there is perennial flow, where ditch side slopes are eroding, or when the ditch requires frequent maintenance due to sediment deposition.

The Hydrologic Engineering Center River Analysis System (HEC-RAS) model was developed from the Clearwater Dam to the streamgage at Corning, AR to evaluate suggestions regarding improvements to the river. The modeling of concepts such as channel cleanouts, channel straightening, small levee removals, and levee setbacks, provided insights to the potential cause and effect on peak water surface elevation, peak flow, and durations. Combining model results, river engineering experience, and local institutional knowledge allowed the study to summarize potential best management practices; however, due to the higher groundwater levels, the local drainage improvements for 2-stage ditches and tile drains would have a more significant impact on reducing flooding for agriculture. The suggestions for river improvements (channel cleanouts and straightening) did reduce some peak elevations, but generally did not have a significant impact on flooding duration like local drainage improvements would. Due to the narrow floodplain width from levee constrictions for much of the Black River, invasive channel cleanouts (such as widespread dredging), channel straightening, and dredging are not recommended. These suggestions can cause head cutting and bank failures that would threaten the nearby levee systems and at times would increase water surface elevations in constricted locations downstream as more flow would convey down the system. Standard channel cleanout or maintenance along with a low water weir at Swift Ditch would improve river efficiency and allow the river to naturally scour and increase carrying capacity with less risk to an abrupt change causing head cutting and bank failures. By restricting flow in Swift Ditch, the river's energy would be directed back towards the Black River removing much of the deposition that has occurred along with manually clearing debris through normal maintenance. Levee setbacks are considered best management practices to provide space for the river to flow. While unpopular for landowners, the buy down in risk to the levees and reducing flood flows in both peak and duration was observed in the analysis of the levee setback scenario and should be considered in some capacity.

Introduction

The Black River (fig. 1) is a tributary of the White River, located in the states of Missouri and Arkansas in the United States. Originating in the Ozark Mountains of Missouri, the river flows approximately 200 miles before emptying into the White River in Arkansas. Flooding along the Black River in Butler County, Missouri has been documented by the U.S. Army Corps of Engineers (USACE) in two separate studies, one in 1976 and one in 1991. The 1976 study was the Appraisal Study by the Little Rock District USACE on the Resumption of Maintenance of the Black River under the original authorization for Black River Navigation (Rivers and Harbors Act of June 1880 and March 1881). The 1991 study was conducted as a Feasibility Study "Black River Obstruction Removal at Butler County, Missouri" under Section 205 of the Continuing Authorities Program and was funded in 1993 as a Clearing and Snagging project. Both reports identified channel debris (mostly trees) as a major contribution to flooding along the Black River in Butler County. The 1991 report led to a channel clearing project between USACE and Butler County where trees were cleared and snagged from River Mile 198.4 to the state line (River Mile 170.9).

Flooding along the Black River has continued to occur since the completion of the 1993 Clearing and Snagging Project. USACE analysis of streamflow in the Black River from below Clearwater Dam to areas below the state line have indicated several reasons for the increased frequency and magnitude of flooding in the Black River and all point to an increase in runoff and baseflow in the Black River.

In Butler Co, MO, the Black River Watershed is primarily rural area. The study area (fig. 2) is located within a wide alluvial valley of the Black River. A study was conducted by the US Army Corps of Engineers, Little Rock District to evaluate flooding in Butler Co, MO. Results of this study are summarized in this report.

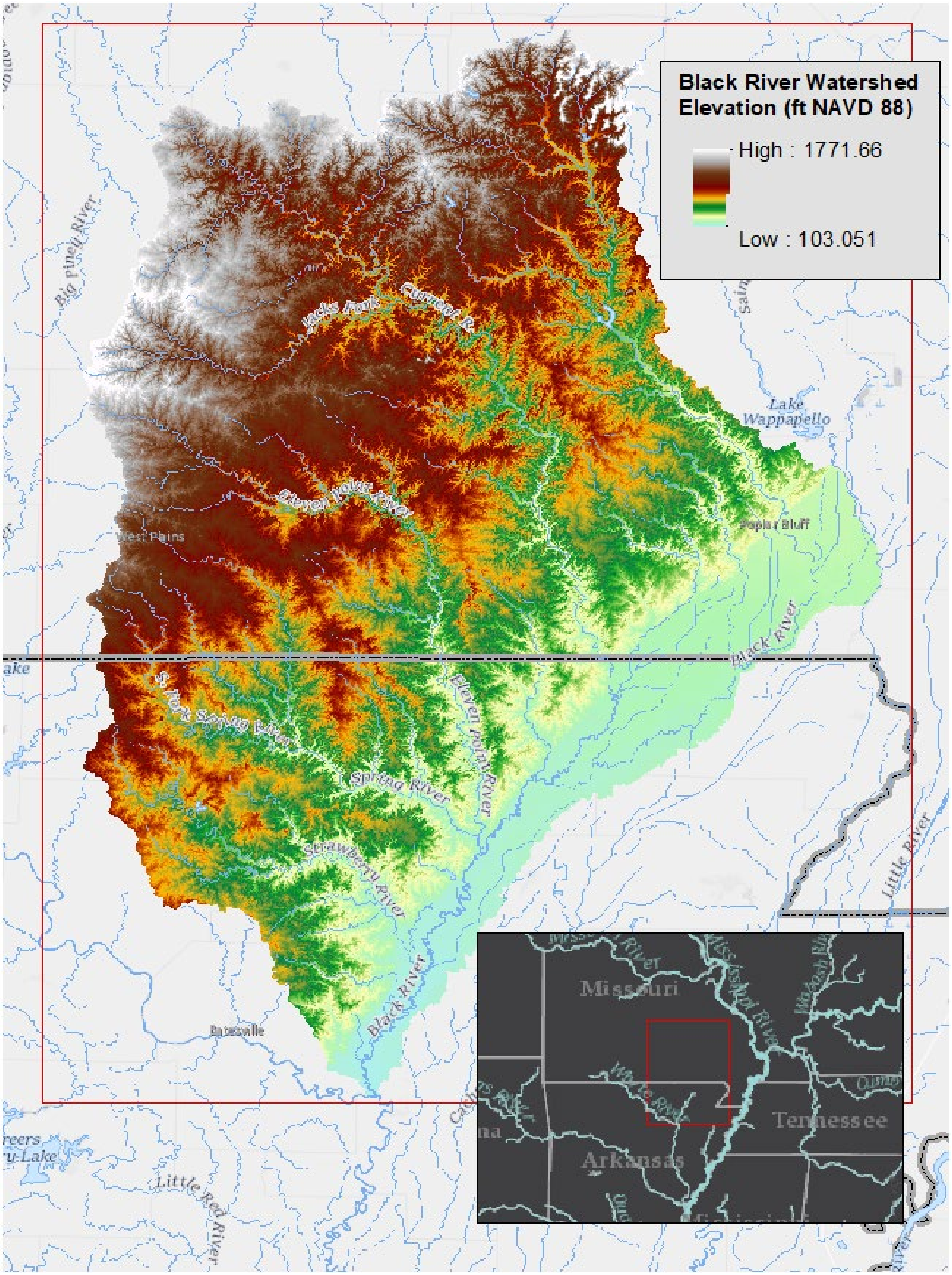

Figure 1 Map showing Black River Watershed in Arkansas and Missouri.

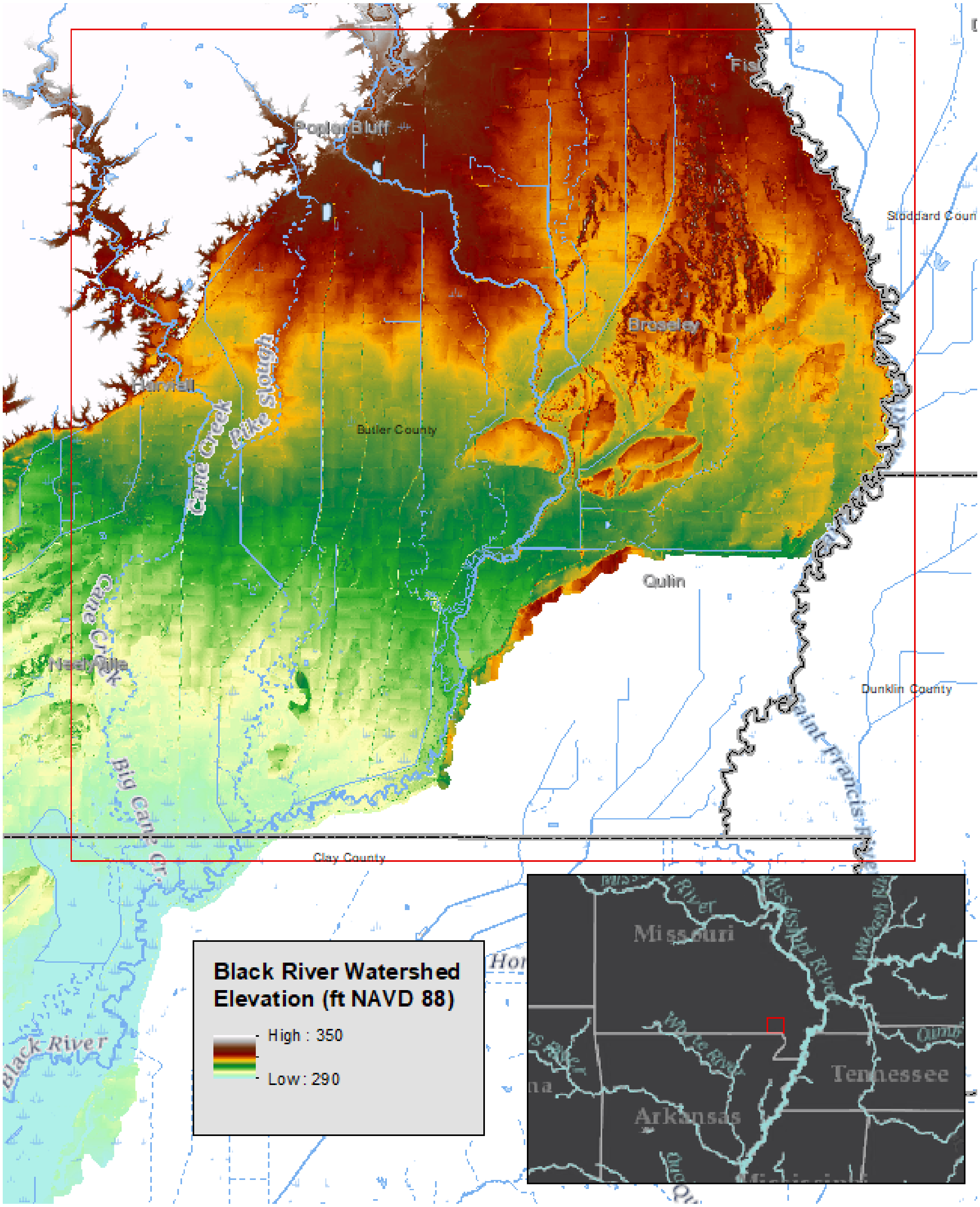

Figure 2 Black River Watershed in Bulter Co., MO

Scope

This report presents the results of a study made to analyze flooding problems in Butler County, MO stemming from high streamflows on the Black River and groundwater in the Black River Basin. Individual parts of this study involved operational scenarios related to Clearwater Dam, geomorphology of the Black River, analysis of groundwater/surface water interaction in areas adjacent to the Black River, and evaluation of obstruction removal as a means of restoring channel capacity and increasing channel efficiency through hydraulic analysis. Major tributary ditches such as Swift Ditch were also included in the hydraulic analysis. Flooding from other sources, such as groundwater, were also evaluated in this study.

Literature Review

When assessing rivers and streams, it is important to understand the history and evolution of the river and science to appropriately represent the challenges and expectations of potential solutions. As such, a prudent literature review was conducted to better understand the changes in the watershed as the time scale of hydrology and geomorphology spans many generations.

The Swamp Land Act in the mid-1800s through the 1900s allowed for clearing, leveling, and ditching for the agriculture and timber industries. In the Black River watershed this resulted in a loss of 75 to 80 percent loss of bottomland hardwoods. This legislation reverted the title of federally-owned swampland to states which agreed to drain the land and turn it to agricultural production. The economic motivation gave little consideration to hydrology in that no comprehensive plan was developed for the changes to the drainage and protection from the river which has resulted in levees in close proximity to the river (to reclaim as much land as possible) and inadequate local drainage. The timber loss also resulted in increased runoff efficiency and higher flood peaks were expected. The Swamp Land Act was later considered to have been ecologically problematic with many of its provisions reversed by the Clean Water Act of 1972 and other legislation, but its historical effects of development and settlement patterns remained.

Construction of levees along the Black River was formalized mostly in the 1940s and into the 1950s. Much of the system is federally authorized, but non-federally operated and maintained with additional earthen levees also construction by landowners. Butler County Levee District 12 and Ring Levee are Federally Authorized levees with non-federal sponsors. Reorganized Butler County #7 and North Inter-River are non-federal levees. The Ring Levee was constructed as part of the North Inter-River levee; however, the Ring Levee portion was federalized because the Corps of Engineers designed and constructed a pump station for it. Many levees are less than 0.25 miles from both sides the channel and generally are not further than 0.5 miles from the sides of the channel. With more recent significant rainfall events, the levee system has suffered many breaches and damages.

There has been some evidence with little records of gravel mining in the Black River. Gravel mining is well known in modern times to negatively impact channel geometry and ecology. Gravel mining increases channel incision, bank erosion, rates of channel migration, turbidity, loss of spawning habitat, and downstream sedimentation. These geomorphic changes are similar risks for dredging as they are for gravel mining. A study conducted by Arkansas State University (Kaminarides and others, 1996), in an area similar to southern Missouri, determined that the economic benefits of instream gravel mining did not outweigh the environmental costs.

Clearwater Dam was completed for flood damage reduction at Poplar Bluff. The construction was completed in 1948 and reduced the average annual peak discharge by about one-half from 20,700 cfs to 10,150 cfs. At the time of analysis and design of Clearwater Dam about 90 percent of the direct flood losses in the valley resulted from damage to crops. Other losses were from rural improvements such as fences and farm building, land erosion, and damage to roads. The reduction in magnitude and frequency of major flooding can be clearly identified by examining peak flows at the Poplar Bluff Gage before and after 1948 (Figure 3).

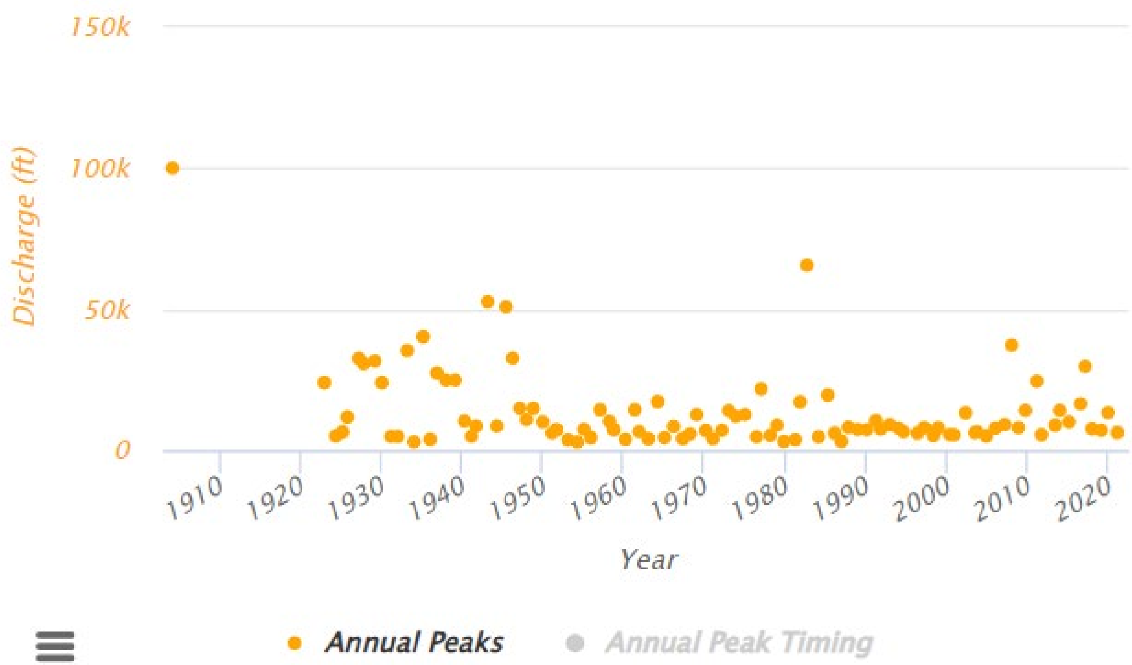

Figure 3 Annual peak streamflow at Poplar Bluff streamgage

Records indicate that snagging occurred from river mile 96.2 to 75 in 1972 and from river mile 144.4 to 96.2 in 1973. Flooding along the Black River in Butler County, Missouri has been documented by the U.S. Army Corps of Engineers (USACE) in two separate studies, one in 1976 and one in 1991. The 1976 study was the Appraisal Study by the Little Rock District USACE on the Resumption of Maintenance of the Black River under the original authorization for Black River Navigation (Rivers and Harbors Act of June 1880 and March 1881). The 1976 clearing and snagging project did not happen because of environmental opposition to the proposed plan, the inability of drainage districts to obtain all of the necessary easements and right of ways, and the non-receipt of the Section 221 agreement. The 1991 study was conducted as a Feasibility Study “Black River Obstruction Removal at Butler County, Missouri” under Section 205/208 of the Continuing Authorities Program and was funded in 1993 as a Clearing and Snagging project. Both reports identified channel debris (mostly trees) as a major contribution to flooding along the Black River in Butler County. The 1991 report led to a channel clearing project between USACE and Butler County where trees were cleared and snagged from River Mile 198.4 to the state line (River Mile 170.9) following the Stream Obstruction Removal Guidelines prepared by the Wildlife Society and American Fisheries Society. The 1991 obstruction removal plan was reduced in scale from the 1976 plan and more sensitive to the environmental concerns of the conservation agencies in Missouri. The proposed 1991 plan that was constructed increased channel capacity for low frequency flow events but had a negligible effect on flows above the 10% Annual Exceedance Probability event (approximately 9,000 cfs). Clearing and snagging of Swift Ditch was included in the plan but never conducted because it was anticipated that the clearing and snagging of Swift Ditch would cause the capture of Black River flow into Swift Ditch unless structural measures were constructed to restrict the flow. Consequently, this capture of flow by Swift Ditch would quickly reduce the Black River in the area to a backwater slough and increase the widening, deepening, and meandering of Swift Ditch causing additional erosion and damage to the nearby levee unless a major bank protection effort was put in place. It is important to note that even without clearing Swift Ditch, this capture of flow naturally took place. As part of the 1991 obstruction removal, the non-federal sponsor (Butler County) was instructed that the improved Black River channel should be protected with continual maintenance to remove large debris that would find its way into the channel. Lack of maintenance would allow for log jams to reoccur and that if Swift Ditch were ever to be cleared that left descending bank protection be provided along with a low water weir to force low flows into the Black River.

The City of Poplar Bluff also participated in a cost-share project with USACE under Section 205 which resulted in construction of a section of pre-cast concrete floodwall approximately 500 feet long and a section of stop-log structure (which is a removable floodwall) approximately 585 feet long along the right bank of the Black River. The floodwall and stop-log structure is approximately 3 feet high and tie into a concrete abutment at the upstream end (RM 210.4) and an existing city levee at the downstream end (RM 210.2). Final inspection of this project was in July 1998.

Geomorphic Mapping and Specific Gage Analysis

The following section summarizes Scientific Investigation Report 2021-5067 entitled: *Historical Hydrologic and Geomorphic Conditions on the Black River and Selected Tributaries, Arkansas and Missouri* which was prepared by the United States Geological Survey in cooperation with the U.S. Army Corps of Engineers in 2021. The full report can be found at https://doi.org/10.3133/sir20215067.

The purpose of the report was to present results of an analysis of long-term streamgage records and historical discharge measurements as well as analyze changes in channel cross section geometry data. The specific gage analysis analyzes the change in stage-discharge relationship over time. The specific gage analyses indicated that most of the streamgages along the Black River were generally stable. This lack of significant geomorphic change at the streamgage sites is not entirely unexpected because the gages are all at bridge crossing which tend to be stable locations. The largest trends (but not significant) in specific stage were decreases observed at the Poplar Bluff gage which are indicative of bed degradation; these small bed degradation trends at Poplar bluff were also verified with the cross section analyses. The overall conclusion of the cross section analyses indicated that no major changes have occurred in the Black River from 1948 – 2019. Major change is defined as long-term, reach trends in aggradation and degradation of the streambed.

Trends in Precipitation and Streamflow

Precipitation patterns in the upper portions of the Black River watershed in the State of Missouri have experienced a statistically significant increasing trend over recent decades. Increasing trends in precipitation, streamflow, baseflow, and flood flows have occurred in the Black River Watershed in southern Missouri and northern Arkansas. This is not unique to the upper Black River Watershed, Missouri, or Arkansas. Numerous studies have been conducted across the continental United States examining trends in precipitation and streamflow. Increases in the frequency and intensity of precipitation events (Zhang and Villarini 2021), flooding (Mallakpour and Villarini 2015), and baseflow (Ayers et al. 2019) have been observed across the Midwest in recent decades.

For the purpose of evaluating changes in streamflow and durations of inundation related areas within and adjacent to the Black River levees in Butler Co, MO, precipitation data was analyzed for the existing precipitation gauges (fig. 3) located at Clearwater Dam, MO (NOAA USC00231674), Poplar Bluff, MO (NOAA USC00236791), Williamsville, MO (NOAA USC00238984), and Corning, AR (NOAA USC00031632). Annual total precipitation accumulations were evaluated. Short-term precipitation accumulations were also evaluated to compare changes in storm intensity over time. Figures 4 through 6 show how these different locations have changed over time with regards to precipitation totals and precipitation intensity.

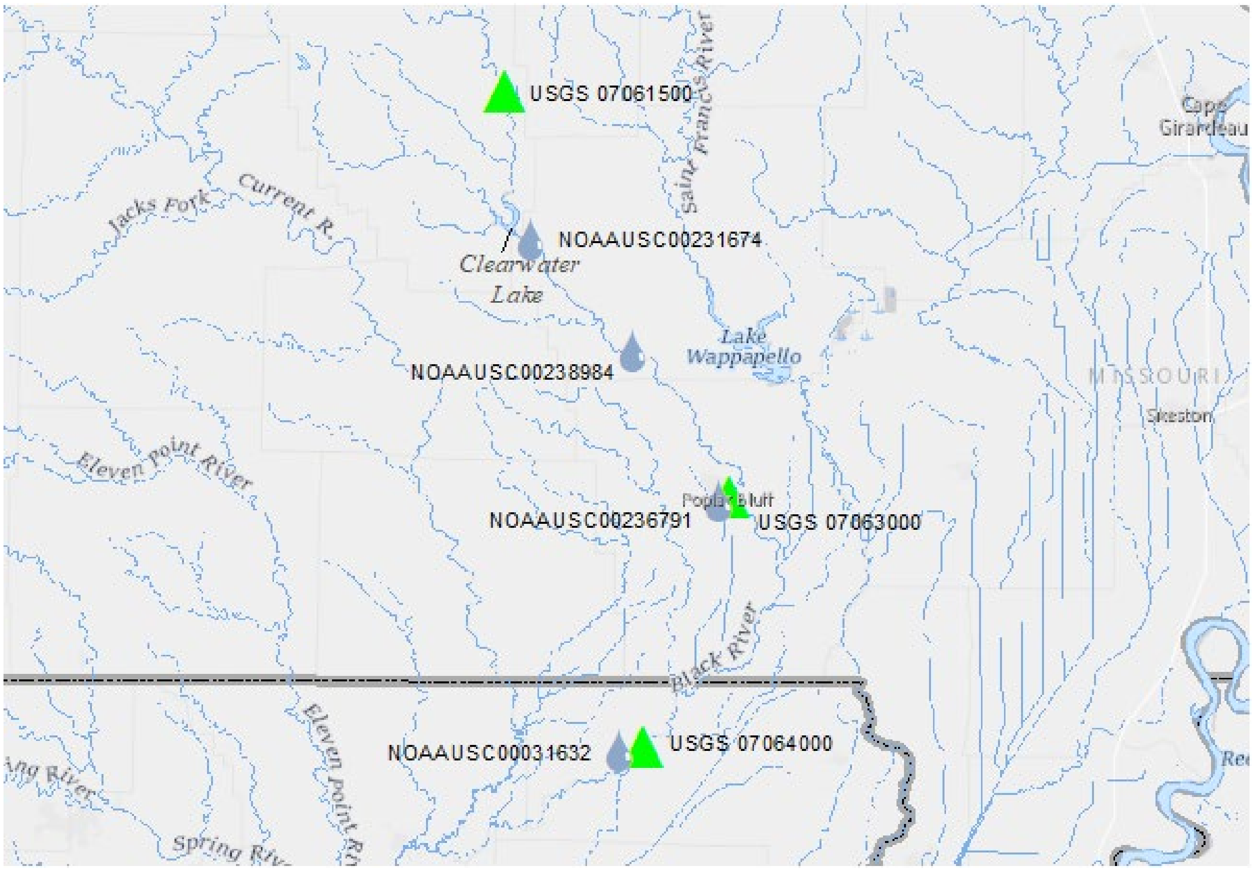

Figure 4 Map showing locations of NOAA precipitation gauges and USGS streamflow gaging stations.

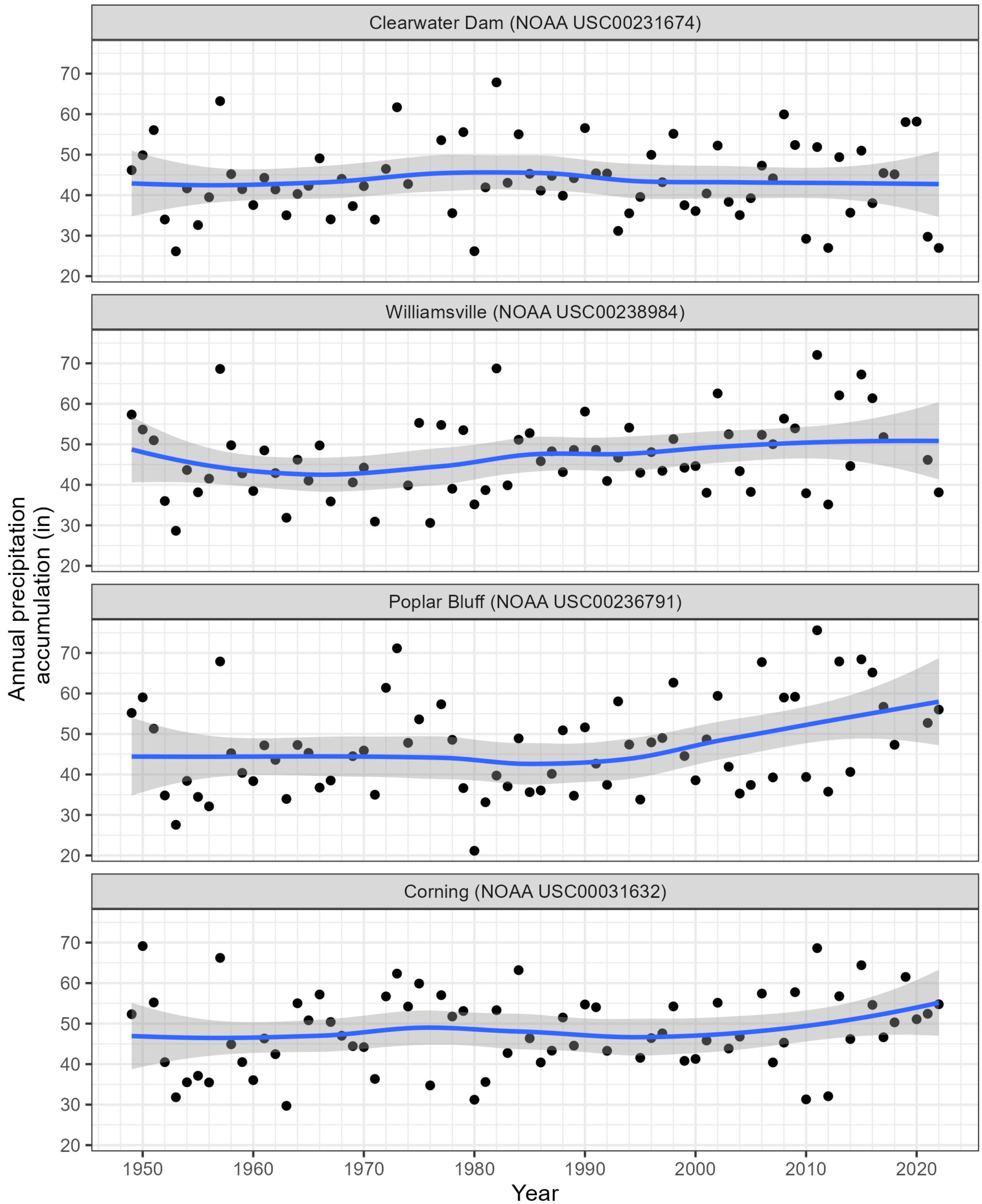

Figure 5 Plots showing annual total precipitation accumulation for precipitation gauges at Clearwater Dam, Williamsville, Poplar Bluff, and Corning.

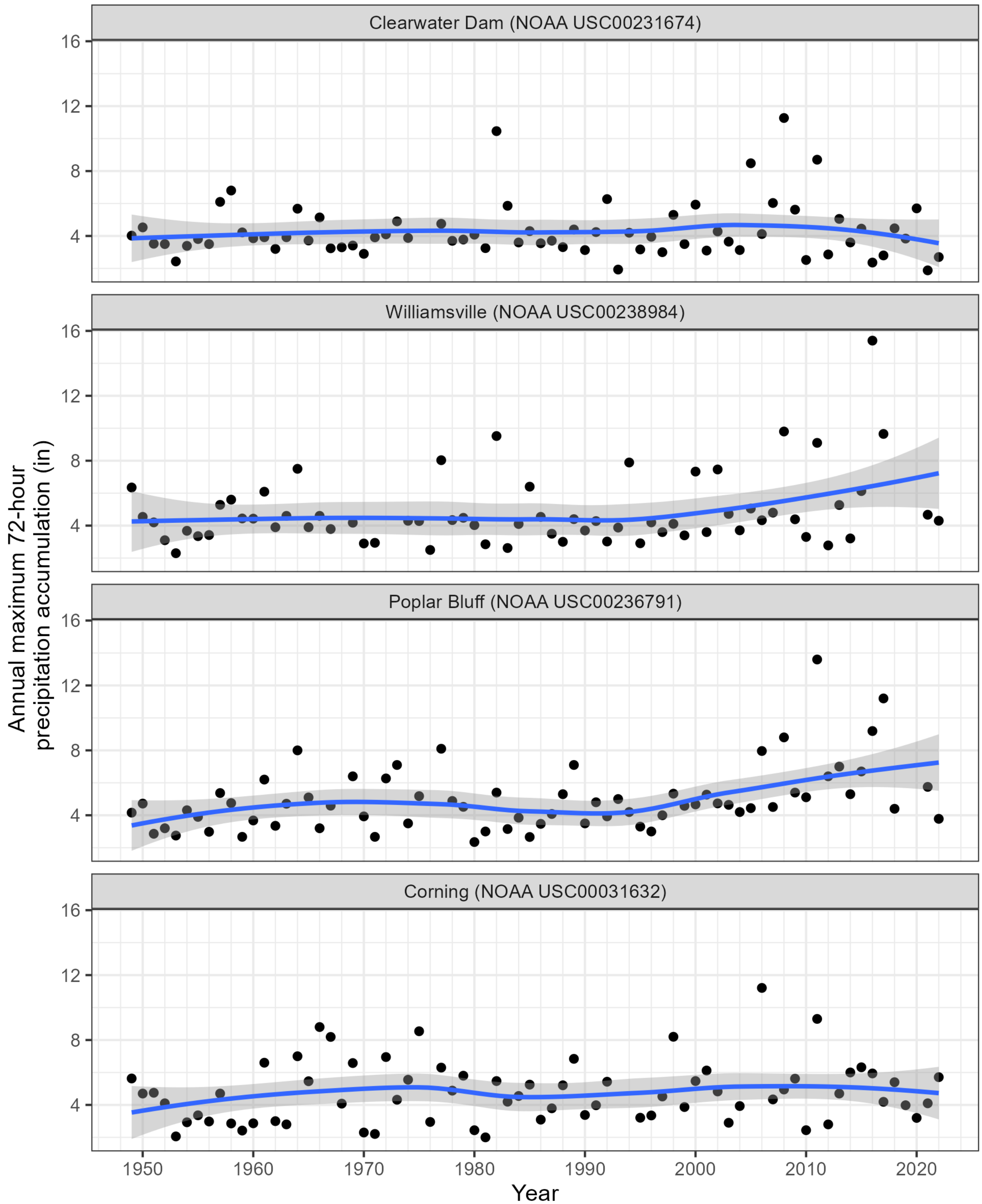

Figure 6 Plots showing annual maximum 72-hour precipitation accumulation for precipitation gauges at Clearwater Dam, Williamsville, Poplar Bluff, and Corning.

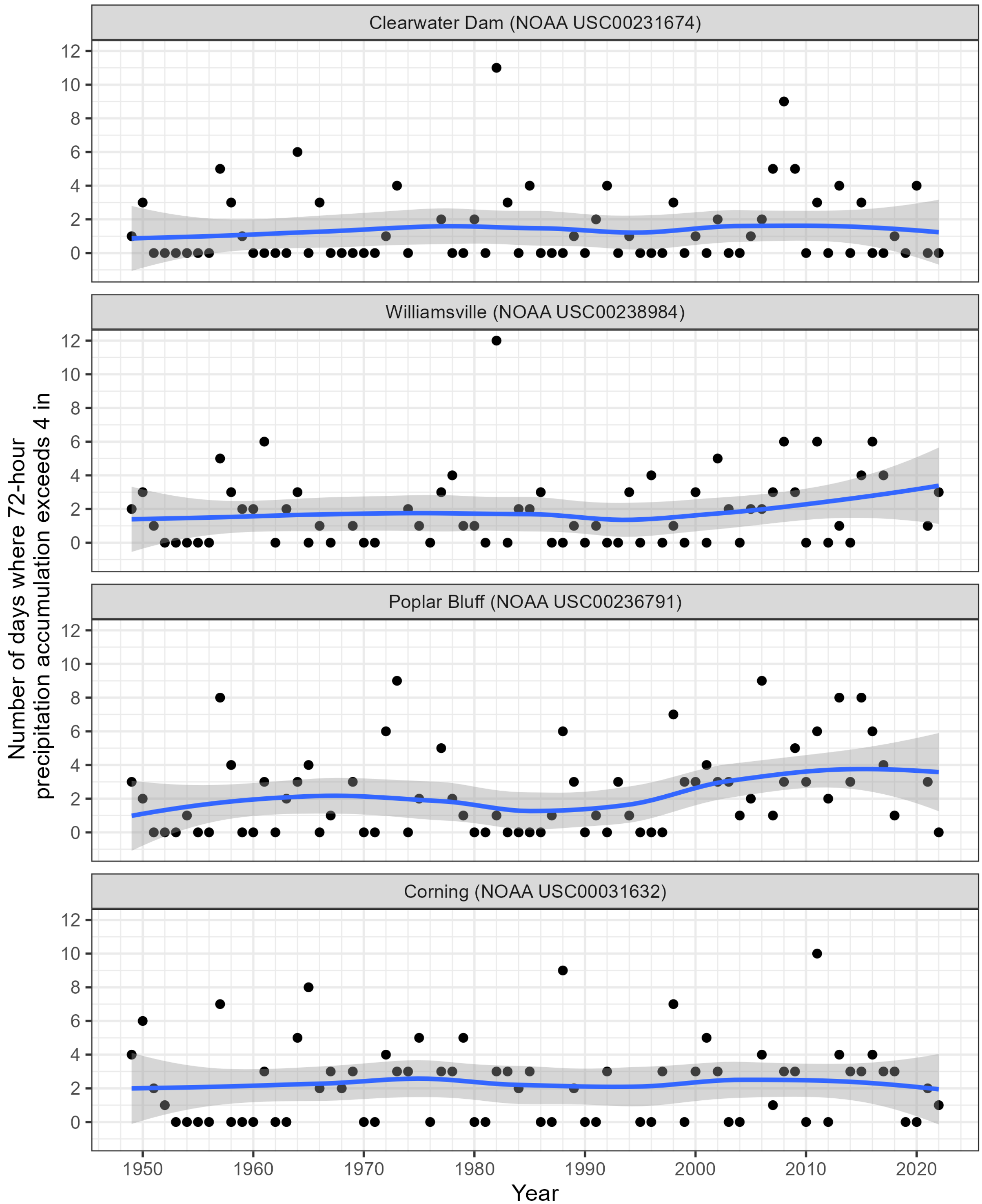

Figure 7 Plots showing number of days where rolling averages of 72-hour precipitation accumulation have exceeded 4 inches for precipitation gauges at Clearwater Dam, Williamsville, Poplar Bluff, and Corning.

The precipitation gauge at Poplar Bluff has experienced the most significant changes in the annual total precipitation, precipitation intensity (72-hour precipitation accumulation), and frequency of high intensity precipitation events (number of days per year where the rolling average of 72-hour precipitation accumulation exceeds 4 inches). The Mann-Kendall test for monotonic trends was applied to precipitation data for the Poplar Bluff precipitation gauge for all available data from 1894 to 2022 was used to determine the statistical significance of changes in precipitation over time. A positive value of Kendall's tau means a trend is increasing and if the significance level of the value of Kendall's tau is less than 0.05, the trend is considered to be statistically significant. Results from the Mann-Kendall test for precipitation for annual maximum 1 to 3 day precipitation accumulations and for annual total accumulation for the precipitation gauge at Poplar Bluff (NOAA USC00236791) are listed in Table 1 and plotted in Figures 7 through 10.

Table 1 Precipitation trends for the precipitation gauge at Poplar Bluff, MO (NOAA USC00236791). The Kendall's tau value represents the slope of the trend and a significance level of less than 0.05 means that the trend is statistically significant.

Precipitation series	Kendall's tau	Significance level
Annual maximum 24-hour accumulation	0.19	0.003
Annual maximum 48-hour accumulation	0.20	0.001
Annual maximum 72-hour accumulation	0.19	0.002
Annual total accumulation	0.12	0.04

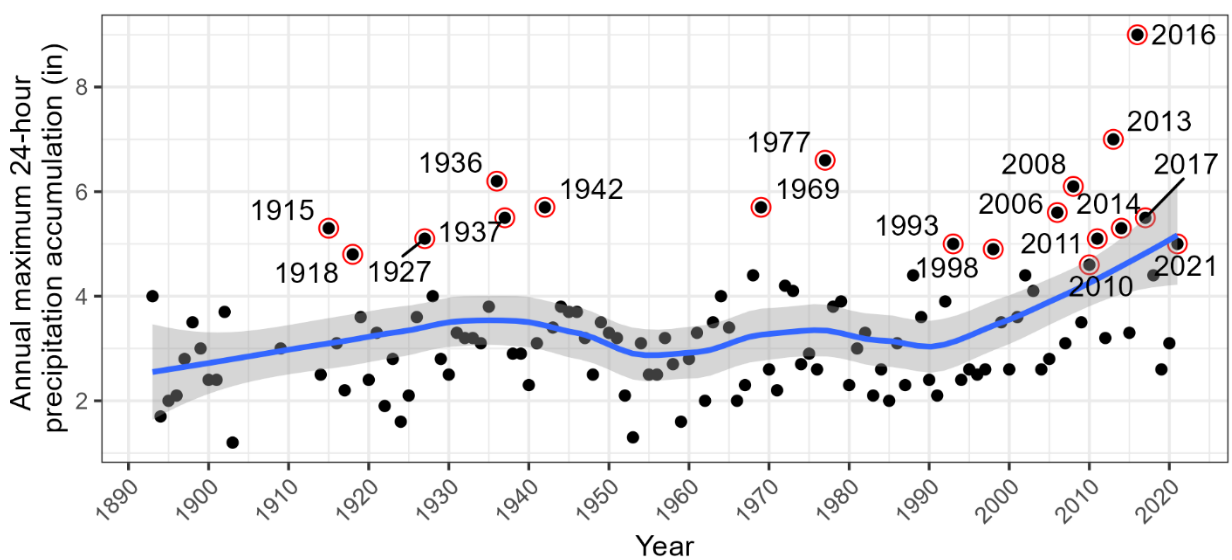

Figure 8 Annual maximum 24-hour precipitation accumulations for the precipitation gauge at Poplar Bluff, MO (NOAA USC00236791). Values above 4.5 inches are highlighted.

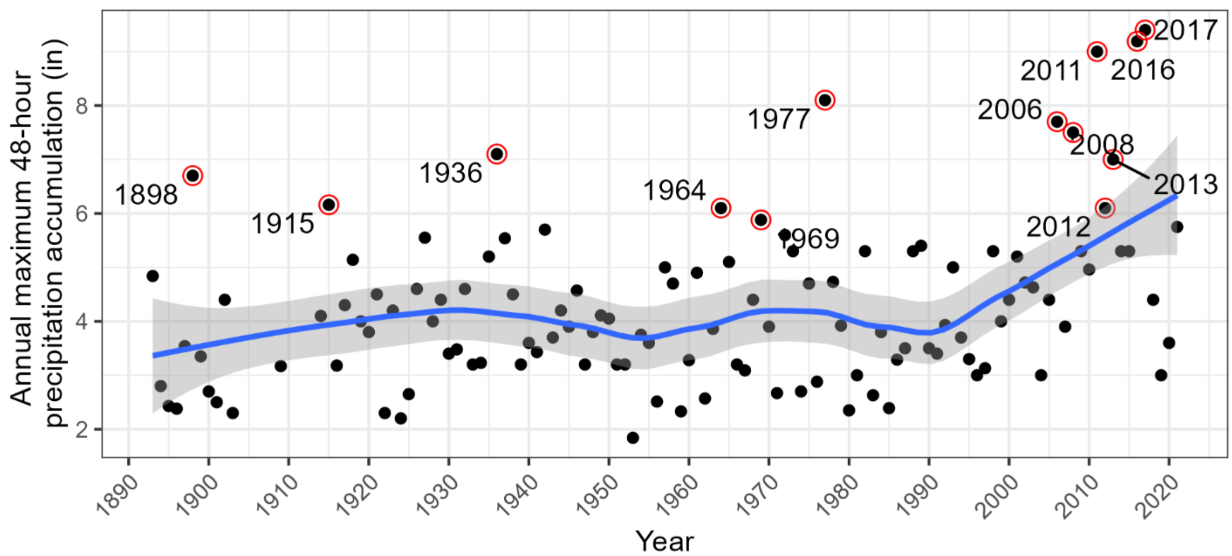

Figure 9 Annual maximum 48-hour precipitation accumulations for the precipitation gauge at Poplar Bluff, MO (NOAA USC00236791). Values above 5.8 inches are highlighted.

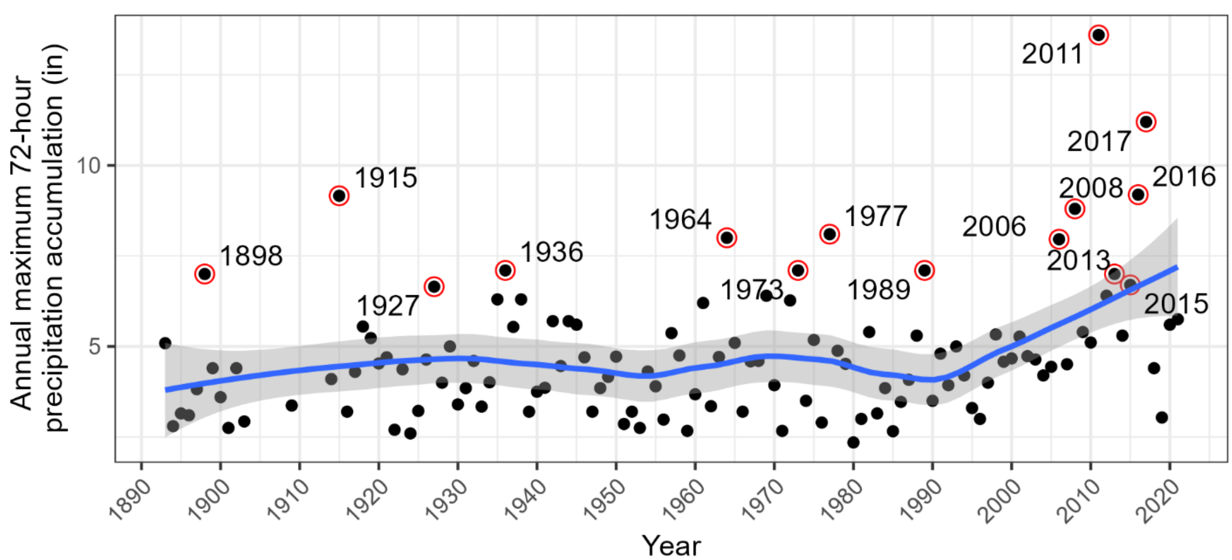

Figure 10 Annual maximum 72-hour precipitation accumulations for the precipitation gauge at Poplar Bluff, MO (NOAA USC00236791). Values above 6.5 inches are highlighted.

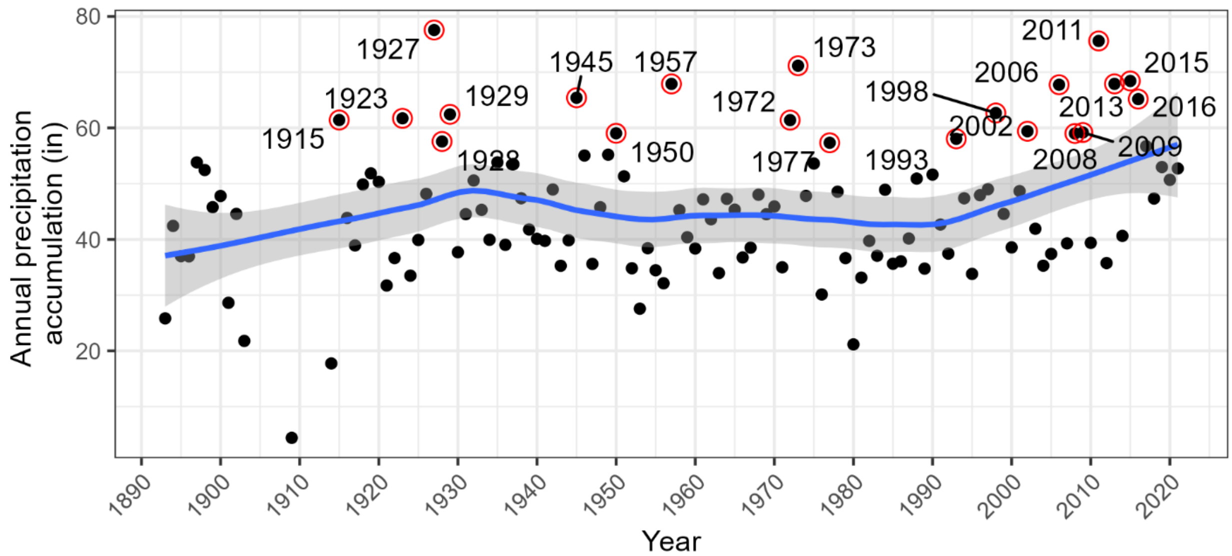

Figure 11 Annual total precipitation accumulations for the precipitation gauge at Poplar Bluff, MO (NOAA USC00236791). Values above 58 inches are highlighted.

Increasing precipitation leads to increasing streamflows. Streamflows at three USGS streamflow gaging stations (streamgages, fig. 3) were evaluated for annual and seasonal trends in baseflow, total flow, and runoff. The streamgages used for evaluation are USGS 07061500 Black River near Annapolis, MO (484 mi^2 drainage area), USGS 07063000 Black River at Poplar Bluff, MO (1,245 mi^2 drainage area), and USGS 07064000 Black River near Corning, AR (1,750 mi^2 drainage area). The PART method (Rutledge, 1998) was used for baseflow separation. Baseflow refers to the portion of total flow that is contributed from groundwater. Runoff refers to the portion of total flow that is contributed from overland flow that enters the stream resulting from precipitation that does not infiltrate soil or go into storage. Table 2 lists selected results from the Mann-Kendall test for monotonic trends for annual and seasonal trends in baseflow, total flow, and run-off. For this analysis, daily mean streamflow values were used and only the period or record after 1948, when Clearwater Dam was constructed, was used for evaluation of streamflow trends.

Upstream of Clearwater Dam, the streamflow gaging station USGS 07061500 Black River near Annapolis, MO is experiencing increased trends in annual mean and annual minimum baseflows as well as total flows. Increasing trends in Spring and Summer total flows and baseflows are also observed. This indicates that the total volume of streamflow that is flowing into Clearwater Lake is increasing, thus requiring Clearwater Lake to release higher volumes of streamflow into the Black River downstream of Clearwater Dam. Downstream of Clearwater Dam, more increasing trends in annual and seasonal streamflow metrics are observed at the streamflow gaging station USGS 07063000 Black River at Poplar Bluff, MO. These increasing trends are a direct result of increased flow into Clearwater Lake combined with an increase in precipitation in the areas between Poplar Bluff, MO and Clearwater Dam, as shown above in the analysis of precipitation data. At the most downstream streamflow gaging station USGS 07064000 Black River near Corning, AR increasing trends are being observed in the annual and seasonal streamflow metrics, as well as increasing trends in runoff, which were not observed at the two upstream streamflow gaging stations. This increase in runoff at the downstream streamflow gaging station is due to the increase in precipitation around the Poplar Bluff precipitation gauge location.

Table 2 Trends in streamflow for USGS streamflow gaging stations.

USGS Site Number	Period	Flow Component	Kendall's tau	Significance Level	Sen's Slope	Median Flow Value (ft^3/s)	Annual Rate of Change
07061500	Annual Mean	Total	0.171	0.03	2.98	584	0.51
07061500	Annual Mean	Baseflow	0.223	0.0047	1.66	347	0.48
07061500	Annual Minimum	Total	0.321	5.20E-05	0.696	112	0.62
07061500	Spring	Baseflow	0.189	0.017	2.24	459	0.49
07061500	Summer	Total	0.18	0.024	1.09	205	0.53
07061500	Summer	Baseflow	0.243	0.0023	0.991	171	0.58
07063000	Annual Mean	Total	0.265	0.00079	9.97	1380	0.72
07063000	Annual Mean	Baseflow	0.315	6.60E-05	8.35	978	0.85
07063000	Annual Minimum	Total	0.312	7.60E-05	2.14	366	0.58
07063000	Annual Maximum	Total	0.158	0.046	36.8	6900	0.53
07063000	Winter	Total	0.157	0.049	8.24	1770	0.47
07063000	Winter	Baseflow	0.239	0.0027	7.51	1220	0.61
07063000	Spring	Total	0.209	0.0085	14.2	1820	0.78
07063000	Spring	Baseflow	0.245	0.002	11.6	1270	0.91
07063000	Summer	Total	0.258	0.0012	4.59	643	0.71
07063000	Summer	Baseflow	0.292	0.00024	3.94	530	0.74
07063000	Fall	Total	0.203	0.011	6.77	961	0.7
07063000	Fall	Baseflow	0.287	3.00E-04	5.25	678	0.77
07064000	Annual Mean	Total	0.198	0.012	11.1	1880	0.59
07064000	Annual Mean	Baseflow	0.187	0.018	7.53	1450	0.52
07064000	Annual Mean	Runoff	0.212	0.0072	3.3	443	0.75
07064000	Annual Minimum	Total	0.166	0.035	1.22	372	0.33
07064000	Spring	Total	0.166	0.04	16.7	2430	0.69
07064000	Spring	Runoff	0.188	0.02	4.66	457	1
07064000	Summer	Total	0.268	9.00E-04	6.79	743	0.91
07064000	Summer	Baseflow	0.183	0.023	3.69	598	0.62
07064000	Summer	Runoff	0.354	1.10E-05	2.17	114	1.9
07064000	Fall	Runoff	0.172	0.033	3.14	266	1.2

Clearwater Dam Operations

Clearwater Dam operations under a USACE approved operational manual that was developed using historic and current hydrologic data as well as relevant land use information such as dwellings, agriculture and businesses located downstream of the Dam. . As part of this study, numerous release scenarios were evaluated to examine whether or not Clearwater Dam could be operated such that the high flows in the Black River in Butler Co, MO could be minimized to reduce the level of flooding occurring in the agriculture areas of the Basin downstream of Poplar Bluff. Several operational scenarios were suggested by local stakeholders and were evaluated using the USACE RiverWare hydrologic modeling software. RiverWare is a river system modeling tool that can evaluate various operational scenarios simultaneously through rule-based simulations. Some of the suggested scenarios and their respective results are described below.

The construction of the project began before the National Geodetic Survey (NGS) monument was certified, resulting in a datum bust that was not discovered and recorded until May 2019. An unofficial memo was written by the Little Rock District on the discovery of the datum bust. The datum that Clearwater dam was built in is referred to as Construction Datum. The conversion from Construction Datum to NGVD29 is +0.487 ft. The conversion between NGVD29 to NAVD88 is -0.02. The water levels in this report for Clearwater Dam are described in the Construction Datum as those reporting levels are more commonly known to the local stakeholders. Water levels described as Construction Datum are not to be used for any type of regulatory or real estate elevations.

Current Operations

Varying seasonal conservation pool elevations for Clearwater Lake exist to control habitat and conditions in shallow areas of the upper portions of Clearwater Lake. From May 1st to June 1st, the conservation pool elevation is 498 ft Construction Datum. From June 1st to September 15th, the conservation pool elevation is lowered to 496.5 ft Construction Datum. From September 15th to October 8th, the conservation pool is lowered from 496.5 to 494 ft Construction Datum. From October 8th to May 1st, the conservation pool remains at 494 ft Construction Datum. The streamflow gaging station USGS 07063000 Black River at Poplar Bluff, MO is used as the regulating station for Clearwater Lake. During the agricultural season, from April to November, a regulating stage of 10.5 ft gage datum (or ~4,400 ft^3/s) is used to guide releases from Clearwater Dam. During the winter period, from December to March, a regulating stage of 11.5 ft gage datum (or ~4,800 ft^3/s) is used to guide releases from Clearwater Dam. However, because of developments that occurred below Clearwater Dam, releases greater than 3,800 ft^3/s cause damages to homes and infrastructure downstream of the project.

When water surface elevations for Clearwater Lake are near the top of the seasonal conservation pool elevation;

- Maintain the lake level near the top of the conservation pool
- Release lake inflow in accordance with regulating stage at Poplar Bluff, MO
- Release minimum flow of 150 cfs during periods of “low” inflow to provide for fishery, aquatic life and City of Poplar Bluff water supply needs, or periods of downstream flooding.

When water surface elevations are in the flood pool (above the seasonal conservation pool elevation but below the spillway crest of 567 ft Construction Datum);

- Make sufficient releases to return the lake level to 494.0 Construction Datum in a prudent length of time
- Releases are limited by Poplar Bluff seasonal regulating stages and safe limits for homes immediately below dam (3800 cfs)
- Maintain a stage at or below 11.5 ft gage datum (Dec-Mar) or 10.5 ft gage datum (Apr-Nov) at Poplar Bluff streamgage until the flood control pool is evacuated.

When the water surface elevation in Clearwater Lake is forecasted to exceed the spillway crest (567 ft Construction Datum);

- Make releases necessary to reduce the flood crest stage at Poplar Bluff if the Black River is forecasted to crest above the regulating stage
- Use available surcharge storage up to 574.0 Construction Datum to provide the greatest amount of flood crest reduction at Poplar Bluff.

When the water surface elevation in Clearwater Lake is forecasted to exceed the top of surcharge storage (574 ft Construction Datum);

- Make sufficient releases to prevent the lake from exceeding a water surface elevation of 574 ft Construction Datum
- Increase releases only to a practicable limit – consider benefits and damages upstream and downstream of the dam
- After lake level has crested and spillway flows begin to decrease, reduce releases to maintain the lake level near 574 ft Construction Datum until lake inflows recede below the spillway flow
- As river levels recede increase releases to maintain the seasonal regulating stage of 10.5 or 11.5 ft at the Poplar Bluff streamgage.

Emergency Operations

When Clearwater Lake water surface elevation exceeds 555 ft Construction Datum, USACE personnel monitor piezometers on the earthen embankment dam daily, check for seepage through the earthen embankment daily. If the water surface elevation is above 555 ft Construction Datum and rising, USACE personnel are monitoring inflows, rainfall, and other conditions remotely and on-site at the dam 24 hours a day. If the water surface elevation of Clearwater Lake is between 540 and 555 ft Construction Datum, USACE personnel are monitoring piezometers on the earthen embankment weekly. Monthly monitoring of piezometers occurs when water surface elevations for Clearwater Lake are below 540 ft Construction Datum.

Scenarios

Alternate operational scenarios are listed below. Many scenarios were tested with different combinations of reduction of regulation stages at the Poplar Bluff streamflow gaging station during the growing season and increases to the Poplar Bluff streamflow gaging station during the non-growing season along with changing operational levels within Clearwater Lake to use more or less storage during the growing season and the non-growing season. Results for alternate operational scenarios, as they pertain to Clearwater Dam and the Poplar Bluff streamflow gaging station are listed in Tables 3 and 4. The RiverWare model used to evaluate these scenarios on a daily time-step from Jan 2nd, 1940 to Jan 1st, 2018. It should be noted that many more scenarios were evaluated as part of this study, but the results were identical to the ones presented below. In order to save time and space, not all of the evaluations are being listed in this report.

- Scenario 1
    - Reduce the regulating stage at the Poplar Bluff streamflow gaging station to 5.5 ft gage datum (~2,240 ft^3/s) from May 15th to Oct 31st
    - Increase the regulating stage at the Poplar Bluff streamflow gaging station to 12 ft gage datum (~4,800 ft^3/s) from Nov 1st to May 14th
    - Guide curve for regulating discharges at Poplar Bluff streamflow gaging station becomes:
        - 4,800 ft^3/s - Apr 01
        - 4,380 ft^3/s - Apr 02
        - 2,240 ft^3/s - May 15
        - 2,240 ft^3/s - Oct 31
        - 4,380 ft^3/s - Dec 01
        - 4,800 ft^3/s - Dec 02
- Scenario 4
    - Reduce the regulating stage at the Poplar Bluff streamflow gaging station to 5.5 ft gage datum (~2,240 ft^3/s) from May 15th to Oct 31st
    - Increase the regulating stage at the Poplar Bluff streamflow gaging station to 12.6 ft gage datum (~5,100 ft^3/s) from Nov 1st to May 14th
    - Guide curve for regulating discharges at Poplar Bluff streamflow gaging station becomes:
        - 5,100 ft^3/s - Apr 01
        - 4,880 ft^3/s - Apr 02
        - 2,240 ft^3/s - May 15
        - 2,240 ft^3/s - Oct 31
        - 4,880 ft^3/s - Dec 01
        - 5,100 ft^3/s - Dec 02
- Scenario 5
    - Reduce the regulating stage at the Poplar Bluff streamflow gaging station to 5.5 ft gage datum (~2,240 ft^3/s) from May 15th to Oct 31st

- Increase the regulating stage at the Poplar Bluff streamflow gaging station to 14.4 ft gage datum (~6,000 ft^3/s) from Nov 1st to May 14th
    - Guide curve for regulating discharges at Poplar Bluff streamflow gaging station becomes:
        - 6,000 ft^3/s - Apr 01
        - 5,100 ft^3/s - Apr 02
        - 2,240 ft^3/s - May 15
        - 2,240 ft^3/s - Oct 31
        - 5,100 ft^3/s - Dec 01
        - 6,000 ft^3/s - Dec 02
        -
- Scenario 6
    - Reduce the regulation stage at the Poplar Bluff streamflow gaging station to 5.5 ft gage datum (~2,240 ft^3/s) from May 15th to Oct 31st
    - Increase the regulation stage at the Poplar Bluff streamflow gaging station to 12 ft gage datum (~4,800 ft^3/s) from Nov 1st to May 14th
    - Increase the top of conservation pool water surface elevation from 498 to 510 ft Construction Datum from May 15th to Oct 31st
    - Decrease the top of conservation pool water surface elevation from 496.5 to 494 ft Construction Datum from Nov 1st to May 14th
    - Guide curve for regulating discharges at Poplar Bluff streamflow gaging station becomes:
        - 4,800 ft^3/s - Apr 01
        - 4,380 ft^3/s - Apr 02
        - 2,240 ft^3/s - May 15
        - 2,240 ft^3/s - Oct 31
        - 4,380 ft^3/s - Dec 01
        - 4,800 ft^3/s - Dec 02
- Scenario 7
    - Reduce the regulating stage at the Poplar Bluff streamflow gaging station to 5.5 ft gage datum (~2,240 ft^3/s) from May 15th to Oct 31st
    - Increase the regulating stage at the Poplar Bluff streamflow gaging station to 12 ft gage datum (~4,800 ft^3/s) from Nov 1st to May 14th
    - Increase the top of conservation pool water surface elevation from 498 to 520 ft Construction Datum from May 15th to Oct 31st
    - Decrease the top of conservation pool water surface elevation from 496.5 to 494 ft Construction Datum from Nov 1st to May 14th
    - Guide curve for regulating discharges at Poplar Bluff streamflow gaging station becomes:
        - 5,100 ft^3/s - Apr 01
        - 4,880 ft^3/s - Apr 02
        - 2,240 ft^3/s - May 15
        - 2,240 ft^3/s - Oct 31
        - 4,880 ft^3/s - Dec 01

- 5,100 ft^3/s - Dec 02

Table 3 Days above elevations related to emergency operations at Clearwater Dam resulting from RiverWare models using the current 'Base' operations and several alternate operational scenarios.

Scenario	Days Above 567 ft Construction Datum	Days Above 555 ft Construction Datum	Days Above 540 ft Construction Datum	Maximum ft Construction Datum
Base	19	197	446	569.43
Scenario 1	73	424	921	569.81
Scenario 2	129	517	1112	571.07
Scenario 3	73	424	921	569.81
Scenario 4	64	370	846	569.61
Scenario 5	58	350	808	569.33
Scenario 6	82	428	962	569.81
Scenario 7	82	428	1012	569.81
Scenario 8	59	355	851	569.33
Scenario 9	59	355	902	569.33
Scenario 10	65	384	837	569.76
Scenario 11	69	388	873	569.76
Scenario 12	49	280	752	569.21
Scenario 13	56	351	763	569.71
Scenario 14	58	355	793	569.71
Scenario 15	44	290	700	569.33
Scenario 16	51	324	709	569.65
Scenario 17	51	327	735	569.65
Scenario 18	39	264	643	569.33

Table 4 Days above specified gage heights at the Poplar Bluff streamgage resulting from RiverWare models using the current 'Base' operations and several alternate operational scenarios.

Scenario	Days Above 5 ft gage datum	Days Above 12 ft gage datum	Days Above 16 ft gage datum	Days Above 19 ft gage datum	Days Above 21 ft gage datum	Maximum Elevation in ft gage datum
Base	5646	285	104	19	5	24.28
Scenario 1	7157	294	107	19	5	24.28
Scenario 2	7593	290	115	21	5	24.28
Scenario 3	7157	294	107	19	5	24.28
Scenario 4	7027	634	107	19	5	24.28
Scenario 5	6947	763	105	19	5	24.28
Scenario 6	6950	290	107	19	5	24.28
Scenario 7	6718	290	107	19	5	24.28

Scenario 8	6769	736	105	19	5	24.28
Scenario 9	6546	727	105	19	5	24.28
Scenario 10	6945	293	107	19	5	24.28
Scenario 11	6748	289	107	19	5	24.28
Scenario 12	6529	797	106	19	5	24.28
Scenario 13	6743	291	107	19	5	24.28
Scenario 14	6535	287	107	19	5	24.28
Scenario 15	6358	729	105	19	5	24.28
Scenario 16	6532	289	106	19	5	24.28
Scenario 17	6330	285	106	19	5	24.28
Scenario 18	6157	724	105	19	5	24.28

A central theme amongst the operational scenarios that were requested for evaluation related to decreasing regulating stages at the Poplar Bluff streamflow gaging station during the growing season and increasing the regulating stage at the Poplar Bluff streamflow gaging station during the non-growing season for the purpose of creating more storage during the growing season. For all scenarios evaluated, minimizing releases during the growing season led to an increased frequency of spillway overtopping at Clearwater Dam, as well as increased the number of days at which water surface elevations require 24-hour surveillance of Clearwater Dam. Because of the increased amount of uncontrolled spill from Clearwater Dam and the increased number of days at high elevations at Clearwater Dam, more days above 5 ft gage datum at the Poplar Bluff streamflow gaging station occur.

Groundwater

Within the study area in Butler Co, MO, Dr. Joshua Blackstock from the University of Arkansas conducted analyses to specifically evaluate interactions between the Black River and the surrounding alluvial aquifer. As a part of this evaluation, groundwater sources within alluvial aquifer were evaluated. Results from Dr. Blackstock's work were used to inform a model used to evaluate interaction between surface water and groundwater in areas adjacent to the Black River.

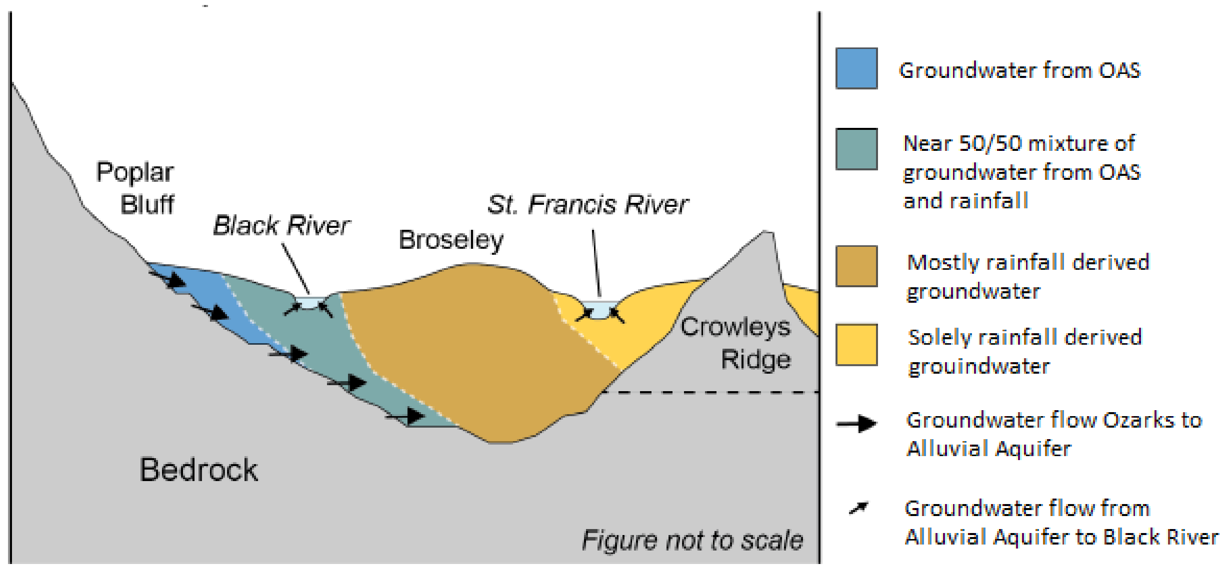

Figure 12 Conceptual groundwater sources within the alluvial aquifer in and around the study area. Divisions are approximated.

Groundwater Study

Findings from the groundwater study are summarized by Dr. Blackstock here. The combination of increased rainfall over the Mississippi Alluvial Plain (MAP) and groundwater contributions from the Ozark Aquifer System (OAS) have likely maintained groundwater storage in the alluvial aquifer but have also increased flood risk from runoff and groundwater. Despite increases in groundwater use over the last 50 years in the alluvial aquifer, spring groundwater levels have not declined at long-term groundwater level monitoring sites. As noted in prior investigations of the OAS (Hays et al. 2016), simulated groundwater recharge to the OAS has increased through time. As such, groundwater contributions to the alluvial aquifer may have also increased. With sustained spring groundwater levels, but increased rainfall totals over the alluvial aquifer, greater amounts of groundwater that intersects drainage networks in the Mississippi Alluvial Plain decrease the drainage capacity during rain events, i.e. increased baseflow. Therefore, the increased OAS contributions and rainfall over the MAP that decrease drainage capacity conversely increase the flood risk of surface waters like the Black River along the OAS-MAP boundary.

Groundwater transfers from the Ozark Aquifer System (OAS) to the alluvial aquifer as determined from geochemical mixing models are relatively significant and must be accounted in numerical modeling. While prior simulations of the alluvial aquifer have been largely ignored, calculations of mixing between rainfall-derived groundwater and OAS end-members indicate some localities where groundwater in the alluvial is estimated to be 50% groundwater. It is highly recommended that future researchers account for these contributions when simulating surface water-groundwater interactions, general hydrology, and regional water availability scenarios using groundwater models. Without accurate accounting of these water fluxes at model boundaries, parameter estimations and potential future scenario models will be fundamentally inaccurate.

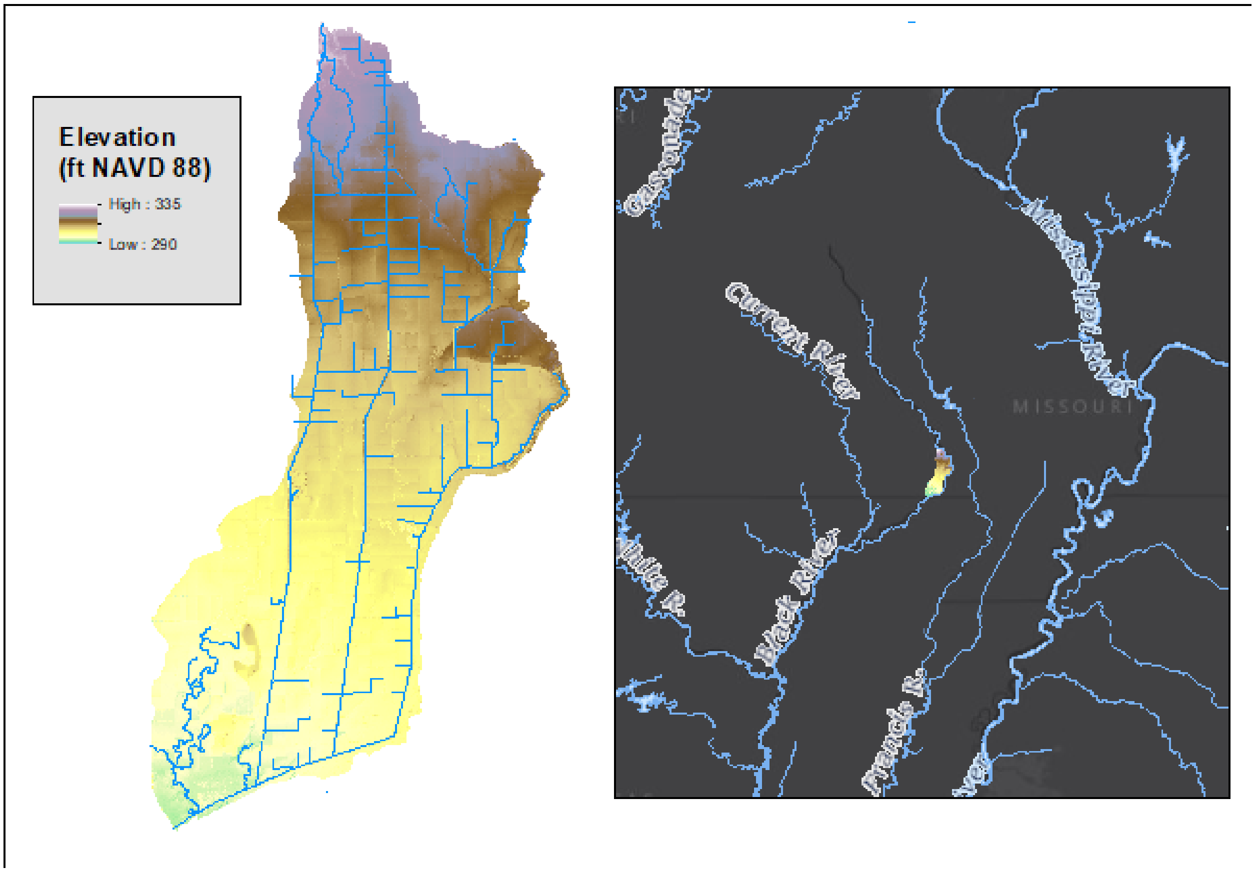

Figure 13 Area of Butler Co, MO where GSSHA model was developed.

GSSHA Modeling

In order to evaluate potential mitigation strategies related to surface water and groundwater within areas adjacent to the Black River in Butler Co, MO, a Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model was developed (fig. 12). The GSSHA model was used to test the effectiveness of cleaning out ditches, increasing slopes of some ditches, and installing 2-stage ditches in some locations in alleviating issues associated with high groundwater conditions, or seeps, that affect the lower lying areas adjacent to the Black River.

The period from April 1st, 2021 to May 31st, 2021 was used to evaluate modifications to the study area with a series of GSSHA models used for comparison of relative differences in scenarios. For the initial model, trapezoidal channels were used to represent the ditches in the study area. The shapes, sizes, and roughness of trapezoidal channels were estimated from LiDAR data and from aerial imagery. For the long-term simulation, air pressure, sky cover, wind speed, and temperature data were obtained from the NOAA station at Dyersburg Municipal Airport and direct radiation and global radiation were obtained from NASA gridded data. Precipitation data were obtained from NOAA Stage IV radar and were spatially distributed across the modeled area (fig. 12). For long-term simulation in GSSHA, the Penman-Monteith method was used for evapotranspiration processes.

For the GSSHA model, the bottom of the aquifer system was estimated to be 30 meters below the land surface. The initial water surface elevations for the groundwater component of the GSSHA model was developed by Dr. Blackstock and were intended to represent typical springtime conditions. Distributed spring groundwater levels estimated for the alluvial aquifer and OAS model boundary are derived from interpolation of: 1, a spatially dense groundwater level measuring campaign; and 2, averaging of available groundwater level data along the MAP-OAS border. The spatially dense groundwater level measuring survey stems from works by Fuller and Luckey (1980) from measurements made in the spring 1976. To the knowledge of the authors, this is one of the most spatially dense groundwater level surveys conducted in the MAP. Use of these historical data are warranted given spring groundwater levels in the region have shown no declines, as previously mentioned. Therefore, these groundwater levels are likely representative of regional conditions. The selected groundwater level for the MAP-OAS boundary was calculated from the mean of limited groundwater level data along the boundary, i.e. the “fall line”. To represent loading on the levee on the eastern boundary of the study area, a HEC-RAS 2D model was used to create a water surface profile for 4,400 ft^3/s (which is about 11.07 ft gage datum at the Poplar Bluff streamgage). The water surface elevation from the RAS model used to represent the groundwater surface elevation along the levees on the eastern boundary of the study area (fig. 13).

For the GSSHA scenarios, slope was added to Black River ditch and the lower portion of Big Hunting Slough. Slope was also added to the part of the Dan River channel and Ackerman Ditch. At the terminus of Big Hunting Slough, channel depth was increased by 1.8 meters and that slope was carried up Big Hunting Slough and Black River Ditch over 8 miles. Some were increased in size where they were deemed insufficient to pass the 1% AEP flows estimated using regional regression equations (RREs) from Southard and Veilleux, 2014. It should be noted that, for this analysis, RREs for region 3 were used to estimate 50% and 1% peak streamflows (fig. 14, table 5). While the study area technically lies in region 2 from Southard and Veilleux, 2014, the slopes and landscape of the study area are better represented by region 3. Environmental ditches were added to the model and the stages of the ditches were designed around the flows estimated from RREs.

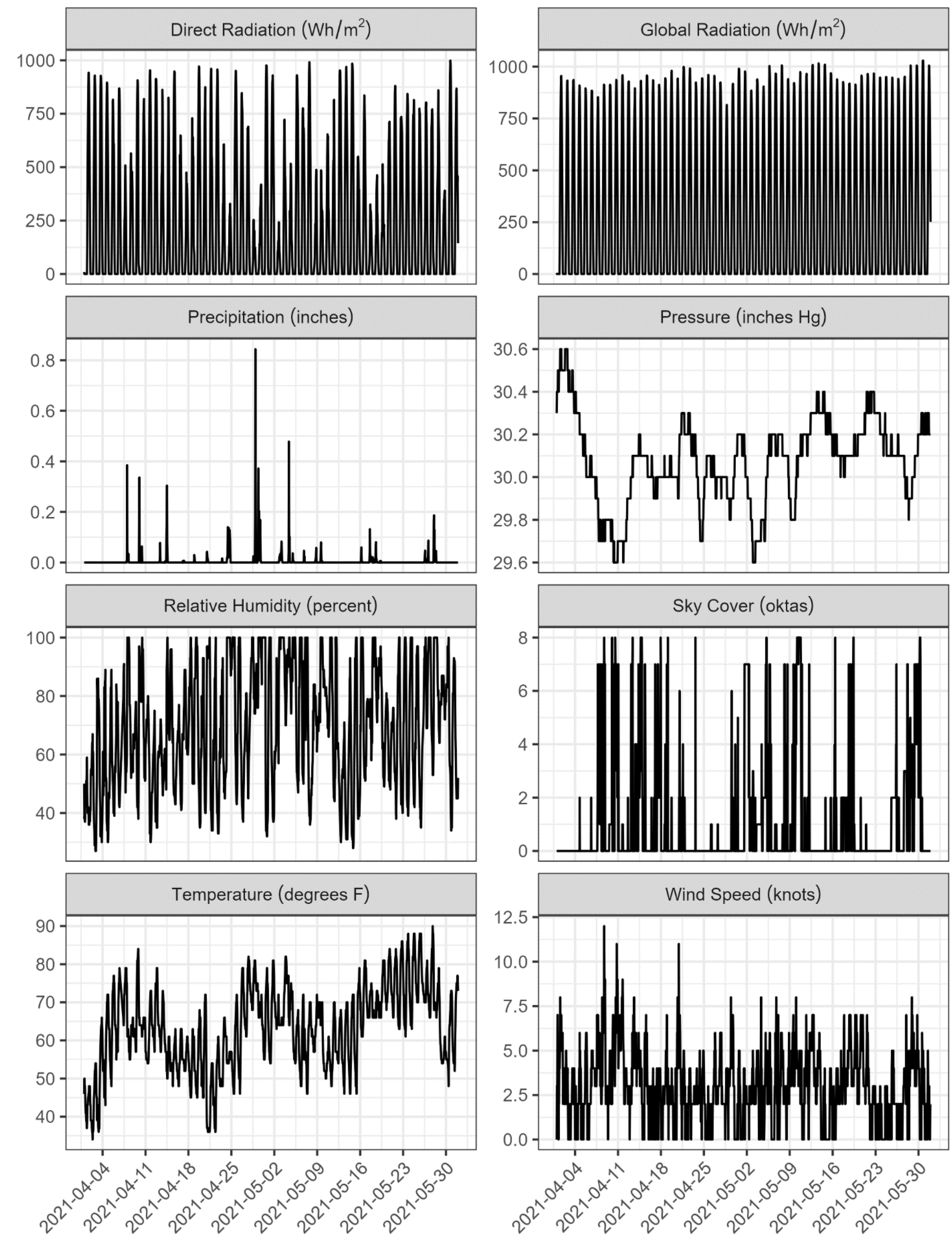

Figure 14 Climate data used for long-term simulation in GSSHA

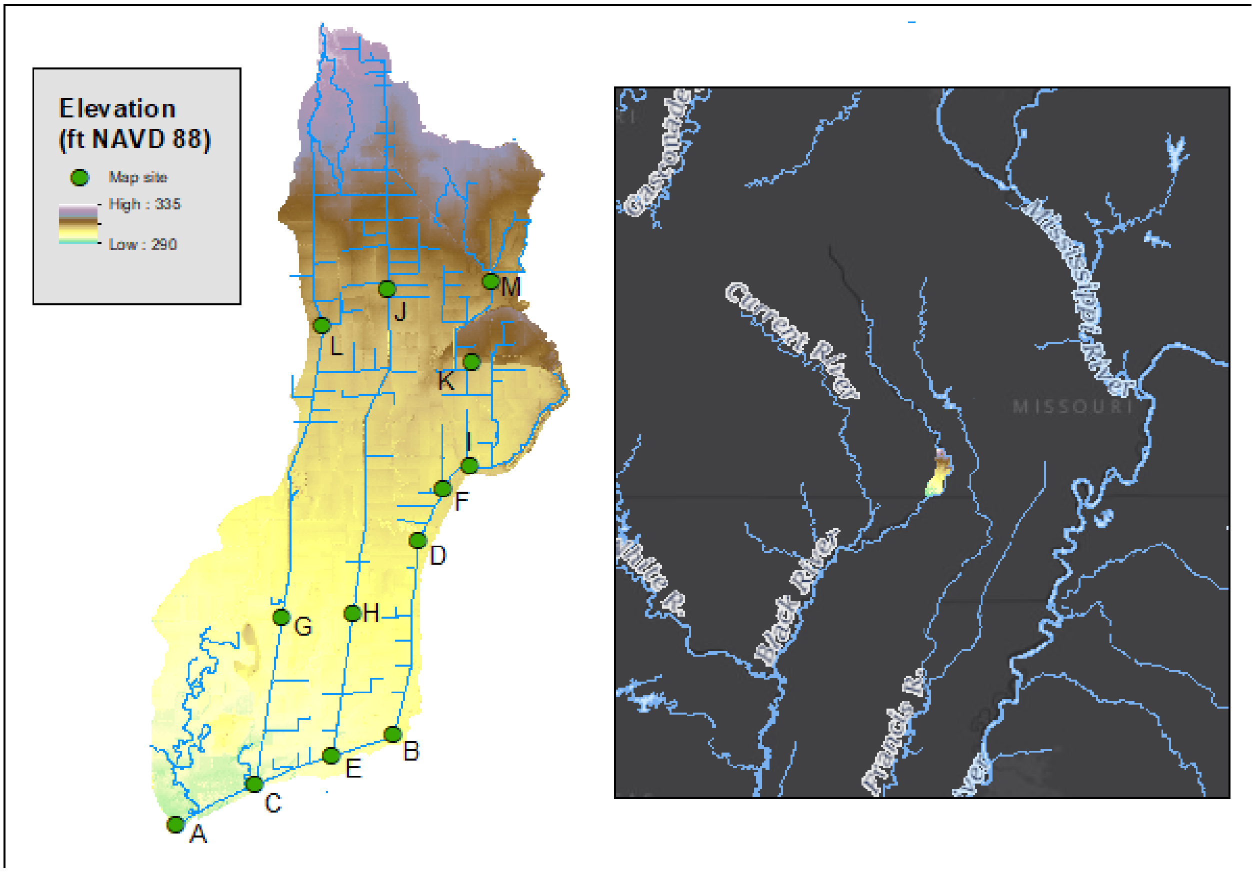

Figure 15 Map showing initial groundwater elevations for GSSHA model.

Table 5 Basin characteristics and peak streamflows for selected locations within the study area.

Map site	Drainage area (mi^2)	Basin shape factor (dimensionless)	Channel slope 10-85 (ft/mi)	Longest flow path length (mi)	50% AEP peak streamflow (ft^3/s)	1% AEP peak streamflow (ft^3/s)
A	69	7.88	1.23	23.31	1430	2910
B	20.4	16.41	1.28	18.32	637	1230
C	20	14.79	2.03	17.2	628	1210
D	18.1	11.27	1.49	14.29	588	1130
E	14.9	16.66	1.96	15.74	517	983
F	14.4	11.8	1.46	13.05	505	960
G	14.4	13.15	2.35	13.74	505	960
H	12.2	13.45	2.14	12.81	452	853
I	11.5	13.13	1.29	12.28	435	818
J	7.94	4.61	3.53	6.05	340	630
K	7.81	10.47	1.52	9.04	336	622
L	6.43	9	3.6	7.61	295	542
M	5.02	6.34	2.03	5.64	251	455

Results from the base and modified GSSHA models showed increases in baseflow from an average of 38 ft^3/s to an average of 64 ft^3/s exiting the modeled area through Big Hunting Slough (fig. 14, Map site A) and reductions in groundwater surface elevations across the model domain. This analysis was intended to show relative differences in these scenarios and it should be noted that no attempt was made to represent culverts in the model. Groundwater surface reductions averaged about 0.5 meters across the modeled area. Local groundwater surface elevation reductions were higher where 2-stage ditches were added, as the addition of a deeper channel with a smoother surface helped to reduce groundwater surface elevations relatively quickly where 2-stage ditches were added to the GSSHA model.

Surface Water Hydraulic Analysis

The objective of the hydraulic modeling and analysis was to aid in evaluating and development of various scenarios primarily along the mainstem Black River to allow the study partners to understand the timing, magnitude, and duration of water levels. The results of the initial scenarios, in tandem with the context of the other portions of the study as they progressed, allowed for additional scenario development and refinement through multiple partner meetings to communicate potential benefits and impacts.

Model Formulation

A two-dimensional, unsteady HEC-RAS model was developed and used for the hydraulic analysis. HEC-RAS is a robust and flexible model reliant on bathymetric and topographic data throughout the model domain and upon hydraulic properties at all boundaries as well as within the model domain. The most important hydraulic properties in this application of HEC-RAS are water surface elevation (stage) and cross-sectional discharge (flow). The most accurate data reasonably obtainable were used for the model development. The final model used the officially released HEC-RAS version 6.1. HEC-RAS 6.1 contains a 2D finite-volume algorithm that solves either the full 2D Saint Venant equations or the 2D diffusive wave equations. The grids for the 2D areas are discretized, and an elevation-volume relationship is computed for each cell based on the underlying terrain and bathymetry. The final model consisted of approximately 400,000 computation cells and extended from downstream of Clearwater Dam to Corning, AR. An overview of the HEC-RAS model is show in Figure 16.

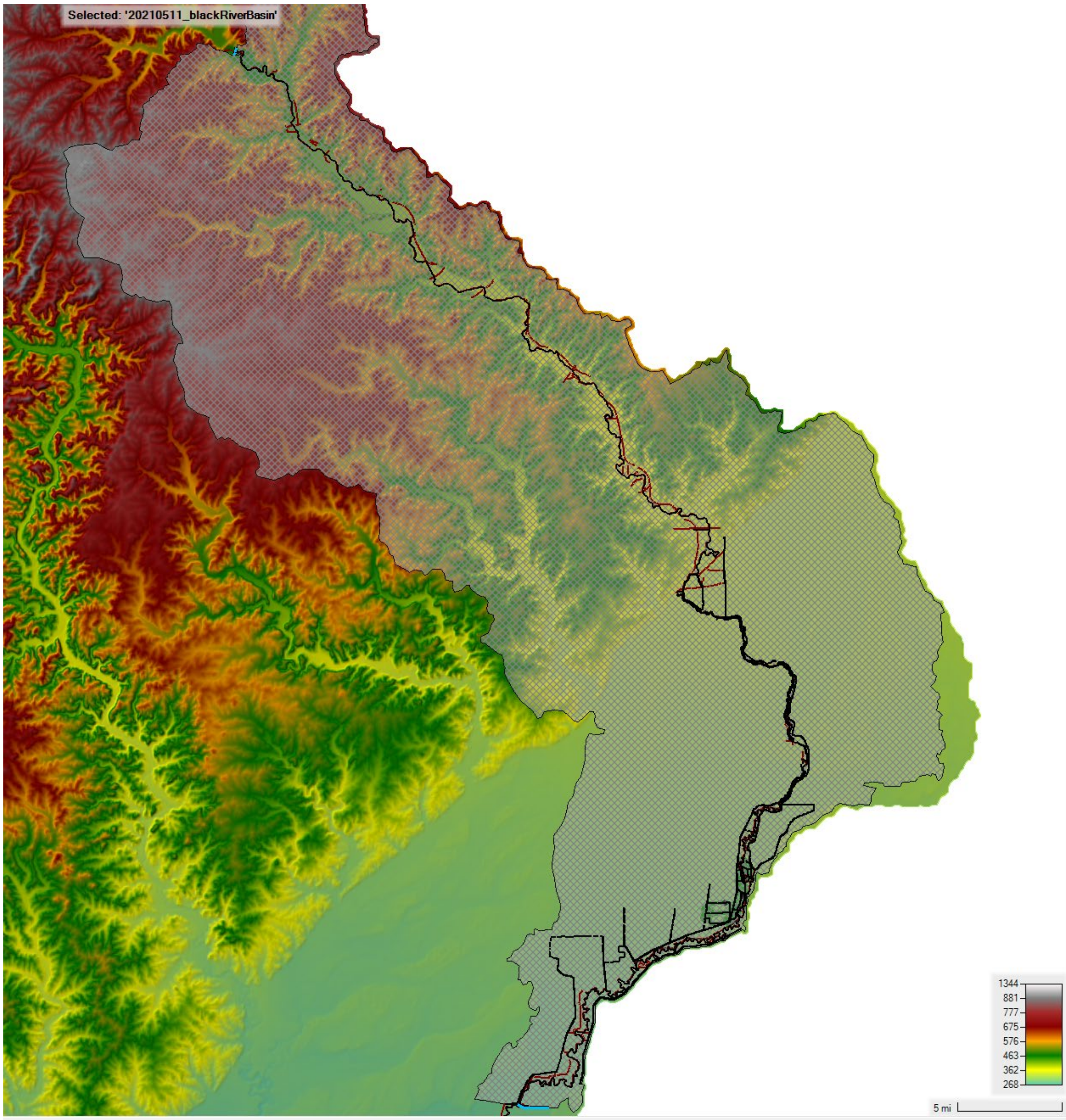

Figure 16 Overview of HEC-RAS model layout

Data Acquisition

The projection and datum for all of the data related to the terrain were USGS Albers Equal Area (US-Foot) and North American Vertical Datum of 1988 (NAVD88), respectfully.

The terrain geometry was developed by combining recent LiDAR elevation datasets flown at the lowest surface water levels available. This data was supplemented with hydrographic surveys of the channel. While these datasets were collected at different times, they were the most comprehensive and recent datasets available. Channel surveys used in the model were collected in 2020, 2018, and 2004. The 2004 survey information was only used in locations where needed in the model when other, more recent data did not exist. The use of geometry data from various years was unavoidable for such a large area.

Levee information was obtained through surveys from the National Levee Database. With recent levee breaches and repairs due to flooding, conversations with USACE Levee Safety personnel assisted in identifying and rectifying existing information. The Missouri Department of Conservation supplied GIS information on their levee or containment features which was represented by extracting elevation information from the LiDAR.

Although survey data were used from multiple years, the overall volume of the system has not change significantly. Modeling and analyzing results using a relative difference approach for this study with these elevation datasets was practical and adequate for the study. Observed flow and stage data were obtained from the United States Geological Survey (USGS) and the USACE. The typical error of the published flow data for calibration is considered to range from plus or minus 2% to 8% or more. The range is largely a function of site conditions which can be turbulent during high flood flows. The USGS publishes the results of flow measurements taken and assigns an estimated accuracy for each measurement. Multiple gage locations that measure stage can also provide flow estimates through the use of rating curves. Rating curves can be developed by fitting a curve that relates stage, the typical value measured in near real-time at a gage, to flow through a number of instantaneous flow measurements.

The National Land Cover Database from 2016 was used to define Manning's n coefficients for most of the model domain.

Model Geometry

The 2D cells which combine to form the 2D mesh varied in size to balance the necessary level of detail with reasonable computation times. In general, cell sizes in the floodplain ranged from 100 – 250 ft. The cell size used for the main channel was 25ft or less. Some areas used smaller cell sizes to capture features such as roadways, embankments, and levees. Elevations volume relationships are computed for each cell using the underlying terrain raster. Each cell face is treated essentially as a cross section by extracting station elevation data from the terrain raster. Manning's n values were initially extracted from relationships assigned to the National Land Cover database raster. These values were modified or spatially overridden as part of the calibration process. For an alluvial river system, there is a hysteresis phenomenon or "loop effect". This hysteresis is noted where the stage does not have a unique value for a particular discharge, because of unsteady, non-uniform conditions (Henderson 1966). Typically, the rising limb of the hydrograph, or as the flow at a location is increasing, exhibits lower stage values than the falling limb of the hydrograph. The four primary factors that influence hysteresis in alluvial rivers are:

1. Dynamic effects are result of the unsteady flow characteristics of the system
2. Resistance changes are due to the variation of the roughness of the channel, overbanks, lakes in the flood plain, and bed forms
3. Viscous effects change based on the temperature of the water and the magnitude of sediment being transported
4. Aggradation or degradation of the river are only quantifiable if the bed is surveyed multiple times during the course of a single flood event

HEC-RAS unsteady flow models can predict purely dynamic effects in a fixed bed channel. Quantifying dynamic feedback in an alluvial (moveable bed) channel is beyond the current state-of-the-art. The version of HEC-RAS used currently does not allow for horizontal variation of Manning's N along a cell face – the single, representative value is computed by the intersection of the center of the 2D face with the Manning's n layer raster or override region. Additionally, the current version of HECRAS also does not allow for vertical variation of Manning's N (change with flow rate). However, these limitations were a reasonable compromise for the higher resolution of computational output. Levees were modeled by leveraging the National Levee Database (NLD) initially. The elevations from the NLD are often not dense or comprehensive enough to capture the full impediment to water within the model; as such, many levee features were extended to tie into the high ground or replaced with new elevations extracted from the LiDAR datasets (provided there was reasonable agreement between the two datasets and confirmed by Levee Safety personnel). Levees were modeled as 2D area connections in order to more easily maintain the necessary elevations within the model mesh. Bridges were modeled and bridge data was taken from a 1D HEC-RAS model developed by USACE in 2004 from a previous project.

Boundary Conditions

The original downstream boundary extent of the hydraulic model was at Pocahontas, AR. After testing model convergence and sensitivity to the boundary extent, the hydraulic model was truncated at Corning, AR to gain more expedient simulation times without compromising the results. The downstream boundary condition for all model simulations was the USGS rating at streamflow gaging station USGS 07064000 Black River near Corning, AR. The upstream boundary condition was observed release data from Clearwater Dam. For some scenarios, StageIV gridded precipitation was used on the grid to represent the local hydrology in the model domain.

To evaluate the performance of each scenario, two boundary condition approaches were used. The first boundary condition was to simulate a stair-stepped increase to flows on the Black River which allowed for an easier understanding of the flow rates and locations where a maximum benefit would be realized as well as the point of diminishing returns. This first boundary condition enables users to make quick comparisons across numerous scenarios. The second boundary condition was simulating the March 2008 precipitation event (without hydrologic losses) to better understand the timing and interaction of streamflows in the watershed which provided additional context to any potential benefits.

Calibration

Model calibration is the process of adjusting model parameters to reproduce observed data for a fixed period of time. The calibration effort primarily focused on the stage-flow relationships at stream gages. Most of the recent flood events caused a variety of levee failures. The detailed information on time of breach, breach progression rates, and final breach dimensions is critical to representing those historic flood events and is not readily available or certain. Because the hydraulic analysis focuses on ideas to improve the efficiency of flow in the river at lower flow rates, it was determined that calibration to the larger events temporally was not essential. The underlying assumption then became that the levees would not breach, but simply overtop at the higher flow rates. Calibration is an iterative process comparing any and all data relevant to the event. The typical data types range from gage data and high water marks to any after action report or inspection narratives and aerial imagery. The general iterative process for calibration that was used is outlined below:

- Added breaklines, 2D connections, or additional refinement to the mesh to capture impediments to flow or details in the terrain such as embankments or leveed areas.
- Adjusted Manning's n values in the channel, numerically and spatially
- Adjusted Manning's n values in the overbanks
- Compared output to ratings and time series gage data

The calibration to the rating at streamflow gaging station USGS 07063000 Black River at Poplar Bluff, MO is illustrated in Figure 17 and the calibration to the rating at streamflow gaging station USGS 07064000 Black River near Corning, AR is illustrated in Figure 18.

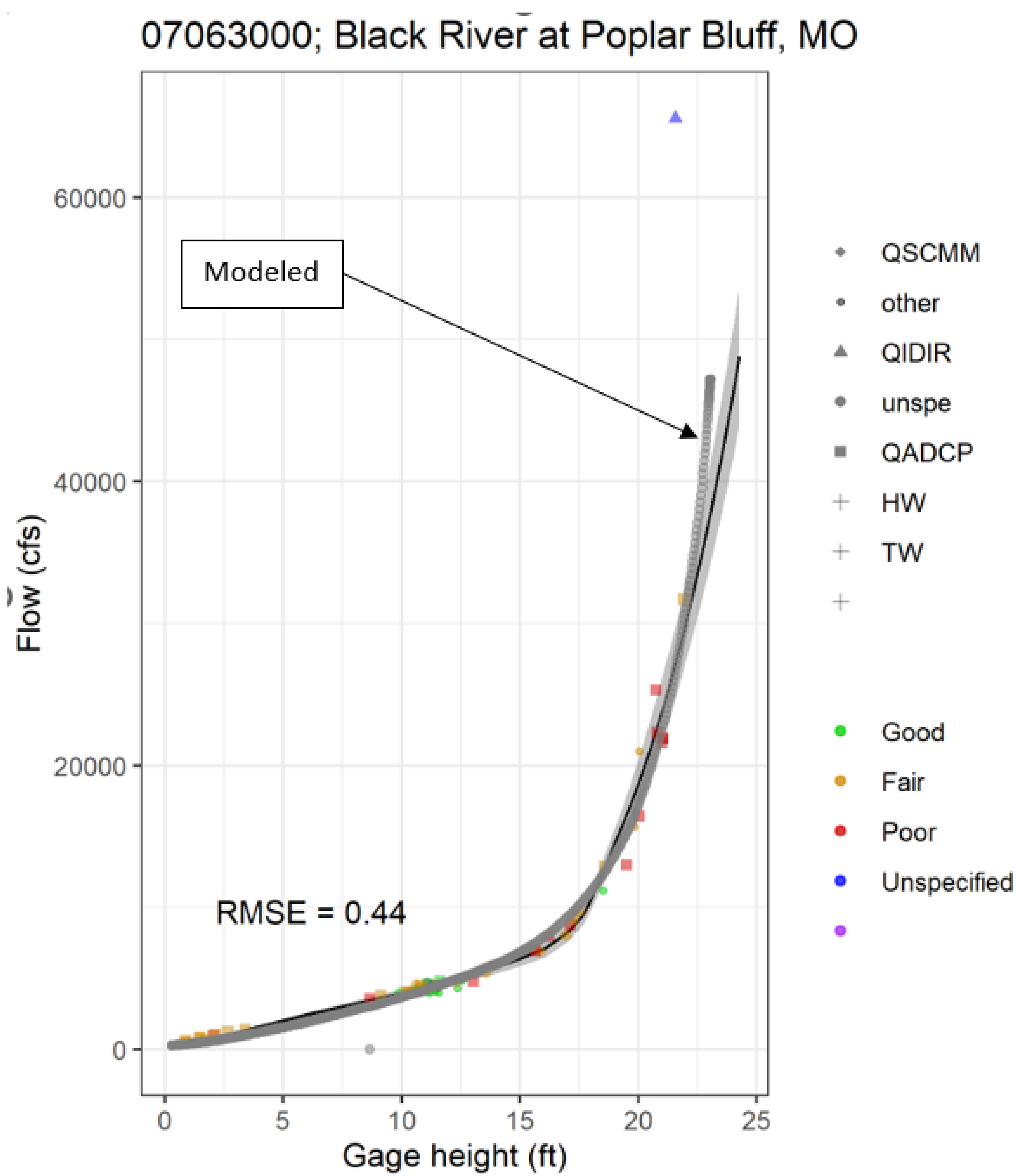

Figure 17 Hydraulic model calibration against USGS Rating at Poplar Bluff, MO

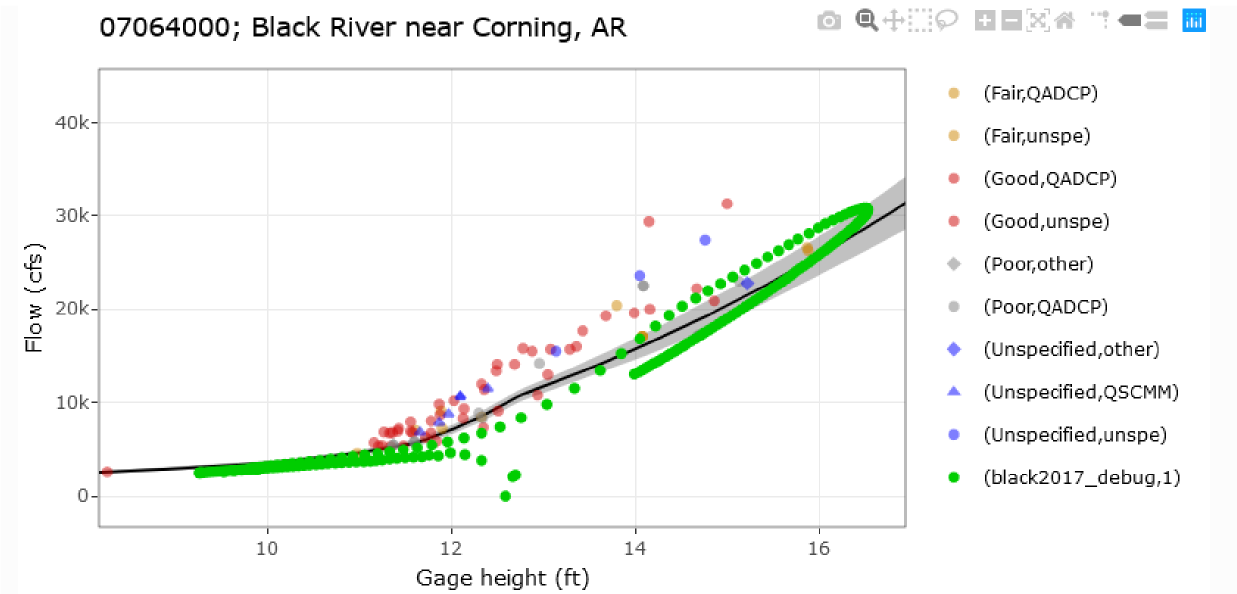

Figure 18 Hydraulic model calibration against USGS Rating at Corning, AR

Note that this figure was from the model with extents to Pocahontas, AR and was later truncated to Corning.

Additionally, the 2008 event was simulated to validate the temporal accuracy of the model. This validation event assumed no levee breaches and no hydrologic losses. With these two assumptions the model predictions were slightly higher than observed with elevation, but the timing overall was reasonable to provide confidence in the model's ability to evaluate the types of scenarios in this study. Figure 19 and Figure 20 depict the results of the modeled 2008 event.

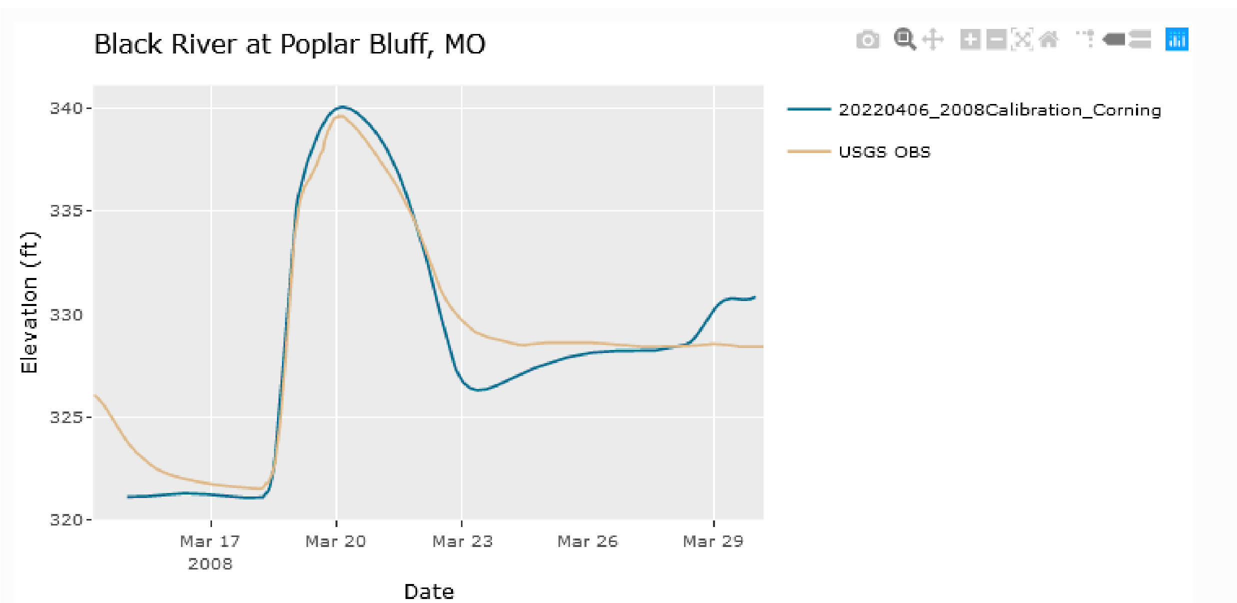

Figure 19 Modeled 2008 Event at Poplar Bluff, MO

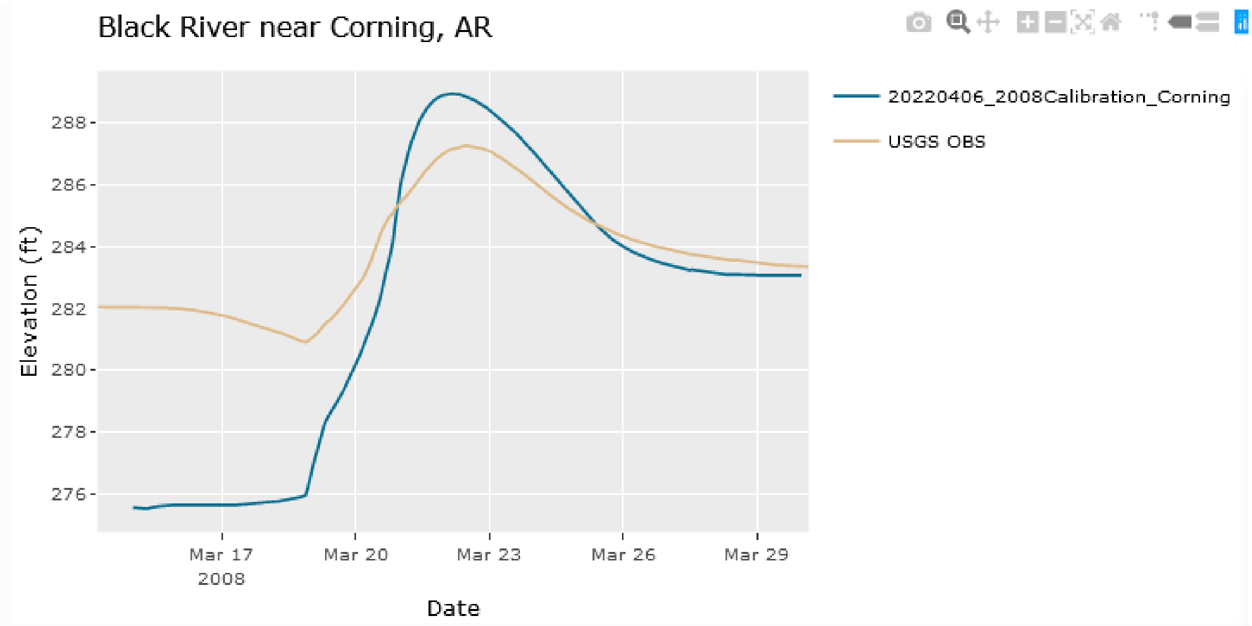

Figure 20 Modeled 2008 Event at Corning, AR

Hydraulic Analysis Scenario Results

In close coordination with the stakeholders, a variety of suggestions were discussed at many locations within the study area based on the varied interests of the group. These ideas were consolidated into five (5) scenarios for model evaluation:

1. Channel Cleanout
2. Channel Straightening
3. Transverse Levee Removal
4. Cleanout upstream of Hargrove Pivot Bridge to the State Line with a Low Water Weir at Swift Ditch
5. Levee Setbacks

The results of all 5 scenarios are summarized in this section with additional details about the individual scenarios and their respective results in the subsequent subsections. Changes in water surface elevations from the modeling are shown for 4,400 cfs (Figure 21), 8,000 cfs (Figure 22), and the 2008 event (Figure 23) to help visualize the potential impact in the main area of interest from the Dan River Access downstream slightly past the AR-MO State Line.

A comprehensive, system-wide channel cleanout is not considered a best management practice for the Black River. While water surface elevation reductions for flow rates up to bank full are anticipated, higher flow events will experience increases in water surface elevations in the lower reaches as more flow is able to convey to the downstream reaches.

Channel straightening is not a recommended best management practice to alleviate flooding and drainage concerns on the Black River. The proximity of the levees to the river is already a known risk. Straightening the channel would cause additional degradation and erosion causing banks to become unstable. In many locations, the riverbank is next to the toe of the existing levees. Channel straightening is an expensive upfront construction measure with an expensive and consistent need to monitor and maintain. If any channel straighten were to be pursued to alleviate flooding and drainage concerns, it should only take place in locations where there is the largest floodplain width on both sides of the river (generally downstream of the point Swift Ditch takes over). Straightening these locations of larger floodplain width would see the largest benefit and would minimize the risk to existing infrastructure; however, doing so would disrupt habitat and the current hydrologic and ecological function of the adjacent floodplains.

Removal of the transverse levees has a limited footprint of water surface elevation reduction on the Black River from around HWY 214 downstream to the point of the end of the last transverse levee. However, this water surface reduction would extend upstream on the drainage ditch to the east of the North Inter-River Ring Levee. Water surface elevation reductions for transverse levee removal are generally not experienced during the higher flood flow rates. In principle, the transverse levee removal could allow for more efficient drainage to those areas on the east side of the ring levee; however, the inefficiencies of the local drainage network and groundwater limit the potential benefits of this scenario. Local drainage improvements would provide benefits more immediately and predictably for a wider range of potential hydrologic conditions than transverse levee removal.

A less invasive, maintenance channel cleanout such as the partial cleanout from upstream of the Hargrove Pivot Bridge to the AR-MO State Line with a low water weir at Swift ditch is considered a best management practice to allow the energy of the river to self-scour and keep the channel from further depositing sediment. Additionally, discussions with the Missouri Highway Patrol indicated that the downed trees and debris have caused life-loss and safety concerns for recreationalists. Due to USACE having cleared and snagged much of the Black River in the 1970s and later in the 1990s for authorized cost-shared projects, the maintenance was turned over and is the responsibility of Butler County (the non-federal sponsor for those efforts). USACE has neither the authority nor the appropriations to maintain either of those projects. This version of the channel cleanout scenario seeks to optimize the potential benefits for the system to drain while reducing the impact footprint horizontally and vertically (less expensive, fewer long-term risks). Additionally, the water surface reduction benefits of this partial channel cleanout out could be slightly better than presented as the river channel would respond to the flow forcings from the low water weir and start to seek a new, slightly deeper equilibrium. With the results of this partial cleanout scenario being the least invasive (standard maintenance) and still resulting in similar reductions as the more aggressive scenarios, the largest benefit to cost ratio (in terms of water surface elevation reduction) would be expected both in the short and long-terms.

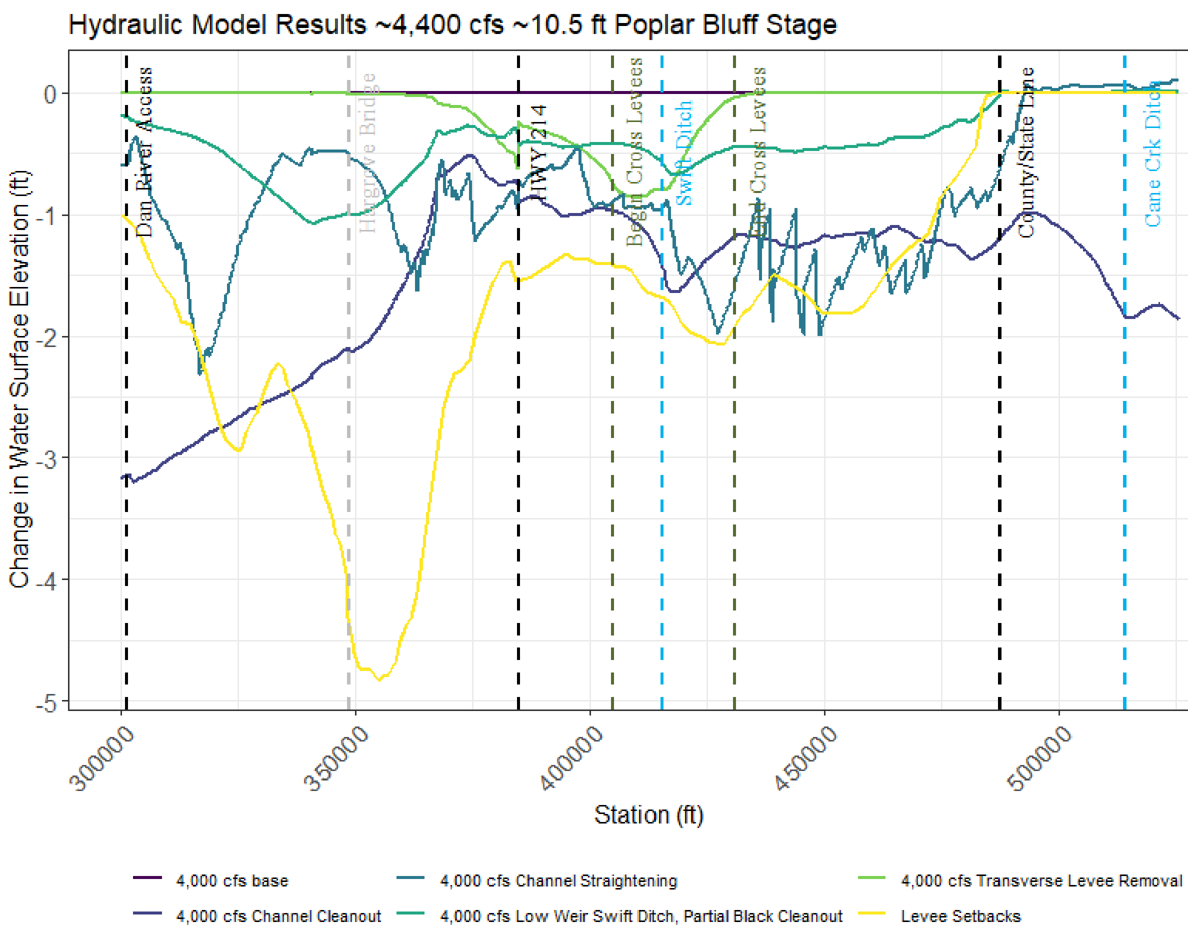

Figure 21 Changes in water surface elevation for all scenarios for 4,400 cfs

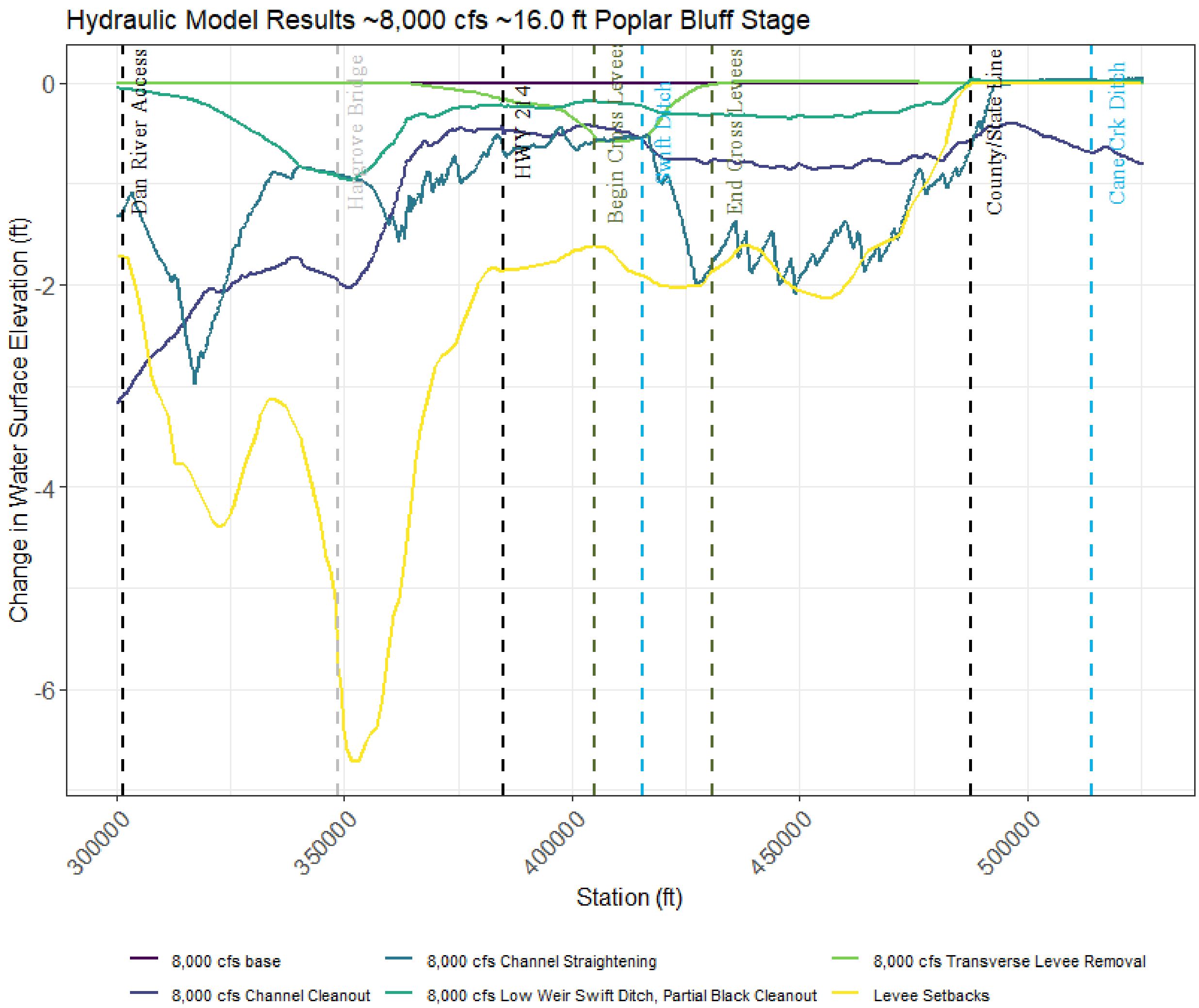

Figure 22 Changes in water surface elevation for all scenarios for 8,000 cfs

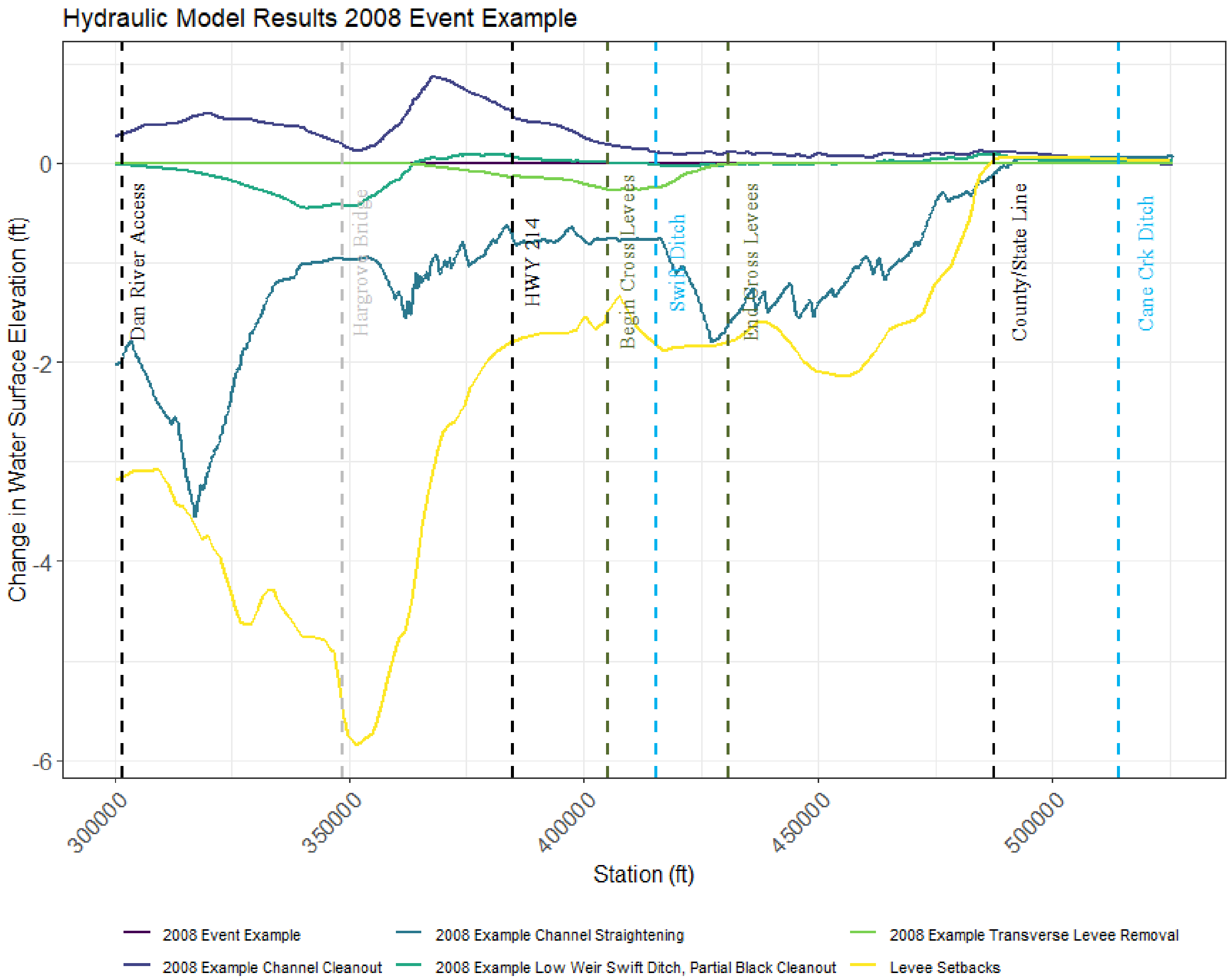

Figure 23 Changes in water surface elevation for all scenarios for the 2008 event

Channel Cleanout

The channel cleanout scenario was represented in the model by reducing Manning's n value (roughness coefficient) in the main channel. The calibrated channel roughness coefficient was 0.047 which is characterized by being a winding channel with some pools and shoals with weeds and stones. The cleanout scenario roughness coefficient used was 0.03 which is characterized as clean, straight, no rifts or deep pools with some stones and weeds. This value of 0.03 is likely lower than what is possible for the Black River, but it was deemed reasonable to evaluate the something more drastic initially to determine expectations. The change in roughness coefficient was applied for the entire river from Clearwater Dam to Corning, AR.

The average maximum water surface elevation decrease was around 1.5 to 2 feet at an approximate flow rate of 4,400 cfs which is equivalent to a 10.5 ft stage at the Poplar Bluff gage (Figure 24). The average maximum water surface elevation decrease was around 0.5 to 1 foot at an approximate flow rate of 8,000 cfs which is equivalent to a 16 ft stage at the Poplar Bluff gage (Figure 25). For the 2008 event simulation, the model indicated there would be an increase in water surface elevations between up to nearly 1 foot between the Dan River Access and the confluence with Cane Creek Ditch as more flow would be able to travel downstream (Figure 26). That additional flow becomes restricted by the narrow floodplain width and other hydraulic controls such as bridge crossings.

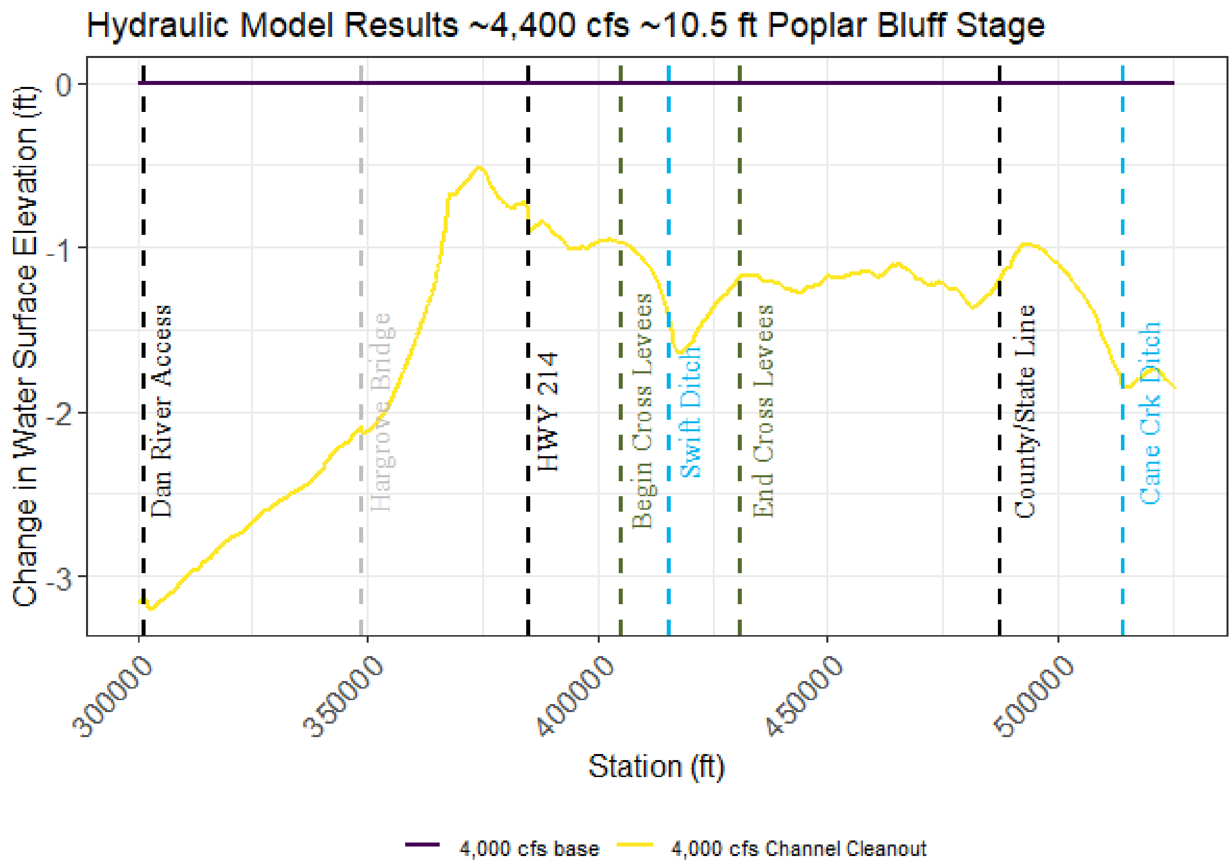

Figure 24 Change in water surface elevation for channel cleanout at 4,400 cfs.

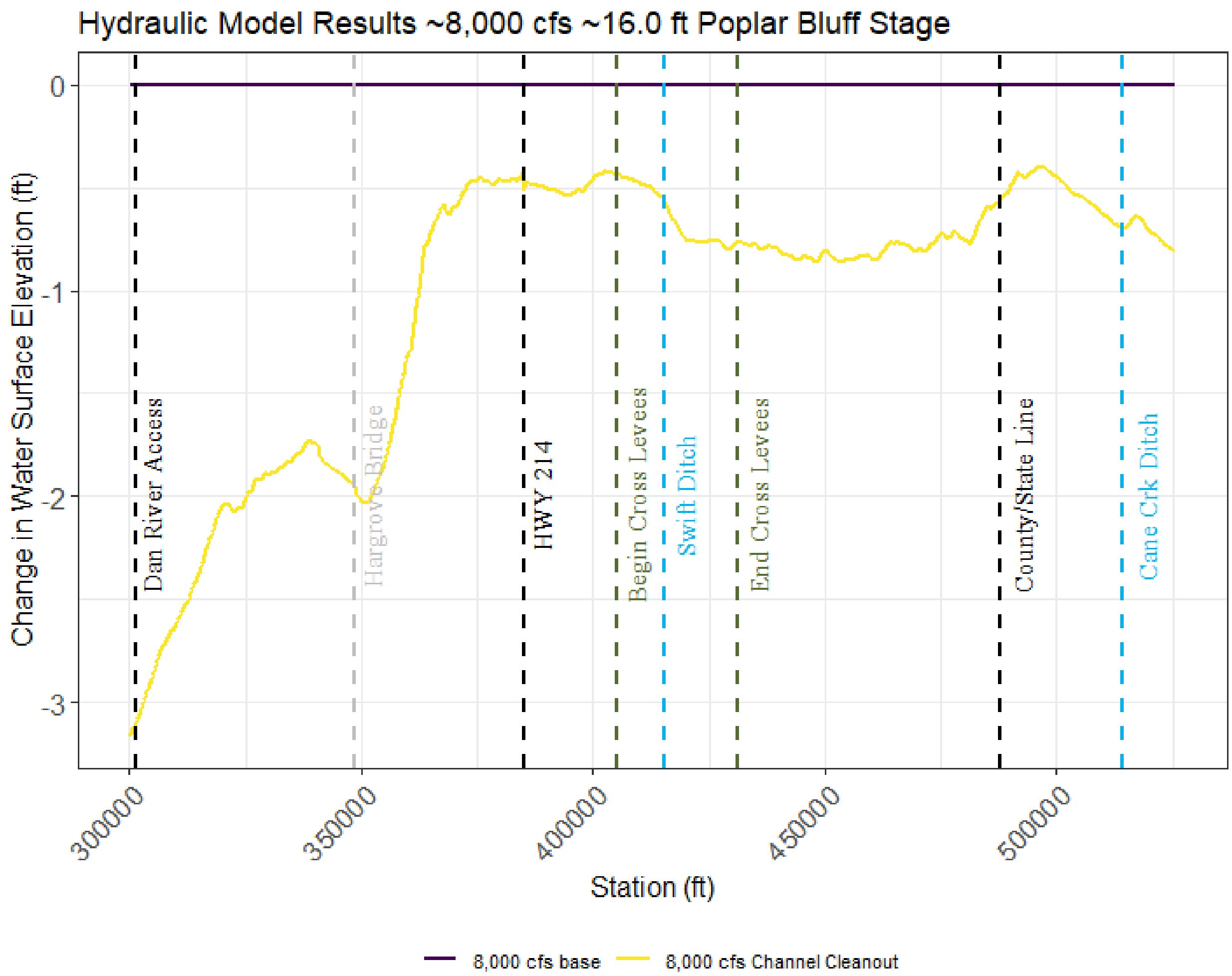

Figure 25 Change in water surface elevation for channel cleanout at 8,000 cfs

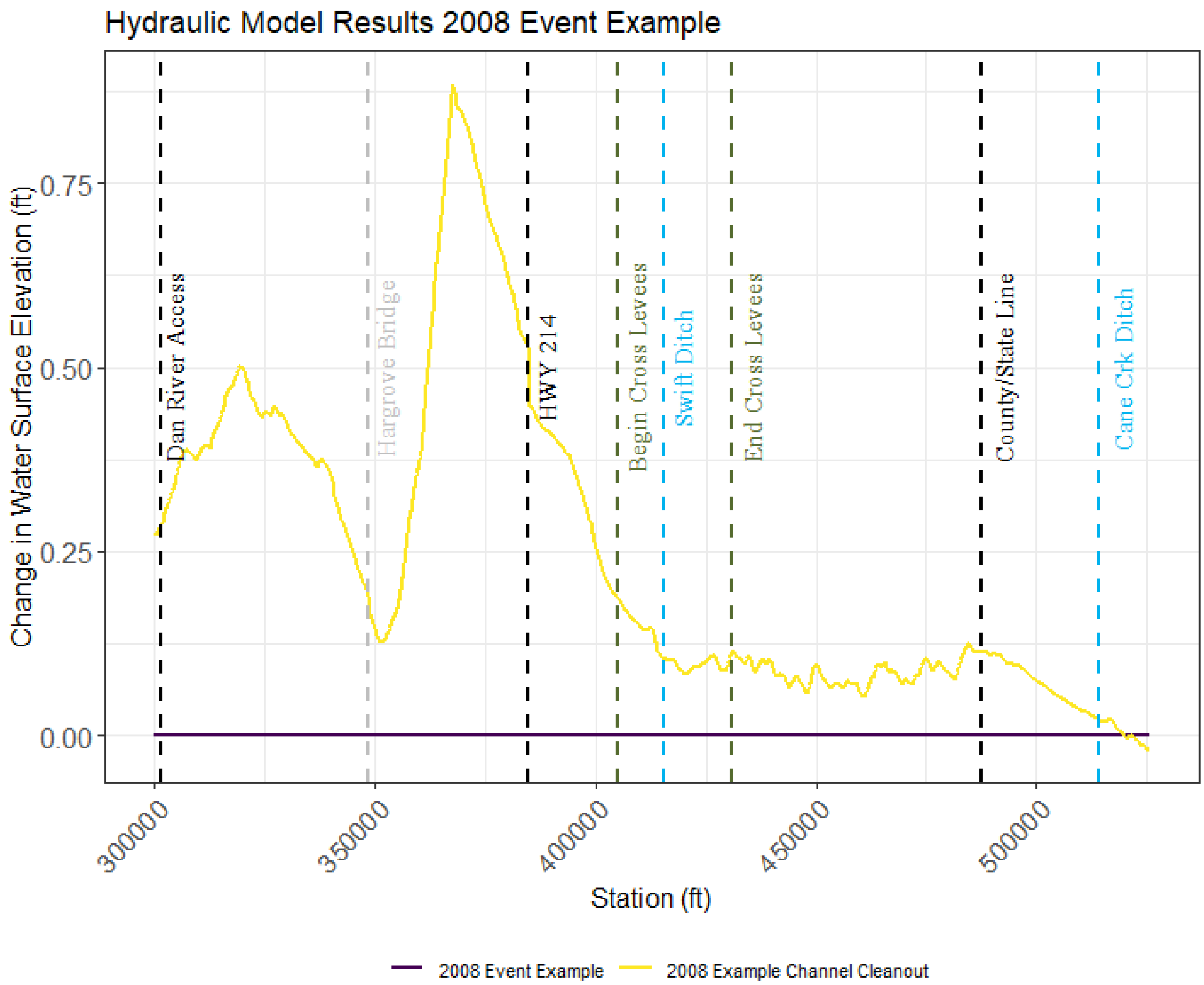

Figure 26 Change in water surface elevation for channel cleanout for 2008 event

Peak elevation reduction is an important aspect to consider, but for local drainage concerns outside the levees in agriculture the change in duration is another important consideration. Anticipated changes in duration are challenging to quantify as duration is highly variable with the nature of the volume of a rain event. In general, the channel cleanout scenario did not appreciably change the duration enough to be considered a widespread benefit to agricultural stakeholders. The flow moves downstream sooner but is sustained above a bankfull threshold for about the same amount of time. In a few locations, the duration above a bankfull threshold was lessened by approximately 6 hours; however, that reduction is not meaningful to reduce agricultural damages when the events generally can last weeks.

Channel Straightening

Another idea to increase drainage efficiency in the Black River proposed with this study and its partners was to straighten the meandering channel by creating many “cutoffs” or oxbows. This approach has been widely used especially for large, navigable and meandering rivers such as the Missouri, Arkansas, and Mississippi Rivers. A major objective in channelization on these larger rivers is to steepen the river slope which, in turn, uses the river's energy to deepen and sustain a navigation channel. Many of the larger rivers are still responding to the cutoffs created in the 1920s. For smaller rivers, the geomorphic response is typically faster and channelization can reduce flooding in the upstream reaches; however, the lower reaches would experience an increase in peak flood levels and higher flood frequency. The major risks with channelization are that the continued degradation of the channel results in headcutting that can propagate up inflow tributaries. This headcutting process causes channel erosion and extensive bank failures as the system attempts to equalize. Additionally, channelization can disconnect adjacent floodplains and habitat.

To simulate channel straightening in the hydraulic model a new channel was cut into the terrain to shorten the river and also maintain reasonable distances between the levees. In the model the channel straightening shortened the Black River by approximately 14.5 miles between HWY 60 and the AR-MO State Line. An example of the straightened channel is shown in Figure 27.

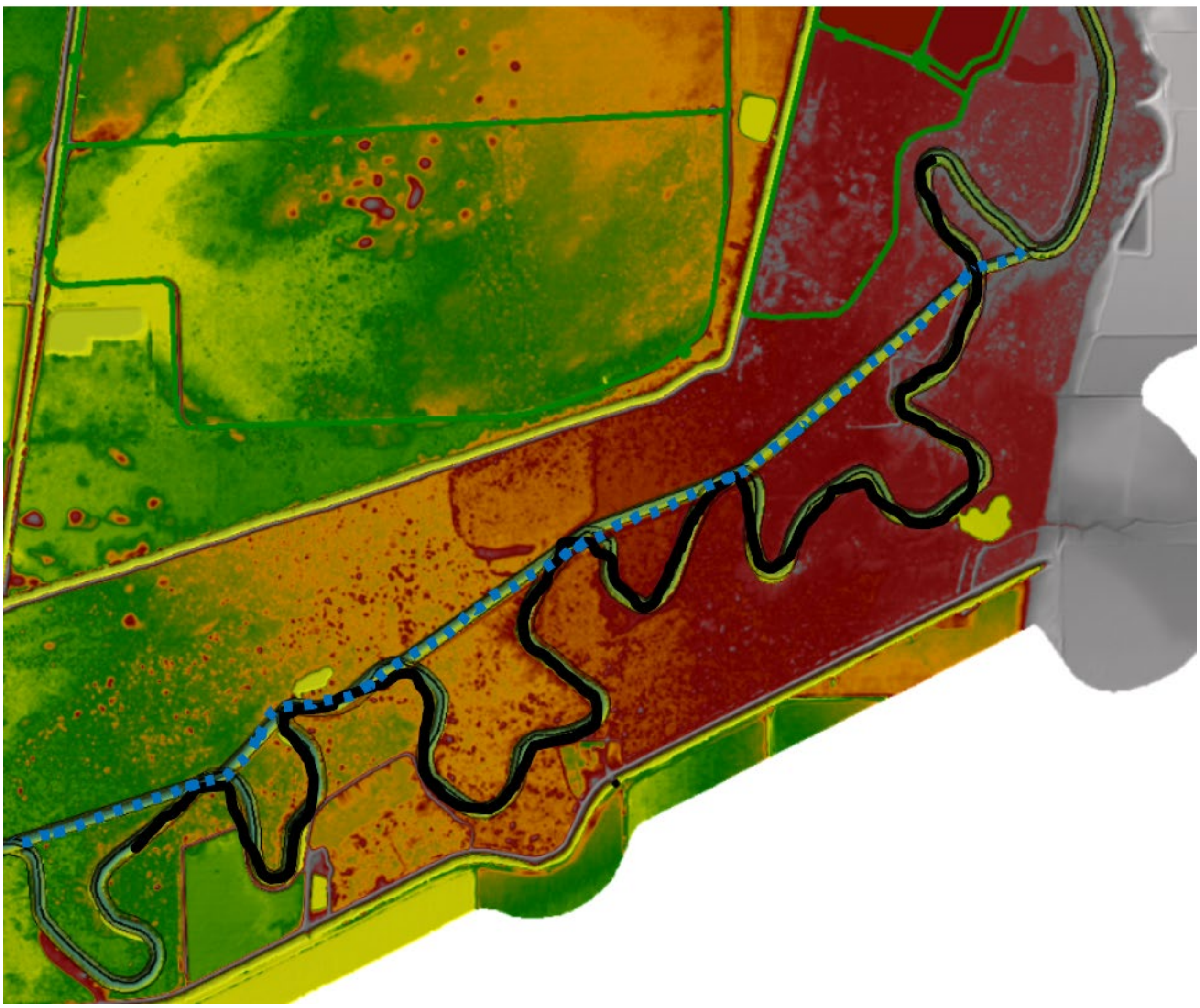

Figure 27 Example of channel straightening as presented in the terrain model

The average maximum water surface elevation decrease was around 1 foot at an approximate flow rate of 4,400 cfs which is equivalent to a 10.5 ft stage at the Poplar Bluff gage (Figure 28). The average maximum water surface elevation decrease was around 1.5 feet at an approximate flow rate of 8,000 cfs which is equivalent to a 16 ft stage at the Poplar Bluff gage (Figure 29). For the 2008 event simulation, the model also indicated there would be a roughly 1 – 1.5 foot decrease in water surface elevation (Figure 30). For all flow conditions, water surface elevations would begin to increase at the AR-MO State Line.

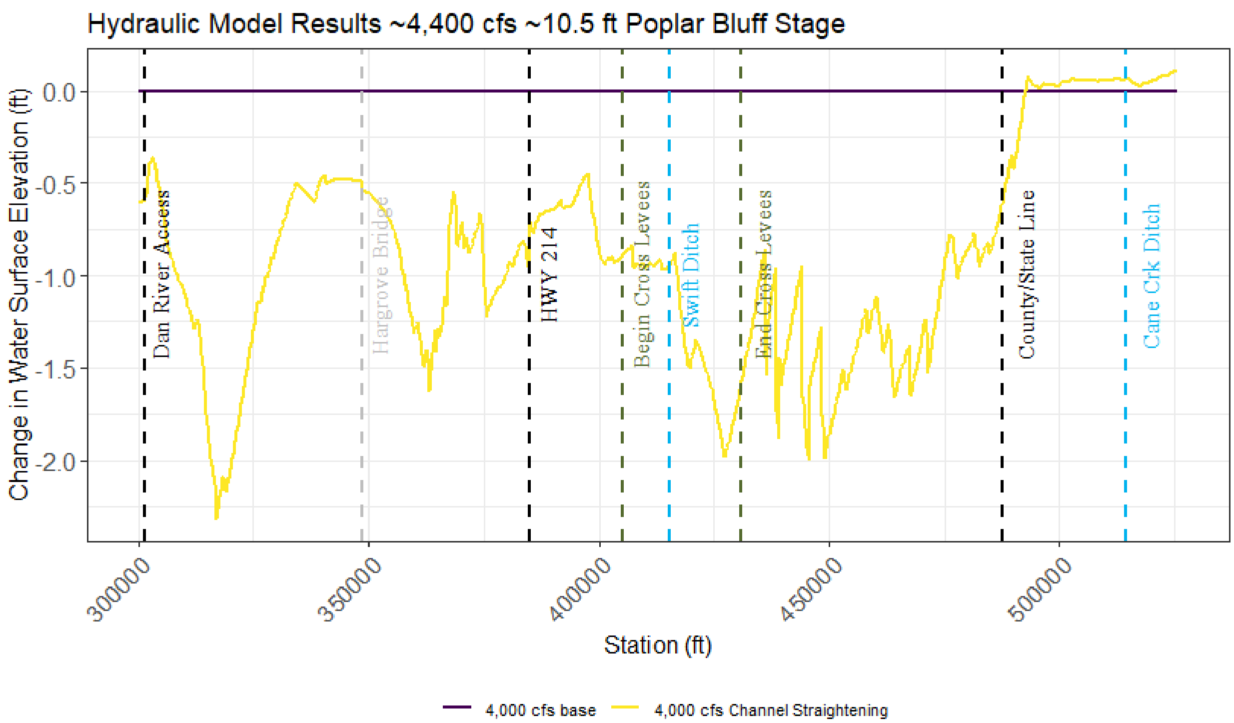

Figure 28 Change in water surface elevation for channel straightening for 4,400 cfs

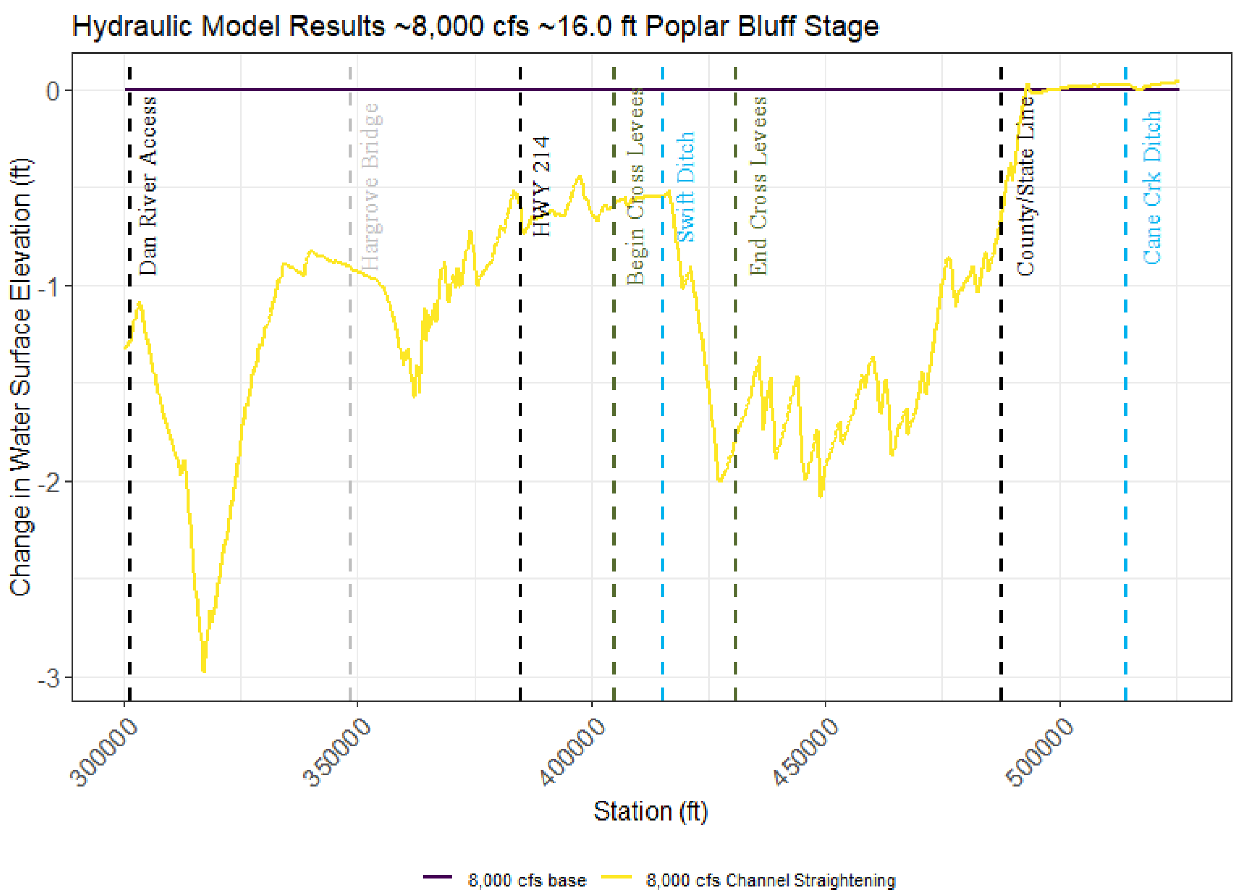

Figure 29 Change in water surface elevation for channel straightening for 8,000 cfs

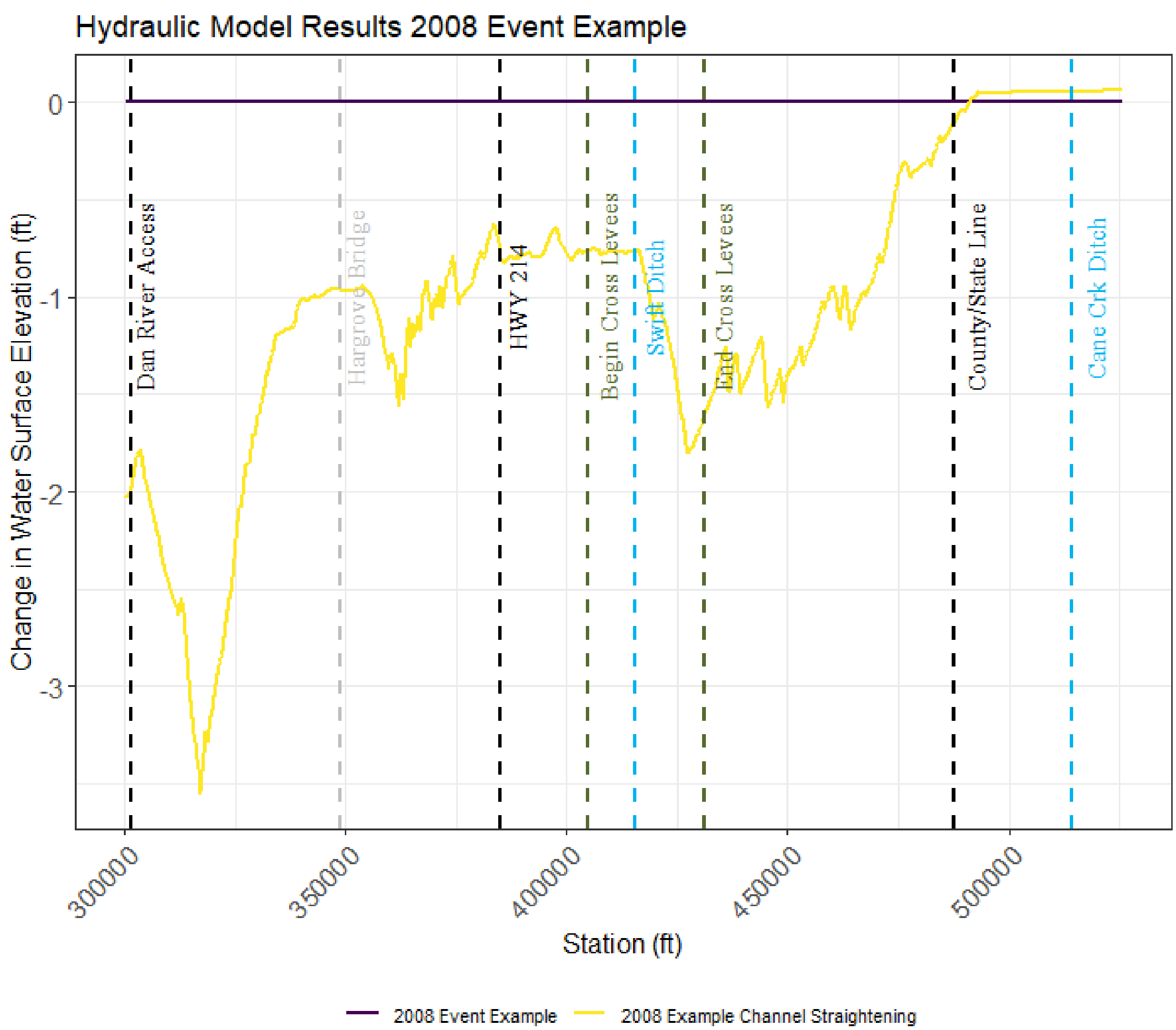

Figure 30 Change in water surface elevation for channel straightening for 2008 event

Peak elevation reduction is an important aspect to consider, but for local drainage concerns outside the levees in agriculture the change in duration is another important consideration. Anticipated changes in duration are challenging to quantify as duration is highly variable with the nature of the volume of a rain event. The channel straightening scenario did have a more significant impact on the duration of flooding than the channel cleanout scenario in some locations as would be expected. The flow moves downstream more efficiently but is sustained above a bankfull threshold for about the same amount of time in areas where the floodplain is narrow (restricted by levees) down to the approximately where the Black River transitions over to Swift Ditch. At locations at the Swift Ditch takeover point and downstream near the end of the Coon Island Conservation Area, the duration above a bankfull threshold was lessened by 1-2 days; however, that reduction may not meaningful to reduce agricultural damages when the events generally can last weeks.

Transverse Levee Removal

At the Coon Island Conservation Area, there are a set of short, levees transverse to the mainline levees and ringed to sustain waterfowl. The study partners hypothesized that the removal of these levees would alleviate the constriction and create lower water levels. A plan and profile depiction of these features is shown in Figure 31.

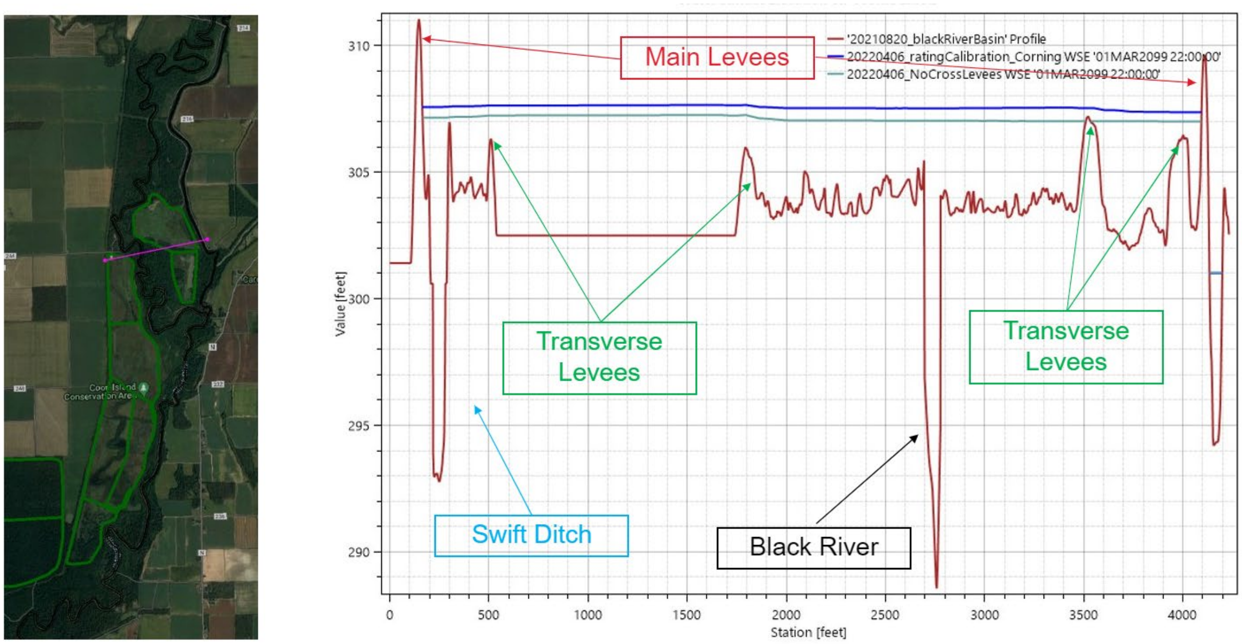

Figure 31 Plan and profile of Transverse Levees at Coon Island Conservation Area

To analyze the impact of the removal of these levees in the model, the elevations representing the levees were overridden to represent the ground elevations adjacent to the toe of the levee. The maximum reduction in water surface elevation for the transverse levee removal happens between 4,000 and 5,000 cfs. The water surface elevation reduction ranges from no change to about 1 foot of reduction with a very localized area of influence (Figure 32 and Figure 33). Water surface elevation reductions above 5,000 cfs are limited to a few tenths of a foot (Figure 34 and Figure 35).

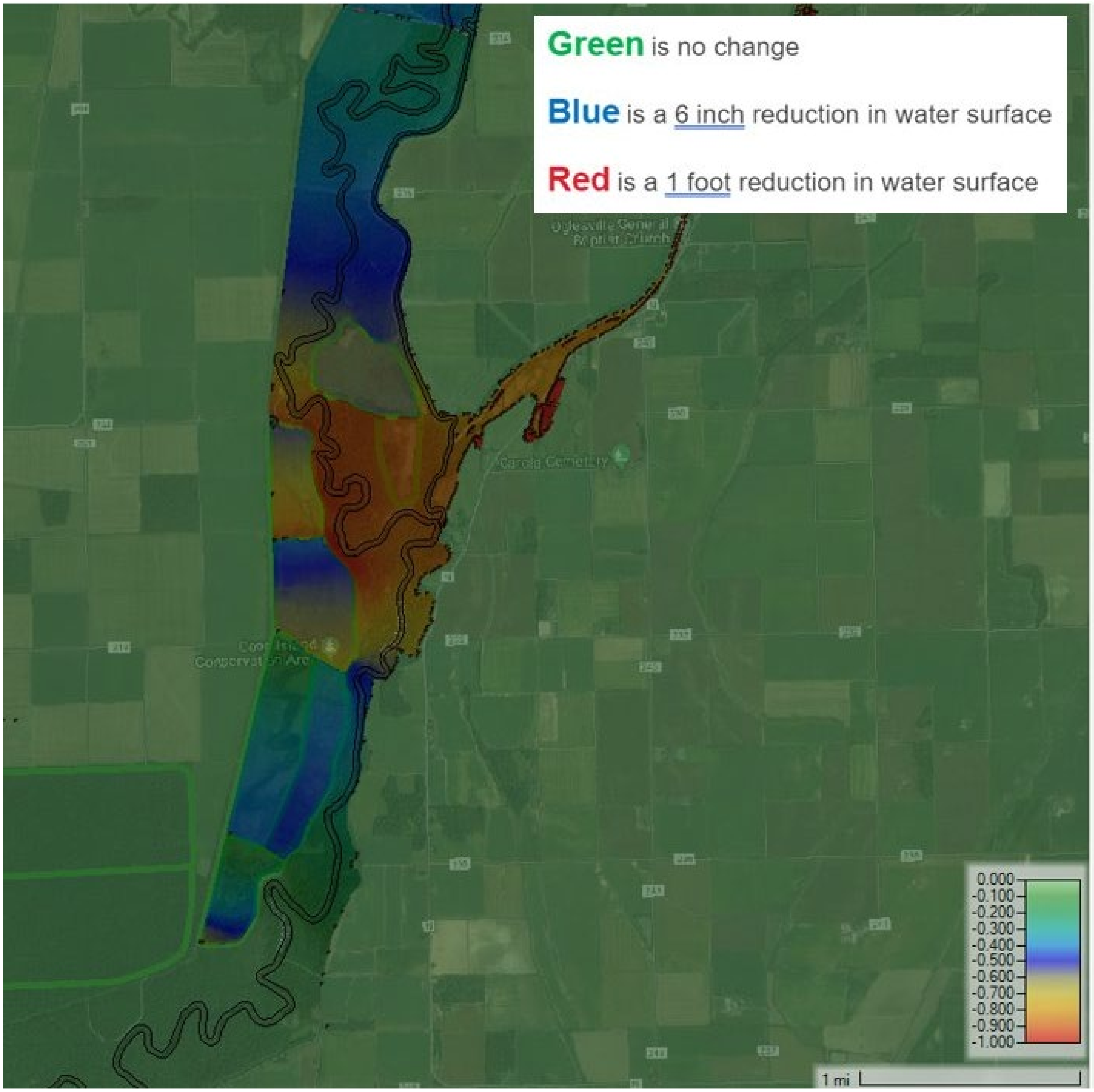

Figure 32 Spatial extents of maximum change in water surface elevation for transverse levee removal for 4,400 cfs

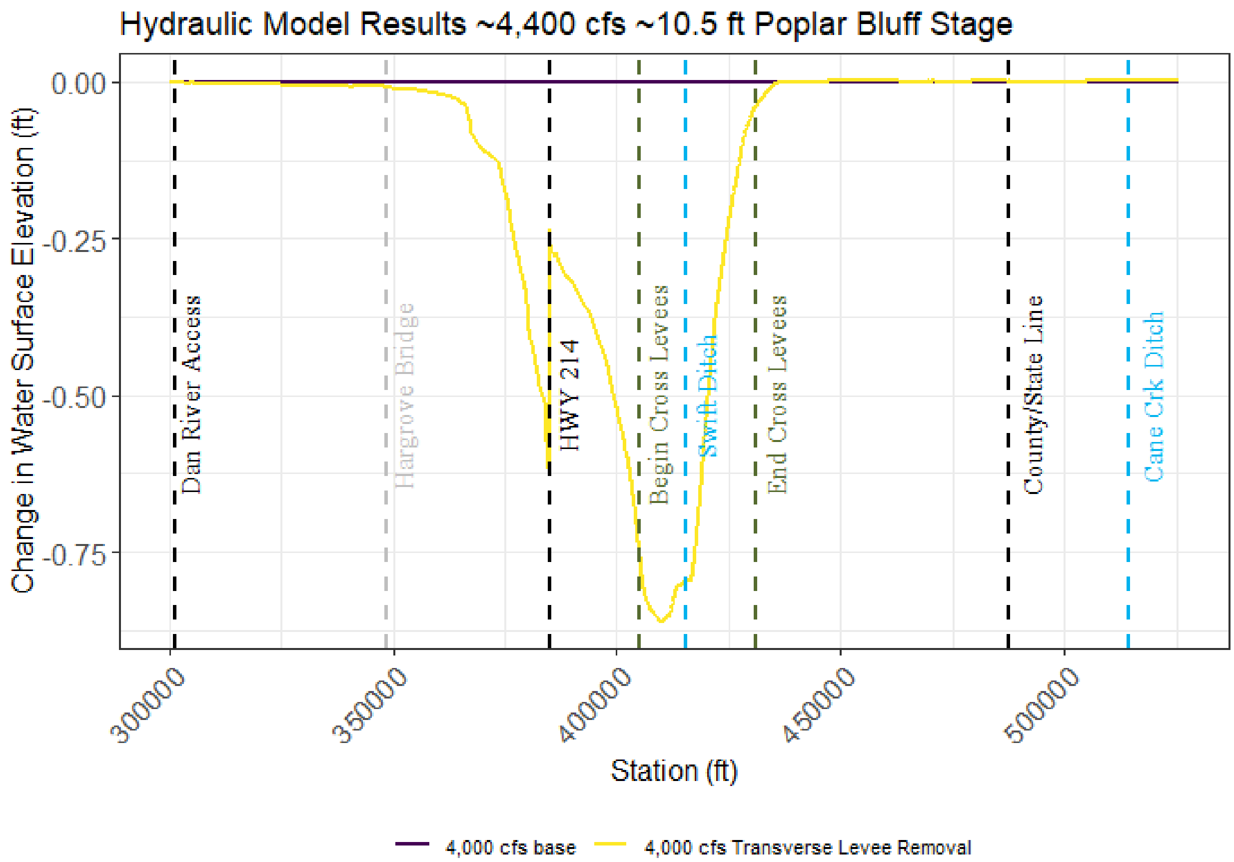

Figure 33 Change in water surface elevation for transverse levee removal for 4,400 cfs

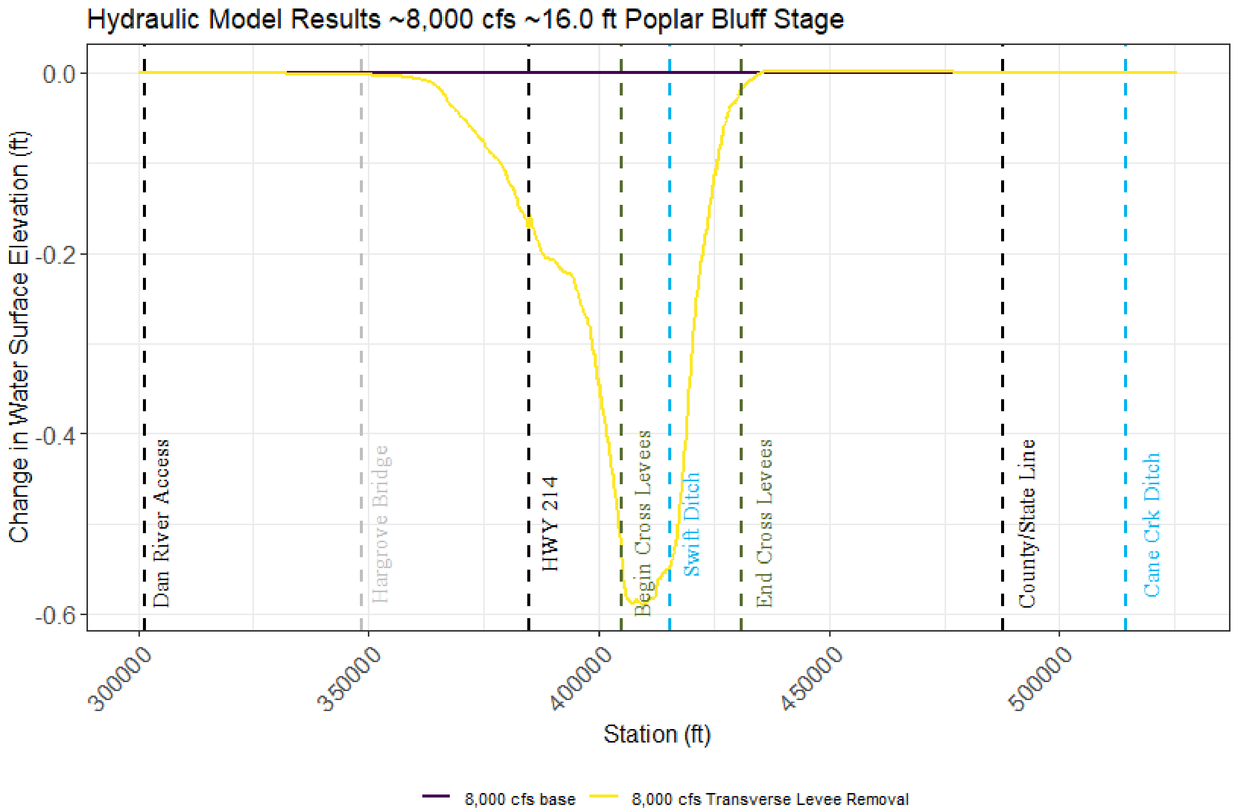

Figure 34 Change in water surface elevation for transverse levee removal for 8,000 cfs

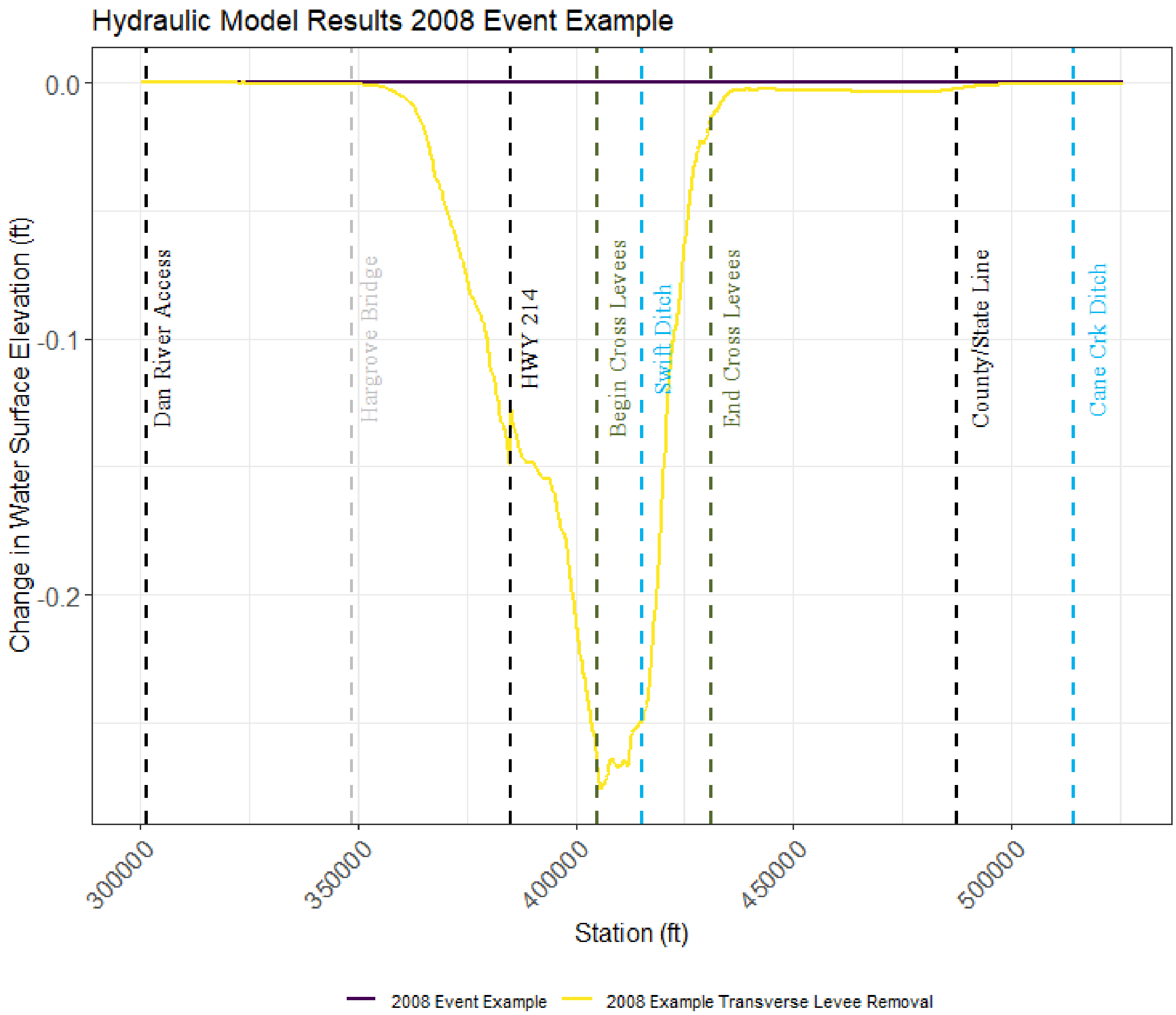

Figure 35 Change in water surface elevation for transverse levee removal for 2008 event.

Peak elevation reduction is an important aspect to consider, but for local drainage concerns outside the levees in agriculture, the change in duration is another important consideration. Anticipated changes in duration are challenging to quantify as duration is highly variable with the nature of the volume of a rain event. The transverse levee removal scenario has a limited footprint of impact on duration as it does peak elevation. The optimum location that experienced a reduction in duration above bankfull flow was at the point where Swift Ditch re-enters the Black River. At this confluence of Swift Ditch and the Black River, the duration above a bankfull threshold was lessened an estimated 0.5 – 1 day; however, that reduction may not meaningful to reduce agricultural damages when the events generally can last weeks.

Cleanout upstream of Hargrove Pivot Bridge to the State Line with a Low Water Weir at Swift Ditch

This refinement of the channel cleanout scenario is equivalent to the recommendations and original obstruction removal completed by USACE in the 1990s. The extents of the channel cleanout in this scenario are the same as what was completed in the 1990s, so results represent the performance to be initially expected with completing maintenance. The addition of a low water weir at Swift Ditch was a recommendation in the 1990's study if Swift Ditch were to be cleared. The concept in this scenario is to complete maintenance, but also control the amount of low flow that is currently in Swift Ditch. The clearing of the channel and forcing flow back into the Black River instead of Swift Ditch will use the river's energy to both slightly deepen the channel back to a new equilibrium minimizing risk to rapid headcutting occurring and keep the deposition conditions from worsening to be more reliable and sustainable with continued maintenance. The results of this scenario do not account for how the Black River will respond (slightly deepen) to the river's flow. Modeling the magnitude of the river's response would require a sediment transport, mobile bed model which is outside the scope of this study; however, the results presented are indicative of reductions that could be expected in the short-term with additional reductions as the channel responds to the clearing and the low water weir. The average maximum water surface reduction was approximately 0.5 feet for 4,400 cfs and for 8,000 (Figure 36 and Figure 37). The change in water surface elevation for the 2008 event was close to 0.5 foot reduction near the Hargrove Pivot Bridge, then generally no change further downstream (Figure 38). Overtime, as the Black River channel responds to the flow restriction with the low water weir at Swift Ditch, these reductions in water surface elevation would likely increase.

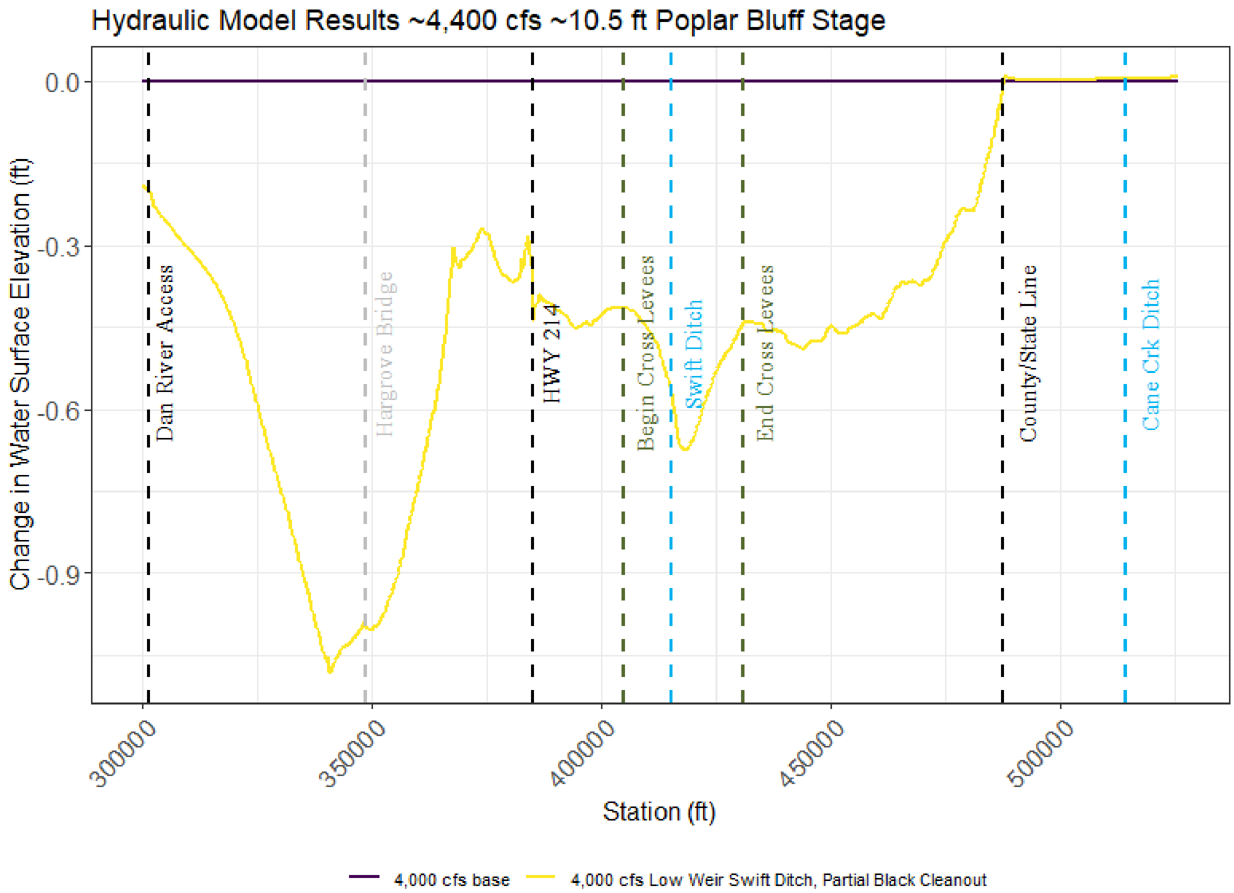

Figure 36 Change in water surface elevation for partial cleanout and low water weir for 4,400 cfs

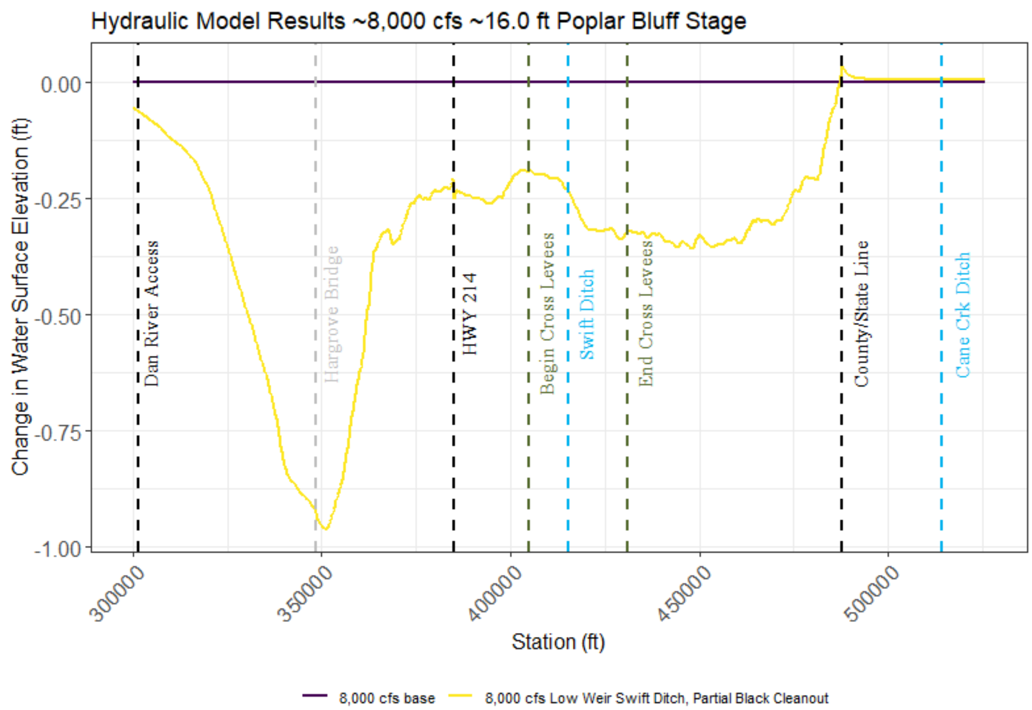

Figure 37 Change in water surface elevation for partial cleanout and low water weir for 8,000 cfs

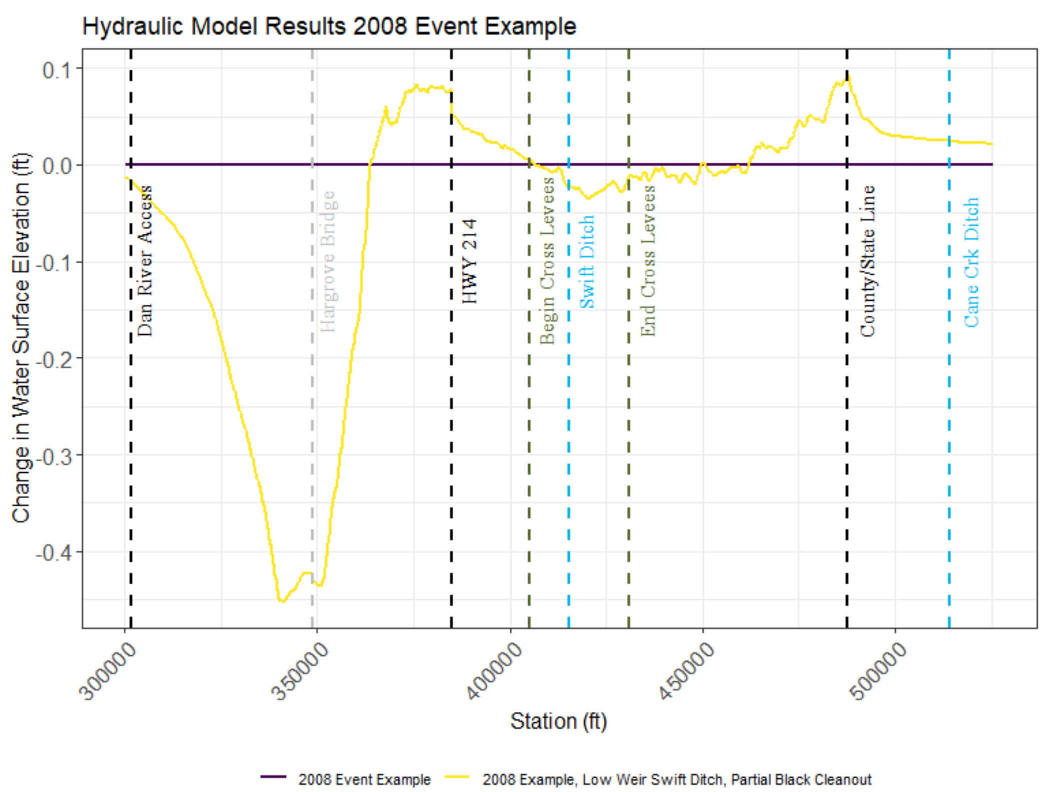

Figure 38 Change in water surface elevation for partial channel cleanout and low water weir for 2008 event

Peak elevation reduction is an important aspect to consider, but for local drainage concerns outside the levees in agriculture the change in duration is another important consideration. Anticipated changes in duration are challenging to quantify as duration is highly variable with the nature of the volume of a rain event. In general, the channel cleanout scenario did not appreciably change the duration enough to be considered a widespread benefit to agricultural stakeholders. The flow moves downstream more efficiently but is sustained above a bankfull threshold for about the same amount of time. The lack of duration reduction is not meaningful to reduce agricultural damages when the events generally can last weeks.

Levee setbacks

Setting back the levees by providing a distance of land between the river channel and the flood protection, while generally unpopular for landowners, is a common best management practice presented in this study for context and consideration. By maintaining more floodplain, setting back the levees would increase conveyance for flow to spread out and decrease velocities. Ultimately, setting back the levees would reduce the water surface elevations and relieve pressure on the levees as well as durations of bankfull flood levels. Determining detailed designs and locations for setback levees is beyond the scope of this study; however, the juxtaposition of the impact of levee setbacks and other suggestions is important for floodplain management decisions. It is imperative to understand that the detailed layout of this scenario is not a specific recommendation – there are no current plans to set the levees back based on the particulars of this study. In the model, levees with significant constrictions were setback on average between 800 – 1500 feet away from the river's edge either side. The conceptual setbacks with additional floodplain evaluated are shown in Figure 42. A one-dimensional model previously developed for developing storage-outflow relationships for a hydrologic model was used for the levee setback scenario. The one-dimensional model was still calibrated and was simpler to develop and quantify the levee setback concept than the two-dimensional model. The average maximum water surface reduction was approximately 2 feet for 4,400 cfs and for 2.5 feet 8,000 (Figure 39 and Figure 40). Downstream of Hargrove Pivot Bridge experienced water surface elevation drops of 4-6 feet. The average reduction in water surface elevation for the 2008 event was close to 2.5 feet with reductions of 3-5 feet upstream of Highway 214 (Figure 41).

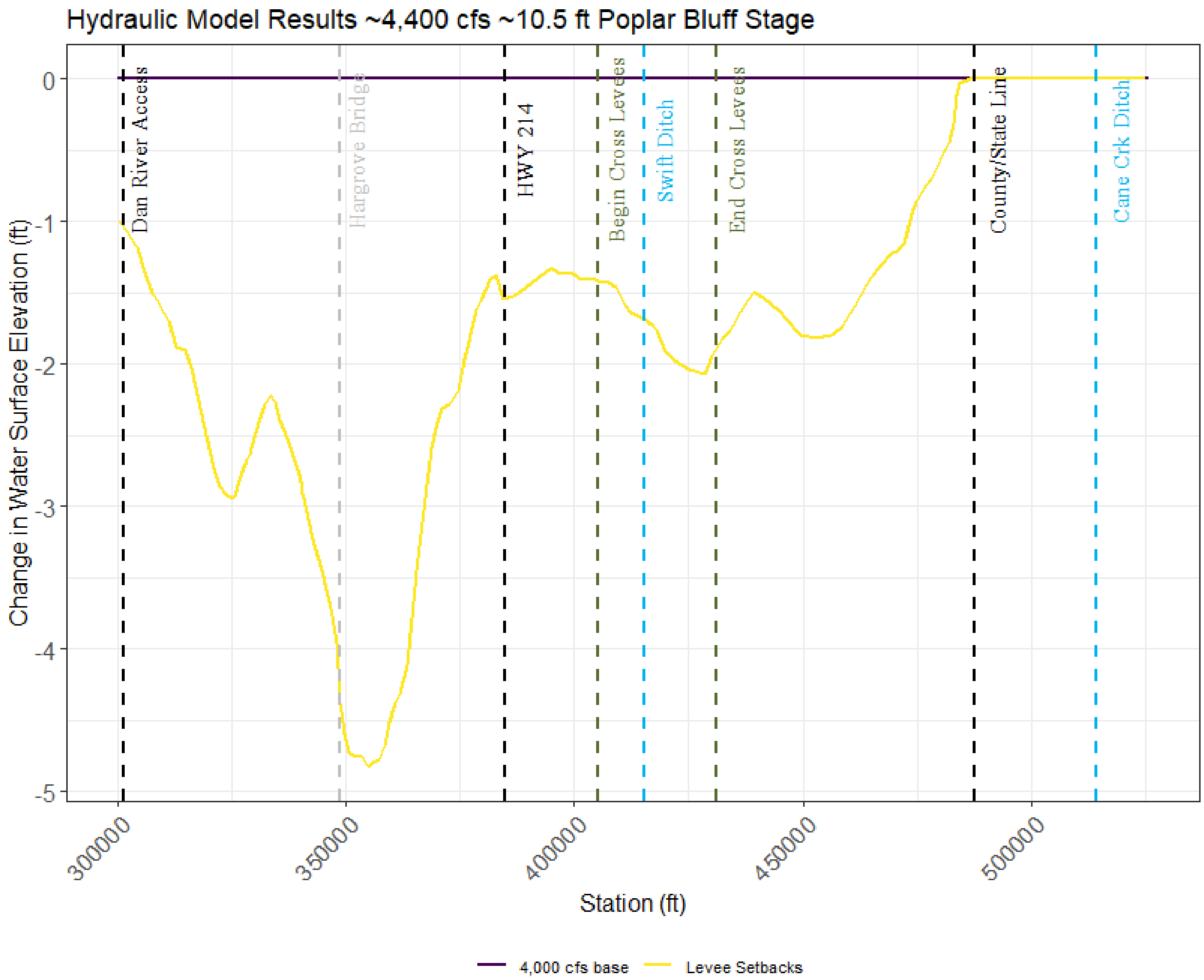

Figure 39 Change in water surface elevation for levee setbacks for 4,400 cfs

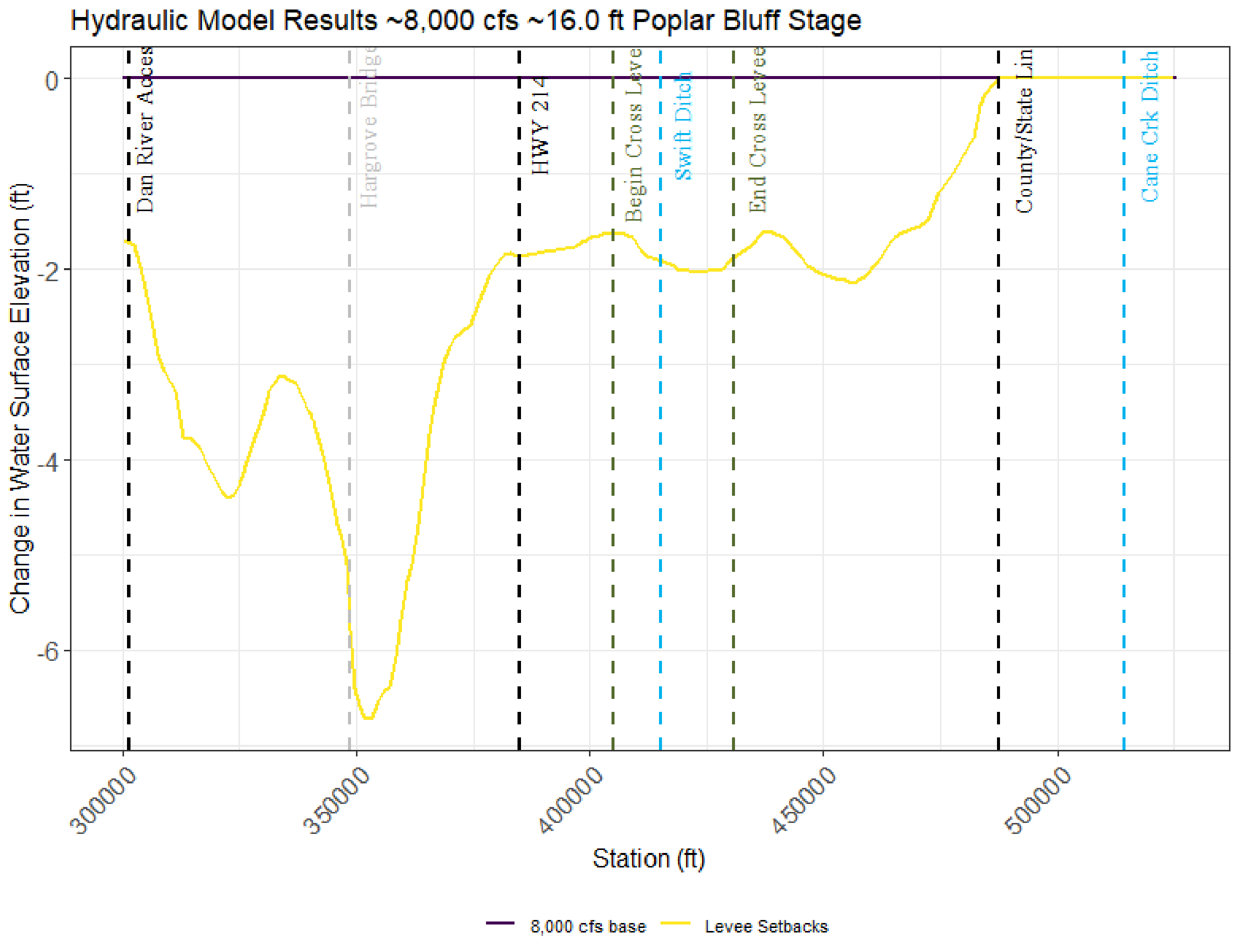

Figure 40 Change in water surface elevation for levee setbacks for 8,000 cfs

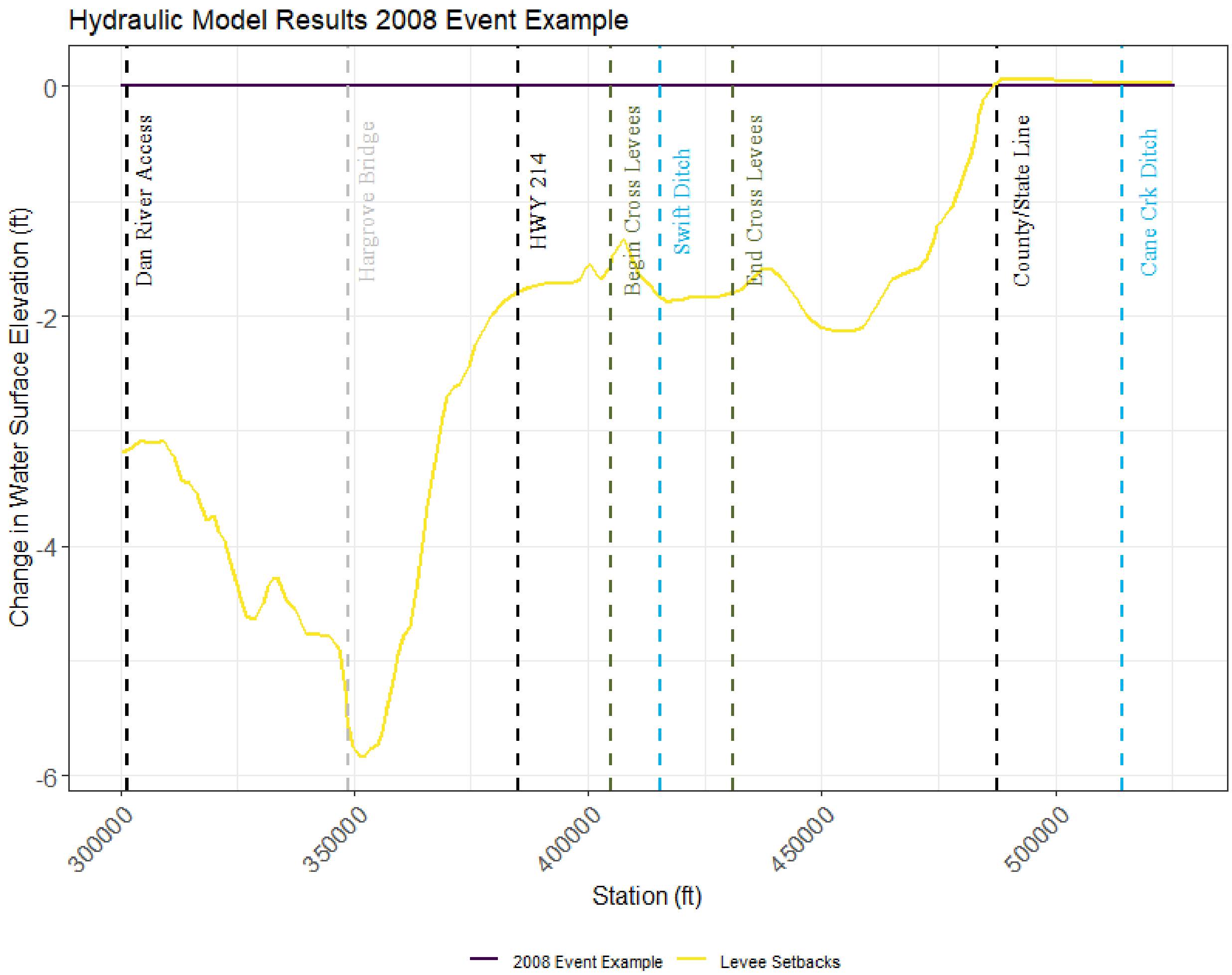

Figure 41 Change in water surface elevation for levee setbacks for 2008 example event

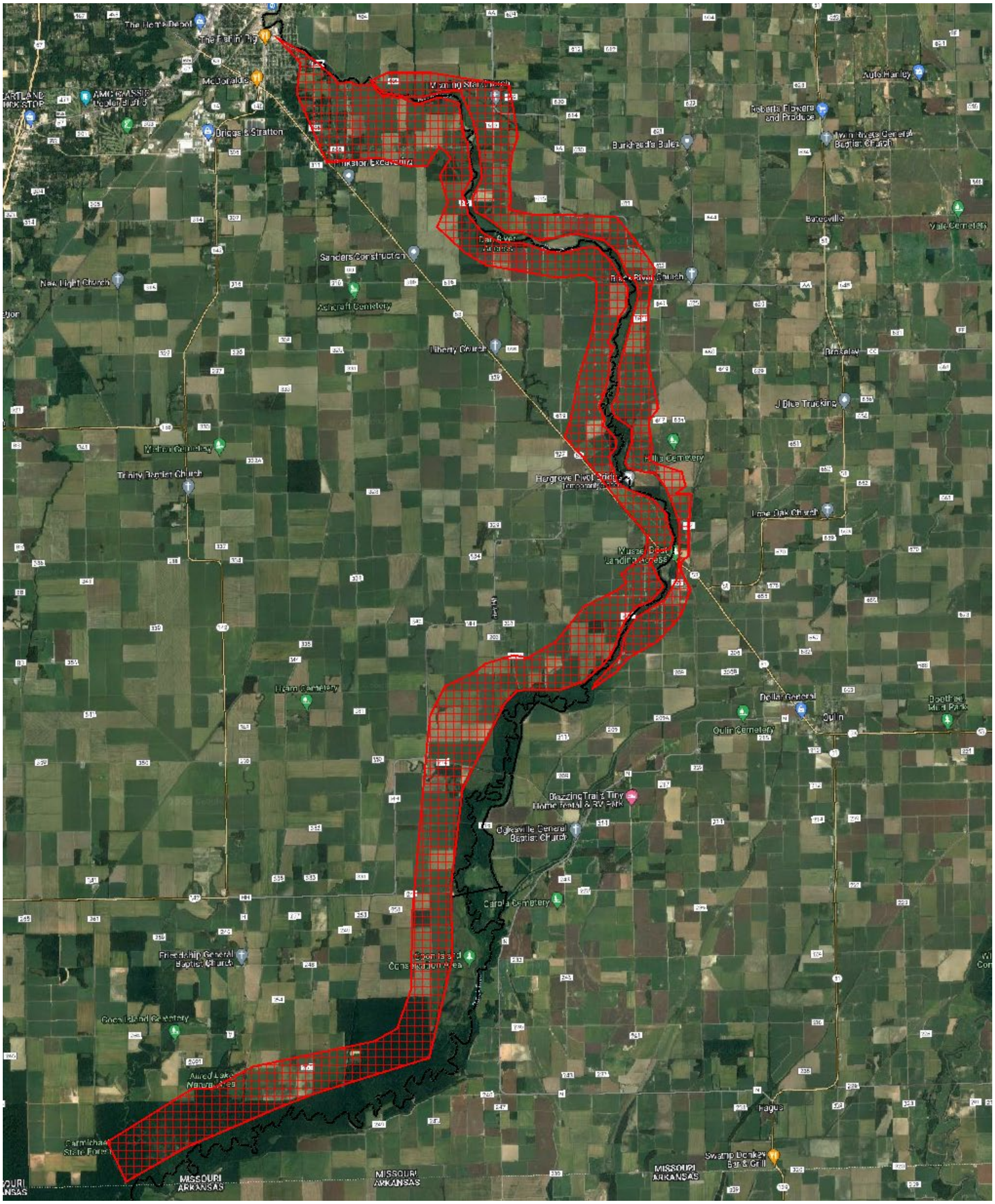

Figure 42 Levee setback concept evaluated (hatched area represents floodplain additions)

Peak elevation reduction is an important aspect to consider, but for local drainage concerns outside the levees in agriculture the change in duration is another important consideration. Anticipated changes in duration are challenging to quantify as duration is highly variable with the nature of the volume of a rain event. In general, the levee setback scenario significantly reduced durations above bankfull flow. Durations above bankfull flow were greater than 2 weeks under existing conditions which was shortened to approximately 4 days with levee setbacks.

Additional Considerations

While the study was comprehensive in terms of quantifying relative impacts from different sources of flooding and drainage concerns, the results presented in this report are not intended to be for comprehensive design and implementation nor optimized to meet a variety of watershed planning objectives. The study effort aided the understanding of the complex issues in the watershed and can be built upon in greater detail as an implementation strategy is developed within the watershed for a variety of objectives and constraints. Progressions of watershed studies and objectives often lead to additional ideas and considerations that time and funding do not always allow for full quantification. Some of these ideas discussed and noted for record as the planning process continues to develop are:

- Including additional drainage through Highway 214
- A more realistic layout for levee setbacks
- Consideration of low water weirs in levee locations that feed ditches to act as a floodway
- Optimizing the height of the low water weir at Swift Ditch takeover point.
- Pumping drainage ditches back into the river
- Increasing levee heights

Conclusion

Increasing trends in precipitation, streamflow, baseflow, and flood flows have occurred in the Black River Watershed in southern Missouri and northern Arkansas causing agricultural challenges and damages. Adjustments to Clearwater Dam operations were shown to have no benefit to areas downstream while increasing the risk to the dam by holding higher pools longer. Some channel improvements to the Black River could be considered best management practices – especially debris removal as the debris can cause deposition in the channel as well present a life safety hazard but has little effect on lowering the water levels during flooding conditions. Adding a low water weir at Swift Ditch would force more flow into the old Black River channel and steadily erode previous deposits, restoring additional channel capacity. Levee setbacks should also be considered as a best management practice as this scenario greatly reduced water surface elevations, pressure on the levees, and durations above bankfull flow. Invasive cleanouts (dredging) and channel straightening are not recommended due to the proximity of the levees and resulting bank failures that would arise as the river would attempt to equalize with the change in slope. Environmental damages would also be expected with such invasive measures as floodplains would become disconnected and turbidity would increase. The most promising mitigation from a practical standpoint to the flooding concerns in Butler County is to focus on local drainage ditches utilizing two-stage ditches and implement levee setbacks. These ditch designs would help convey the existing groundwater and allow for a more targeted approach to draining existing agricultural land repeatedly and timelier than channel improvements to the Black River. Levee setbacks would not only lower water surface elevations for nearly the full range of flows, but it also reduces the pressure and risk of failure on the existing levee layout.

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Appendix A – Stakeholder Comments

Butler County Commission

SECOND FLOOR - ROOM 203 - BUTLER COUNTY COURTHOUSE
POPLAR BLUFF, MO 63901

VINCE LAMPE
PRESIDING COMMISSIONER

DON ANDERSON
EASTERN DISTRICT

DENNIS LEGRAND
WESTERN DISTRICT

Phones: 573-686-8081
573-686-8069

May 3, 2023

US Army Corps of Engineers-Little Rock District
700 W Capitol Ave
Little Rock, AR 72201

To Whom It May Concern:

It has come to our attention that with the continuing problem of the debris littering Black River, it is in need of debris removal and cleaning. This is causing erosion on the levees as the water level rises.

Your help is appreciated in this matter.

Vince Lampe
Presiding Commissioner

Don Anderson

Don Anderson
Eastern District Commissioner

Dennis LeGrand
Western District Commissioner