Appendix K
Hydrologic and Hydraulic Engineering

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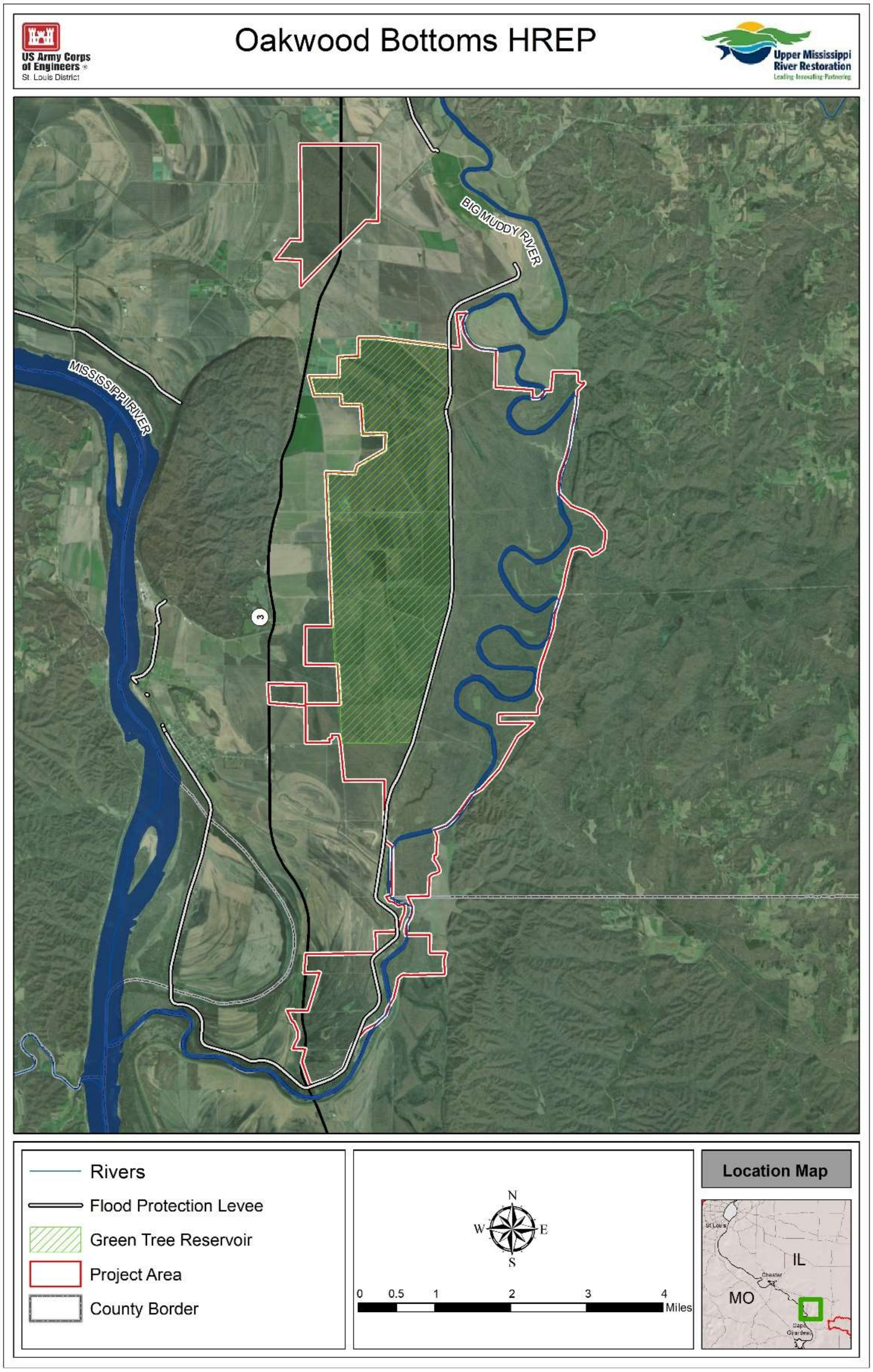
1 EXISTING CONDITIONS

Part of the USFS national forest portfolio is the Shawnee National Forest, which includes approximately 280,000 acres of upland and bottomland forest in southern Illinois. Oakwood Bottoms Green Tree Reservoir, consisting of approximately 13,500 acres bottomland forest and wetlands, is located within the Shawnee National Forest in the Mississippi River floodplain on the left descending bank of the Mississippi River between River Miles (RM) 73-84 in Jackson County, Illinois. The Oakwood Bottoms HREP focuses on the 4,700-acre Greentree Reservoir portion of Oakwood Bottoms (Oakwood Bottoms Greentree Reservoir, or OBGTR). (


Oakwood Bottoms HREP
US Army Corps of Engineers
St. Louis District
Upper Mississippi River Restoration
Leading Innovating Partnering
BIG MUDDY RIVER
MISSISSIPPI RIVER
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Rivers
Flood Protection Levee
Green Tree Reservoir
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Location Map
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Figure 1).

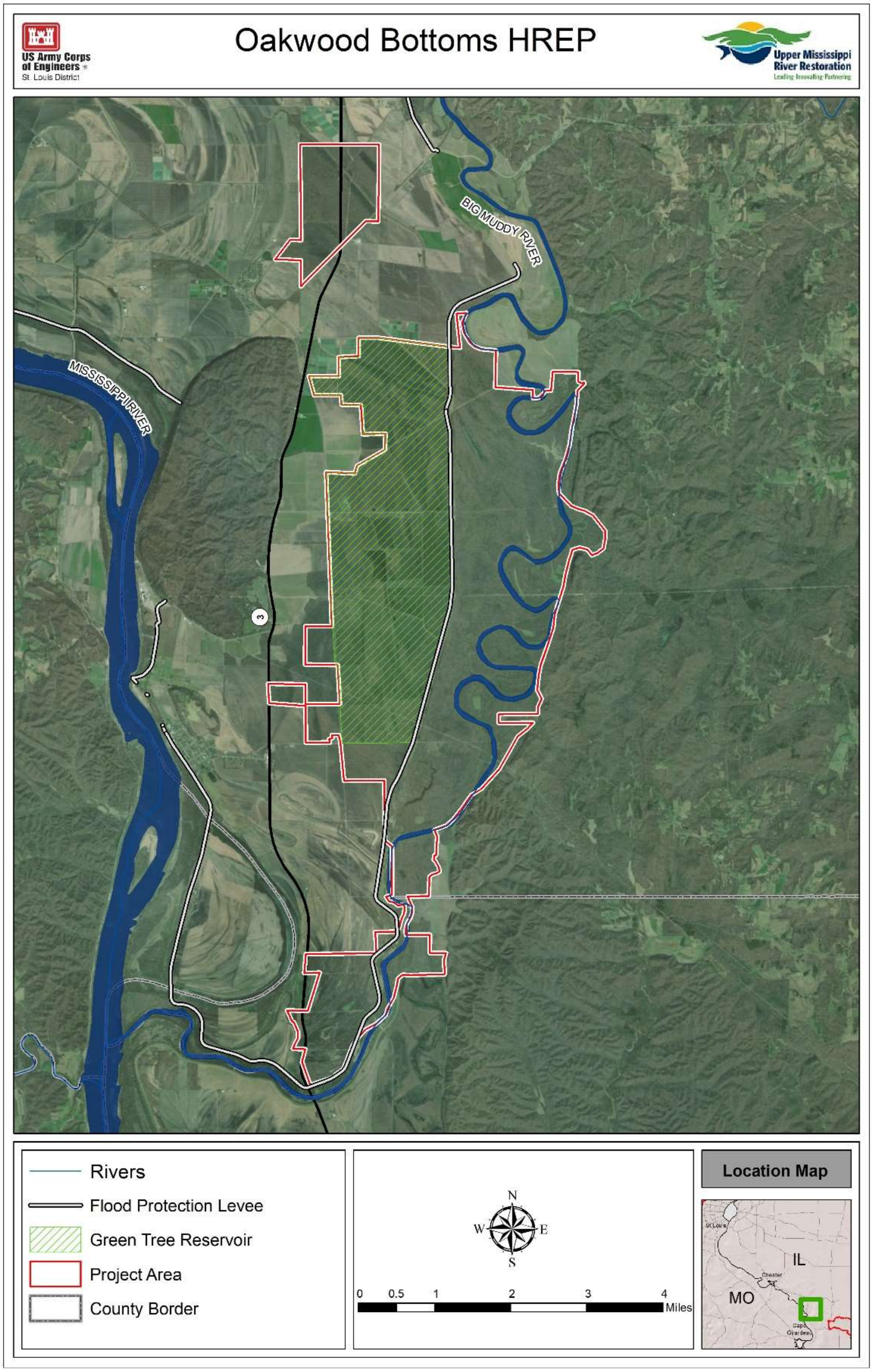
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Figure 1 – Study Area Map

The majority of OBGTR was intensively farmed and or grazed prior to USFS acquisition in the late 1930s. As part of the early agricultural development, drainage ditches, fences and buildings were constructed by the landowners. The Degognia and Grand Tower Levee System, built in 1945, separated the current-day OBGTR from the Big Muddy River floodplain, which initiated a hydrologic functionality change for lands west of the newly constructed levee system.

1.1 Pertinent Data for Hydraulic Modeling

In terms of hydrologic and hydraulic engineering for existing conditions, the main objective was to develop a hydraulic model of the Oakwood Bottoms Green Tree Reservoir that would enable the simulation of flow of water within and around the reservoir. Simulation of both draining and filling of the reservoir was desired. A hydraulic modeling technique known as two-dimensional modeling was used. This technique makes possible the depiction of the movement of water in accordance with gravity, details of the terrain, berms and water control structures (WCS). The calculations for two-dimensional hydraulic modeling are detailed, complex and time intensive. The advanced computing capability of contemporary computers makes routine use of this modeling technique possible. Several computer programs were used for the hydraulic modeling, one of which was used to perform the hydraulic calculations with the other programs providing support to the modeling process. Data that is required for development of a two-dimensional hydraulic model includes information on the topography, WCS and land cover.

1.2 Computer Programs

The computer program that was used to perform the hydraulic calculations is the Hydrologic Engineering Center River Analysis System (HEC-RAS), Version 5.0.7 (March 2019). This program was developed by U.S. Army Corps of Engineers (USACE) HEC (Davis, California). An earlier version of this program, Version 5.0.5 (June 2018), was used in the early stages of this project. Geometric drawing and calculations were performed with the computer program ArcMap 10.3.1. This program was developed by the Environmental Systems Research Institute, Inc. (ESRI, 2015). Visualization with aerial photography was accomplished with the computer program Google Earth Pro, which was developed by Google Inc. (2015). The computer program Microsoft Excel was used for spreadsheet calculations.

1.3 Topographic Data

The topographic data used for the hydraulic modeling was LiDAR data that was received from USACE St. Louis District (MVS) Geodesy, Cartography and

Photogrammetry Branch (EC-S). The vertical datum for the LiDAR data was the North American Vertical Datum of 1988 (NAVD88). For more information regarding the topographic survey that resulted in the LiDAR, please see Appendix B – *Civil Engineering* and Appendix L – *Structural Engineering*. An image of the LiDAR data is shown in Figure 2, and the various colors indicate ranges of topographic elevations. The scale for the colors and corresponding elevations is given in the bottom right corner of the figure.

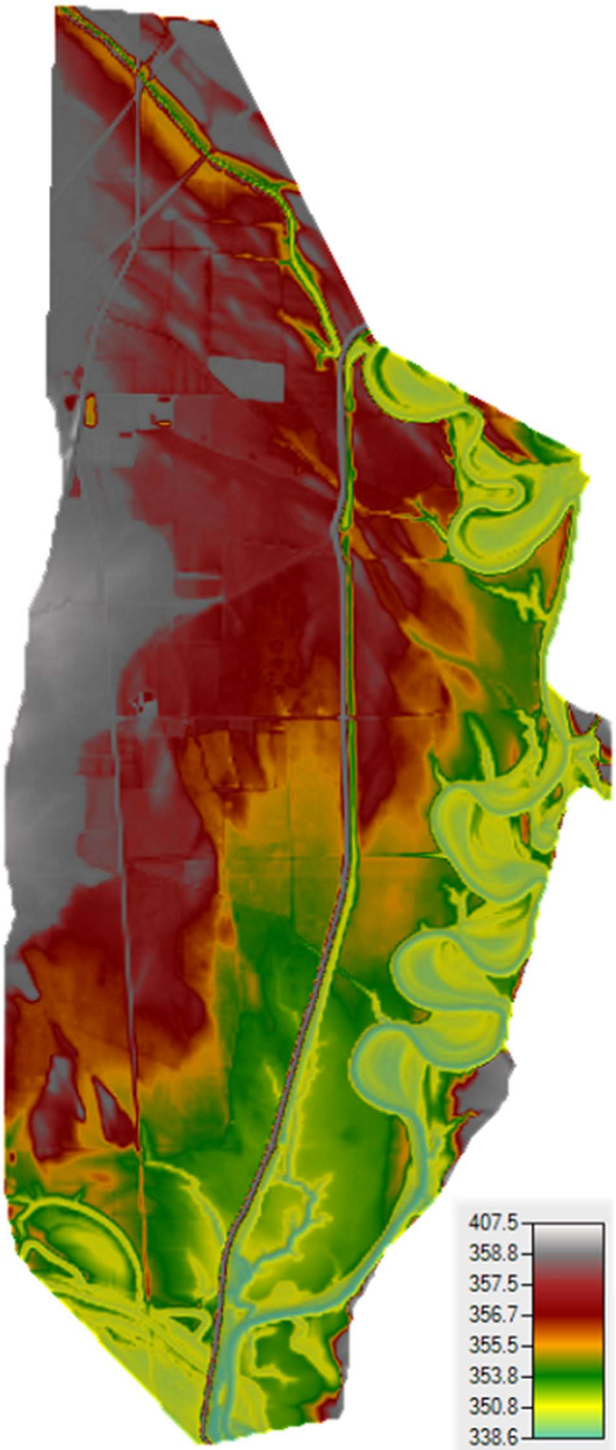


Figure 2 – Image of LiDAR Data

1.4 Water Control Structure Data

The WCS data used for the existing conditions hydraulic modeling was taken from five sources. All five sources provided valuable information for the modeling.

The first source is a document that was received from the U.S. Forest Service (USFS) in Jonesboro, Illinois. This document is entitled "Oakwood Bottoms Green Tree Reservoir Operation Guide and Management Plan" (Chad Deaton, USFS Wildlife Biologist; Hidden Springs / Mississippi Bluffs Ranger District; Shawnee National Forest; 27 January 2014). This document has information on existing WCS, existing wells and pumps, and the existing pipeline system used to distribute well water within OBGTR. Some information on the structures located within the Degognia and Grand Tower Levee System of the Big Muddy River are also included.

The second source is a collection of documents developed by Bowen Engineering and Surveying, P.C., a consultant in Cape Girardeau, Missouri. These documents summarize the planimetric and topographic surveys of the Oakwood Bottoms Green Tree Reservoir and its various components. Three of these Bowen Engineering documents were used for the hydraulic modeling of existing conditions. This information was collected during the first half of 2018, and the documents were finalized in July 2018. Water control structures that are located within the berms of the OBGTR are discussed, as are the structures located within the Degognia and Grand Tower Levee System. Information that was requested of the consultant for each WCS included horizontal coordinates of the pipe, shape, invert elevation, dimensions, material, and berm elevation profile. The vertical datum for the survey data was NAVD88.

The third source is a survey of WCS conducted by USACE. This survey was conducted to obtain survey data for WCSs that were not included in the survey conducted by Bowen Engineering and Surveying, P.C., or were not able to be obtained during the Bowen surveying. This information was collected during April 2019. Information that was requested of EC-S for each WCS included pipe horizontal coordinates, shape, invert elevation, dimensions, and material. The vertical datum for the survey data was NAVD88.

The fourth source was the National Levee Database (NLD). The NLD is the authoritative resource for information about levees in the United States. It is an internet-based information system that connects levee-related information and activities. It was authorized by Congress in 2007 and was developed by USACE. The NLD can be found at internet address https://levees.sec.usace.army.mil/.

The fifth source was a file received from EC-S that was designed to be loaded onto the computer program Google Earth Pro. When loaded onto this computer program, levee stationing can be viewed, as well as engineering and survey data for the gravity drains that are located within the levee. The name of the file is GrandTowerDegogniaLeveeFeatures.kmz. The vertical datum for the data was NAVD88.

To compare the available data for the Degognia and Grand Tower Levee System gravity drains, a document was written that contained the pertinent data from the second and fourth sources of data mentioned in the previous paragraphs. This document is shown in TABLE 1. Several items of pertinent data that were not able to be determined are indicated by question marks. The Bowen Engineering data was used for the existing conditions model because it is the most recently collected date. If it was unavailable from the Bowen documents, the EC-S data was then used.

Table 1 – Comparison of Available Data for Degognia and Grand Tower Levee System Gravity Drains

Levee System Gravity Drain	Bowen Engineering & Surveying data	Data received from EC-S
levee station 0714+90	18-in. HDPE surrounded by concrete ups. inv. el. = 346.112 ft NAVD88 dwn. inv. el. = 344.197 ft NAVD88 gate structure on east side of levee inv. el. = 344.203 ft NAVD88	slip-lined 30-in. CMP 21-in. HDPE ups. inv. el. = 346.235 ft NAVD88 dwn. inv. el. = 344.271 ft NAVD88 sluice gate
levee station 0731+55	west pipe and east pipe underwater and unable to be located gate structure on east side of levee inv. el. = 343.033 +/- ft NAVD88 (sediment in bottom of structure)	slip-lined 42-in. CMP 30-in. HDPE ups. inv. el. = 344.701 ft NAVD88 dwn. inv. el. = 343.252 ft NAVD88 sluice gate

Levee System Gravity Drain	Bowen Engineering & Surveying data	Data received from EC-S
levee station 0759+59	west pipe 27-in. HDPE east pipe underwater and unable to be located ups. inv. el. = 347.657 ft NAVD88 gate structure on east side of levee inv. el. = 344.036 ft NAVD88	slip-lined 36-in. CMP 27-in. HDPE ups. inv. el. = 347.738 ft NAVD88 dwn. inv. el. = 342.885 ft NAVD88 sluice gate
levee station 0787+49	west pipe 60-in. CMP (rusted out) ups. inv. el. = 345.072 ft NAVD88 dwn. inv. el. = 343.841 ft NAVD88 east end of pipe ends at gate structure	72-in. CMP to be slip-lined in the future ups. inv. el. = 345.248 ft NAVD88 dwn. inv. el. = 344.548 ft NAVD88 sluice gate
levee station 0787+62	west pipe 60-in. HDPE ups. inv. el. = 345.461 ft NAVD88 dwn. inv. el. = 343.841 ft NAVD88 east end of pipe ends at gate structure	slip-lined 72-in. CMP 60-in. HDPE ups. inv. el. = 345.627 ft NAVD88 dwn. inv. el. = 344.569 ft NAVD88 sluice gate
levee station 0824+77	west pipe and east pipe underwater and unable to be located gate structure on east side of levee inv. el. = 348.022 +/- ft NAVD88 (sediment in bottom of structure)	66-in. CMP ? (according to the National Levee Database), but a survey indicated 60-in. ups. inv. el. = 350.5 ft NAVD88 dwn. inv. el. = 348.63 ft NAVD88
levee station 0877+98	west pipe 54-in. HDPE east pipe 54-in. HDPE	slip-lined 66-in. CMP ? -in. HDPE
	ups. inv. el. = 351.418 ft	ups. inv. el. = 352.194 ft

Levee System Gravity Drain	Bowen Engineering & Surveying data	Data received from EC-S
	NAVD88 dwn. inv. el. = 349.586 ft NAVD88 gate structure on east side of levee inv. el. = 349.967 ft NAVD88	NAVD88 dwn. inv. el. = 351.565 ft NAVD88 sluice gate
levee station 0938+10	west pipe 36-in. HDPE east pipe underwater and unable to be located ups. inv. el. = 350.981 ft NAVD88 gate structure on east side of levee inv. el. = 350.199 ft NAVD88	42-in. CMP ups. inv. el. = ? dwn. inv. el. = ? sluice gate
levee station 0961+28	west pipe 36-in. HDPE east pipe 36-in. HDPE ups. inv. el. = 350.643 ft NAVD88 dwn. inv. el. = 348.308 ft NAVD88 gate structure on east side of levee inv. el. = 349.457 ft NAVD88	slip-lined 48-in. CMP 42-in. HDPE ups. inv. el. = 354.358 ft NAVD88 dwn. inv. el. = 353.217 ft NAVD88 sluice gate

1.5 Land Cover Data

During the early stages of hydraulic modeling of existing conditions, land cover data that is available within the computer program HEC-RAS was used to determine the aerial extents of various land uses. A representative roughness parameter used in hydraulic modeling known as the Manning's n value was assigned to each of the 12 land uses that existed within, and in the vicinity of, the Green Tree Reservoir. Two of the project design team members, the forester and the biologist, viewed the land cover data that was originally used in the hydraulic modeling. They determined that a more-detailed representation of land cover / land use information was available from USACE Upper Mississippi River Restoration Program Long Term Resource Monitoring (UMRR LTRM). The aerial extents of the various land uses contained in this UMRR LTRM information are shown in FIGURE 3.

There are 54 different land uses contained in this information. A cooperative effort of the hydraulic engineer, the forester and the biologist resulted in a Manning's n value being assigned to each of the 54 land uses. These n values range from 0.012 to 0.15 for the OBGTR and the adjoining Big Muddy River floodplain with was used for an exterior boundary conditions. The land cover designation, the Manning's n value and the land cover description for the 54 land uses are given in Table 2. This information was used in the hydraulic modeling instead of the roughness data used during the early stages of the work since it provided greater detail and a better representation of on-site conditions. The Degognia and Grand Tower Levee of the Big Muddy River is located near the center of FIGURE 2, and extends from the top of the image to the bottom. The computer program HEC-RAS has a mapping and animation utility named RAS Mapper. The image shown in FIGURE 3 was taken from RAS Mapper. The Manning's n value that was assigned to any of the 54 land uses can be determined by mouse clicking on the location of interest, and the information will be displayed (e.g., the information shown as "1='ag' n=0.035").

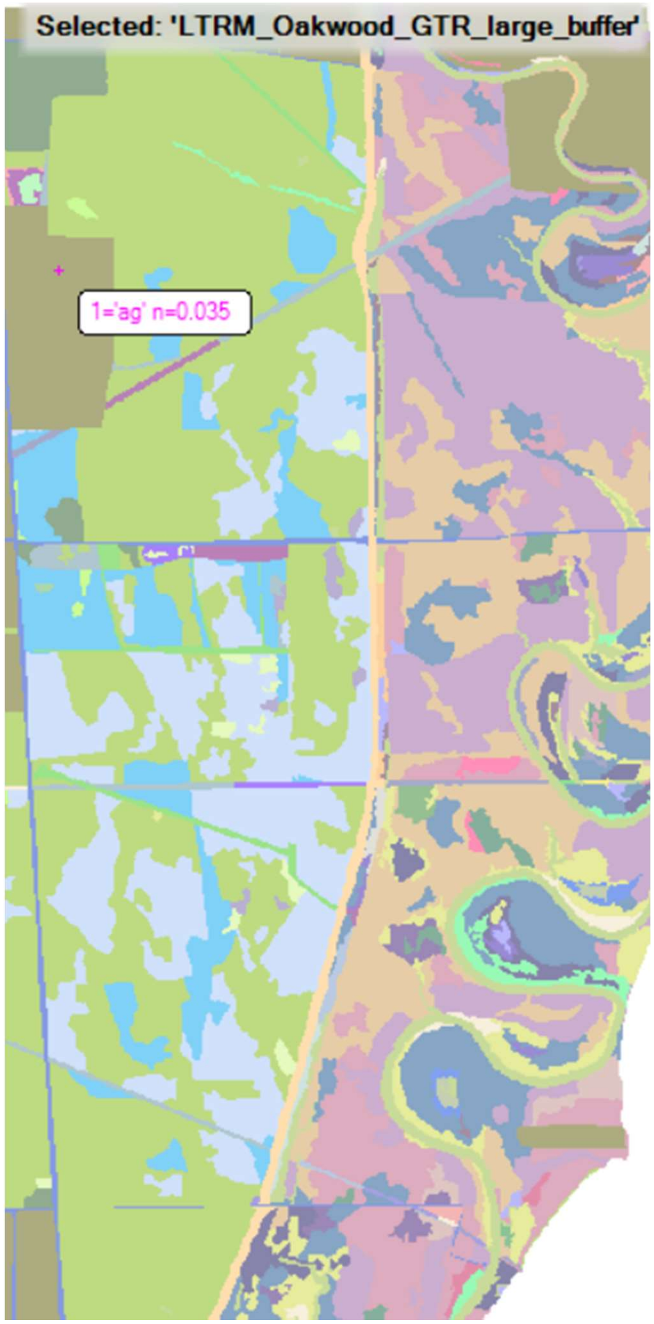


Figure 3 – UMRR LTRM Land Use / Land Cover Information

Table 2 - Land Cover Designation, Manning's n Value and Land Cover Description for 54 Land Uses

Land Cover Designation	Manning's n Value	Land Cover Designation
ag	0.035	agriculture
ffb2	0.070	floodplain forest, 33-66% density, 20-50 feet
ffb3	0.070	floodplain forest, 33-66% density, > 50 feet
ffc1	0.080	floodplain forest, 66-90% density, 0-20 feet
ffc2	0.080	floodplain forest, 66-90% density, 20-50 feet
ffc3	0.080	floodplain forest, 66-90% density, > 50 feet
ffd1	0.100	floodplain forest, > 90% density, 0-20 feet
ffd2	0.100	floodplain forest, > 90% density, 20-50 feet
ffd3	0.100	floodplain forest, > 90% density, > 50 feet
lfa1	0.100	lowland forest, 10-33% density, 0-20 feet
lfa3	0.100	lowland forest, 10-33% density, > 50 feet
dmsa	0.060	deep marsh shrub, 10-33% density
lfb1	0.100	lowland forest, 33-66% density, 10-20 feet
lfb2	0.100	lowland forest, 33-66% density, 20-50 feet
lfb3	0.100	lowland forest, 33-66% density, > 50 feet
lfc2	0.100	lowland forest, 66-90% density, 20-50 feet
lfc3	0.100	lowland forest, 66-90% density, > 50 feet
lfd1	0.100	lowland forest, > 90% density, 0-20 feet
lfd2	0.100	lowland forest, > 90% density, 20-50 feet
lfd3	0.100	lowland forest, > 90% density, > 50 feet
lvd	0.030	levee grass/forbs, > 90% density
ow	0.070	open water
dmsc	0.070	deep marsh shrub, 66-90% density
pcc3	0.100	populus community, 66-90% density, > 50 feet
pcd3	0.100	populus community, > 90% density, > 50 feet
rdd	0.020	roadside grass/forbs, > 90% density
sb	0.020	sand bar
scb2	0.150	salix community, 33-66% density, 20-50 feet
scc2	0.150	salix community, 66-90% density, 20-50 feet
scd1	0.150	salix community, > 90% density, 0-20 feet
scd2	0.150	salix community, > 90% density, 20-50 feet
scd3	0.150	salix community, > 90% density, > 50 feet
smaa	0.040	shallow marsh annual, 10-33% density

dmsd	0.080	deep marsh shrub, > 90% density
smab	0.060	shallow marsh annual, 33-66% density
smac	0.060	shallow marsh annual, 66-90% density
smad	0.060	shallow marsh annual, > 90% density
smpd	0.060	shallow marsh perennial, > 90% density
smsa	0.060	shallow marsh shrub, 10-33% density
smsb	0.060	shallow marsh shrub, 33-66% density
smsc	0.060	shallow marsh shrub, 66-90% density
smsd	0.060	shallow marsh shrub, > 90% density
wmb	0.035	wet meadow, 33-66% density
wmc	0.035	wet meadow, 66-90% density
dv	0.012	developed
wmd	0.050	wet meadow, > 90% density
wmsa	0.060	wet meadow shrub, 10-33% density
wmsb	0.080	wet meadow shrub, 33-66% density
wmsc	0.080	wet meadow shrub, 66-90% density
wmsd	0.100	wet meadow shrub, > 90% density
ffa1	0.060	floodplain forest, 10-33% density, 0-20 feet
ffa2	0.060	floodplain forest, 10-33% density, 20-50 feet
ffa3	0.060	floodplain forest, 10-33% density, > 50 feet
ffb1	0.070	floodplain forest, 33-66% density, 0-20 feet

1.6 Major Rivers near Project Site and Their Effect upon Operations

The Oakwood Bottoms Green Tree Reservoir lies near the confluence of the Mississippi River and the Big Muddy River. It lies between these two major rivers, and its operation is affected by these rivers. The mouth of the Big Muddy River lies at Mississippi River mile 75.7. Mississippi River gages that are closest to the mouth of the Big Muddy River are at Grand Tower, Illinois (river mile 81.9), and at Moccasin Springs, Missouri (river mile 66.3). For the gage at Grand Tower, the drainage area upstream of it is 709,210 square miles and flood stage is defined as 28 feet. For the gage at Moccasin Springs, the drainage area upstream of it is 711,696 square miles and flood stage is defined as 28 feet. The Big Muddy River gage that is closest to its mouth is near Sand Ridge, Illinois. This gage is located at Big Muddy River mile 27.6 and has a drainage area upstream of it of 2,240 square miles. Historic daily data for the two Mississippi River gages and the Big Muddy River gage were used to develop data to assess the effect of these major rivers upon the operation of the Oakwood Bottoms Green Tree Reservoir.

Because two major rivers affect the operation of the Oakwood Bottoms Green Tree Reservoir, it was desired to compare historical data for the two Mississippi River gages and the one Big Muddy River gage that were involved in the analysis. One way to compare historical data for the three gages was to plot average daily stages or elevations for the same period of record, and then to compare the general shapes of the hydrographs of average daily stages or elevations. Since it was planned to develop plots of average daily stages or elevations for three river gages, it was important to use the same period of record for each gage. The periods of record were examined for the three gages, and it was learned that the location of the Grand Tower gage changed in April 1960. Therefore, the first full year that the Grand Tower gage was at its present location was 1961. The periods of record for the other two river gages (Moccasin Springs and Sand Ridge) both began prior to 1961. At the time these plots were developed, the last full year of data that was available for all three gages was 2017. Therefore, it was decided to use the period of record of 1961 through 2017 to develop the plots for all three river gages.

The following plots were developed: average daily stages for the Grand Tower and Moccasin Springs gages and average daily elevations for the Sand Ridge gage. In developing the plots, the use of stages for two of the gages and elevations for the other was dictated by the computer utility used to develop the plots. Mississippi River at Grand Tower average daily stages in feet for the period of 1961 through 2017 are shown in FIGURE 4. Mississippi River at Moccasin Springs average daily stages in feet for the period of 1961 through 2017 are shown in FIGURE 5. Big Muddy River near Sand Ridge average daily elevations in feet NGVD29 for the period 1961 through 2017 are shown in FIGURE 6. It was judged that, if the general shapes of the average daily hydrographs for these three spatially close river gages for the same period of record were similar, that duration analyses developed for these three gages could be used to draw conclusions about the historical behavior of these rivers within the vicinity of these three gages.

The general shapes of the plots for Mississippi River gages in FIGURE 4 and FIGURE 5 are very similar. This similarity is expected since both the Grand Tower and Moccasin Springs gages are located only 15.6 miles apart, and the drainage area upstream of the Moccasin Springs gage is only 0.35 percent larger than that upstream of the Grand Tower gage.

The general shape of the plot for the Big Muddy River gage in FIGURE 6 is similar to those for the Mississippi River gages in FIGURE 4 and FIGURE 5. The plots for all three gages exhibit the ascension-side of the hydrograph beginning during mid-February, the peak of the hydrograph occurring during early May, and the bottom of the recession side of the hydrograph occurring during late August. One difference between the shapes of the plots for the Mississippi River gages in FIGURE 4, FIGURE 5, and the Big Muddy River gage in FIGURE 6 is that the Big Muddy River gage shows a gradual rise beginning during mid-November. It was judged that the hydrographs in FIGURE 4,

FIGURE 5 and FIGURE 6 during most of the calendar showed similarities such that duration analyses developed for these three gages for the same period of record were worth comparing. Thus, the duration analyses were used to draw conclusions about the historical behavior of these rivers within the vicinity of these three gages.

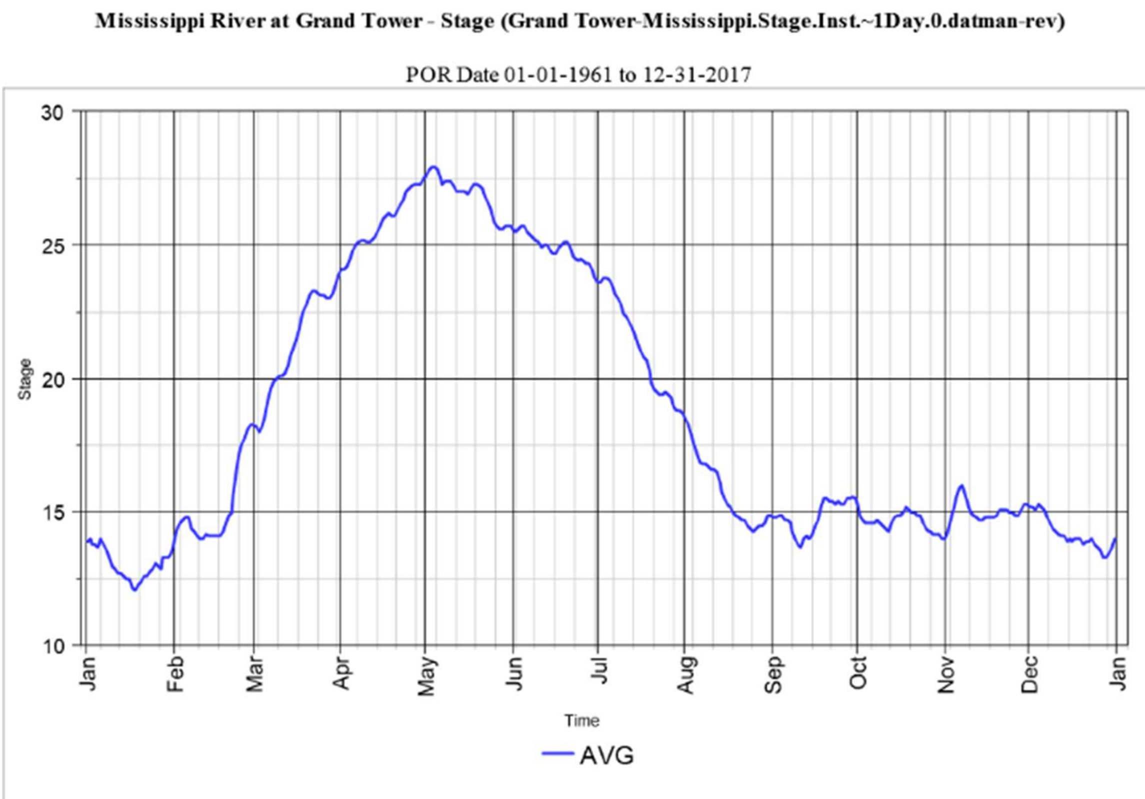


Figure 4 – Mississippi River at Grand Tower Average Daily Stages (feet), 1961-2017

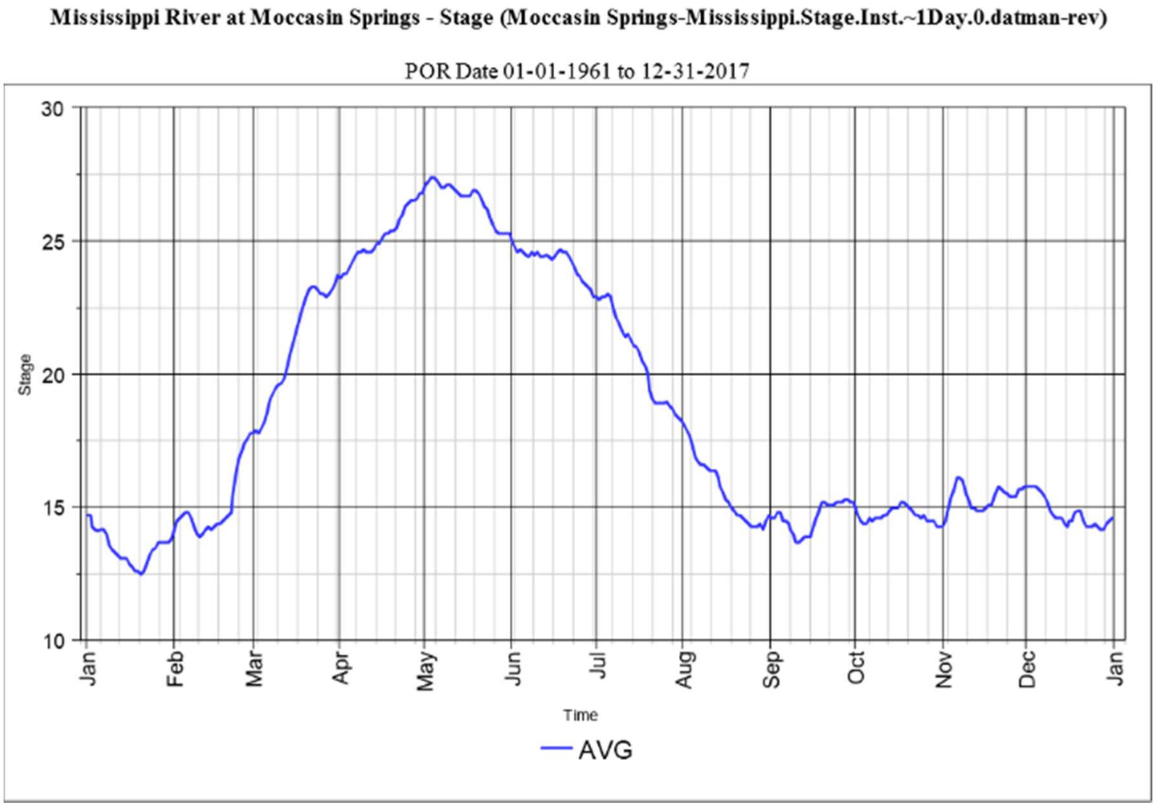


Figure 5 – Mississippi River at Moccasin Springs Average Daily Stages (feet), 1961-2017

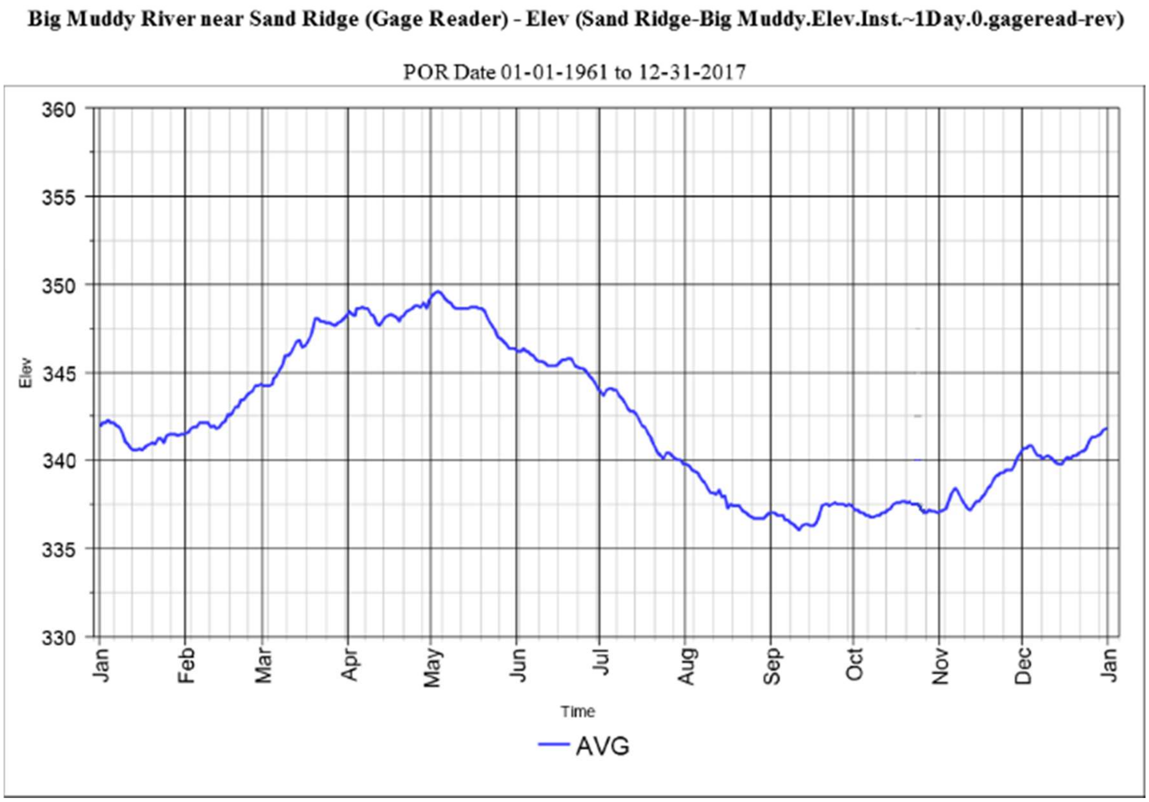


Figure 6 – Big Muddy River near Sand Ridge Average Daily Elevations (feet NGVD29), 1961-2017

Duration analyses were developed for the two Mississippi River gages and the Big Muddy River gage. The purpose of a duration analysis is to determine the percentage of time during a specified period of record that a given river level was equaled or exceeded. The same reasoning in regard to the period of record discussed above was used. The periods of record were examined for the three gages, and it was learned that the location of the Grand Tower gage changed in April 1960. Therefore, the first full year that the Grand Tower gage was at its present location was 1961. The periods of record for the other two river gages (Moccasin Springs and Sand Ridge) both began prior to 1961. However, at the time these duration analyses were developed, the last full year of data that was available for all three gages was 2018. Therefore, it was decided to use the period of record of 1961 through 2018 to develop the duration analyses for all three river gages.

Duration data were developed in five percent increments for all three river gages for durations from five percent to 100 percent. Using the Mississippi River duration data that were developed for the Grand Tower and Moccasin Springs gages, duration data for the Mississippi River at the mouth of the Big Muddy River (i.e. Mississippi River mile 75.7) was developed by linear interpolation. The Mississippi River duration data for river mile 75.7 was assumed to be representative of the duration data at the mouth of the Big Muddy River, or essentially duration data at Big Muddy River mile 0.0. Then, a plot was developed of duration data for Mississippi River mile 75.7 (Big Muddy River mile 0.0) and Big Muddy River mile 27.6 (the Sand Ridge gage location). For all durations calculated (five percent increments from five to 100 percent), the data for these two points along the Big Muddy River were plotted and the two points for each duration were connected by a straight line. These straight lines represented estimates of water-surface durations along the Lower Big Muddy River. Duration data apply to specific locations along a river, and connecting the two points for each duration with a straight line gives an estimate of duration data at locations between the two points.

The duration data that were developed as described in the previous two paragraphs were based upon the entire calendar year for all the years of the period of record for the three gages. After these duration analyses were completed and examined, members of the project design team asked if the analysis could be redone to examine a specific period of the calendar year. They requested that the period of 01 February through 31 March be examined since this is traditionally the period during which the Green Tree Reservoir is drained, in accordance with its normal operational cycle. The draining of OBGTR depends upon being able to use the gravity drains within the Degognia and Grand Tower Levee System. If the Big Muddy River rises above the invert elevation of any of these gravity drains, drainage of OBGTR is hindered or prevented and thus the normal operational cycle is disrupted.

Therefore, the analysis was redone exactly as it had been executed previously with the exception that the period of 01 February through March 31 was examined for all the years of the period of record for the three gages. As mentioned in the previous paragraph, the draining of OBGTR depends upon being able to use the gravity drains within the Degognia and Grand Tower Levee System. Thus, the invert elevations of these gravity drains is a key parameter. Invert elevations for the Degognia and Grand Tower Levee System gravity drains were taken from what was judged to be the best available data in TABLE 1. For each of the Degognia and Grand Tower Levee System gravity drains, an estimate of its respective location along the Big Muddy River (in terms of river mileage) was based upon the hydraulic model developed for the Big Muddy River by the engineers assigned to the Corps Water Management System (CWMS) Program work effort. In this model, the most-downstream cross section was located at Big Muddy River mile 0.35.

A graphical representation that combines the results of the duration analysis for the period of 01 February through 31 March and the invert elevations of the Degognia and

Grand Tower Levee System gravity drains is shown in FIGURE 7. In this figure, three durations (25, 30, and 35 percent) are plotted for the mouth of the Big Muddy River and the location of the gage near Sand Ridge (Big Muddy River mile 27.6). On the plot, the horizontal coordinate of the mouth of the Big Muddy River was estimated as river mile 0.35 (the most-downstream cross section in the CWMS model of the river). It should be noted that all elevation data were plotted in the vertical datum of NAVD88. These elevation data include water-surface elevation data for the mouth of the Big Muddy River and the Big Muddy River at the location of gage near Sand Ridge, as well as invert elevation data for the Degognia and Grand Tower Levee System Levee System gravity drains.

Only durations of 25, 30, and 35 percent are shown in FIGURE 7 because these are the durations at and around which gravity drainage through the Degognia and Grand Tower Levee System gravity drains is hindered or prevented. If gravity drainage through any of these structures is hindered or prevented, then the system of drainage through the Degognia and Grand Tower Levee System is disrupted and does not function as designed. The data shown in FIGURE 7 indicate that drainage through many of the most-downstream structures is prevented at the 33 percent duration.

A comparison of profiles from the duration analyses (first analysis for entire calendar year, second analysis for 01 February-31 March) with those from an unsteady flow model of the Big Muddy River was undertaken. The HEC-RAS hydraulic model developed for the Big Muddy River by the engineers assigned to the CWMS Program work effort was used. A flood event that occurred during 2011 was studied during model development. The average slope was calculated for five profiles that this model calculated for the 2011 flood, four along the ascension side of the flood and one at the peak of the flood. For this comparison of profiles, the reach examined in the duration analyses and in the HEC-RAS modeling extended from river mile 0.35 to river mile 28.19 (which includes the entire extent of the Oakwood Bottoms Green Tree Reservoir). A comparison of slopes of profiles from the HEC-RAS model and the duration analyses is given in Table 3. The slopes of the profiles from the HEC-RAS model are generally closer to those from the January-December 1961-2018 duration analysis. The February-March 1961-2018 duration analysis would tend to have a larger slope because of generally lower Mississippi River elevations during February-March than at most other times during the calendar year. The slope of the profiles from the HEC-RAS model compare favorably to those of both duration analyses.

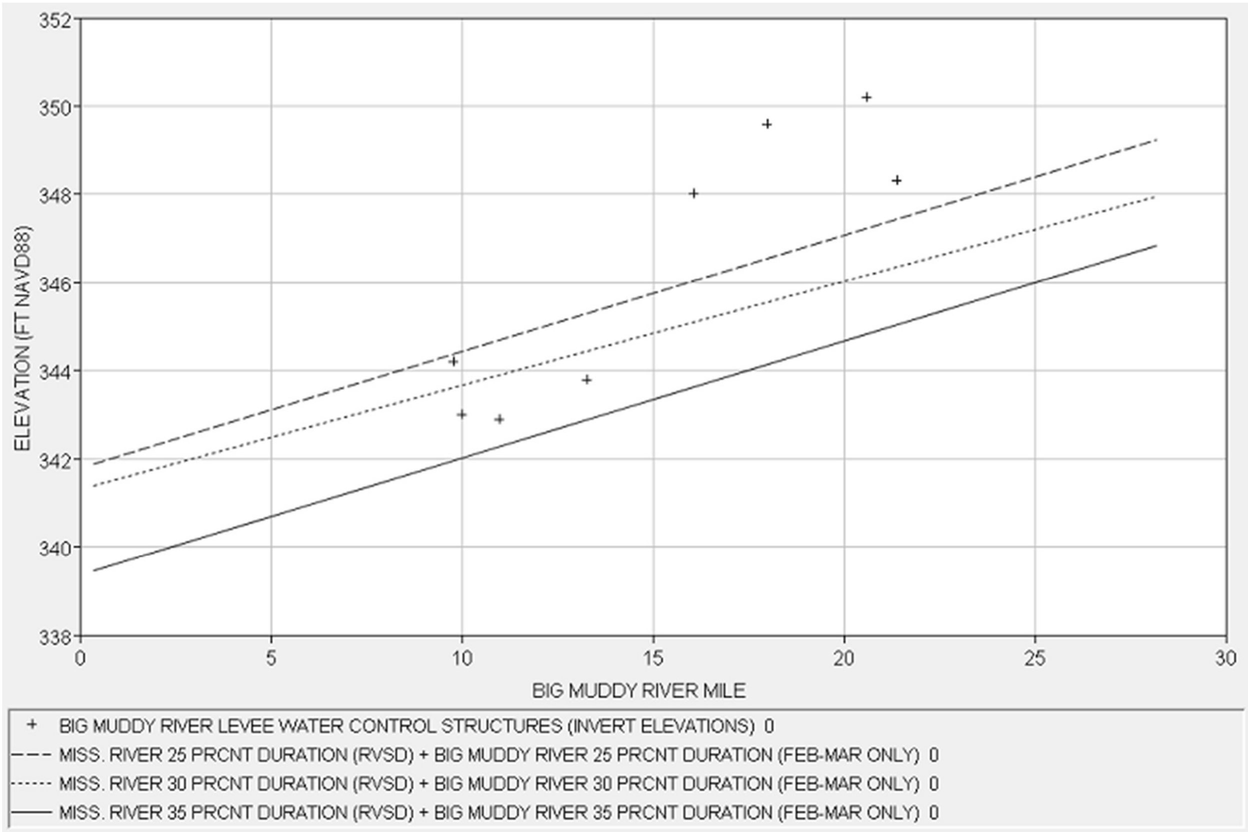


Figure 7 – Results of Duration Analysis for Period of 01 February-31 March and Invert Elevations of Degognia and Grand Tower Levee System Gravity Drains

Table 3 – Comparison of Slopes of Profiles from HEC-RAS Model and Duration Analyses

Source of Profile	Profile (date and time or duration)	Slope (feet / mile)
CWMS HEC-RAS	12 Apr 2011, 0800	0.0952
	23 Apr 2011, 0800	0.0773
	27 Apr 2011, 0800	0.1153
	30 Apr 2011, 0800	0.1512
	04 May 2011, 2200	0.1455
Feb-Mar 1961-2018 duration	05% duration	0.2288
	10% duration	0.2486

	15% duration	0.2572
	20% duration	0.2640
	25% duration	0.2644
	30% duration	0.2360
	35% duration	0.2658
Jan-Dec 1961-2018 duration	05% duration	0.1304
	10% duration	0.1393
	15% duration	0.1551
	20% duration	0.1595
	25% duration	0.1638
	30% duration	0.1606
	35% duration	0.1548

1.7 Volumetric Characteristics of Existing Management Units

One of the types of data that was calculated for the Oakwood Bottoms Green Tree Reservoir was elevation-volume data for all of the existing management units. This information quantifies the volume of water contained within each management unit below a given water-surface elevation.

The existing management units were digitized in the computer program ArcMap 10.3.1, and digitized management units were imported into the computer program HEC-RAS 5.0.5 (which was the version of this program in use at that time). A geometric data utility in this program calculates the elevation-volume relationship for areas bounded by natural high ground, by berms or by levees based upon the elevations of these high areas and the terrain within them. For the existing management units, the LiDAR data was used in the computer program HEC-RAS 5.0.5 for the calculation of the elevation-volume relationship for each unit. The LiDAR data provided a depiction of the berms surrounding the management units, as well as the terrain within the berms.

The top elevation along the berms bordering any given existing management unit varies. For the calculation of the elevation-volume relationship for each existing management unit, it was assumed that the highest elevation for which a volume would be calculated was the lowest bordering berm elevation for that unit. In other words, the volume was calculated for each unit such that no water would be overtopping any of the bordering berms. Elevation-volume data for existing management units is given in TABLE 2. The data that are given in TABLE 2 for each existing management unit include the lowest elevation (for which the volume is zero acre-feet), the lowest bordering berm elevation and the volume for the lowest bordering berm elevation.

Table 2 – Elevation-Volume Data for Existing Management Units

Management Unit	Elevation (feet NAVD88)	Volume (acre-feet)
Unit 01	349.60	0.00
	353.00	8.78
Unit 02	354.42	0.00
	353.00	24.98
Unit 03	352.21	0.00
	355.00	58.26
Unit 04	354.09	0.00
	356.00	22.18
Unit 05	352.65	0.00
	355.90	106.78
Unit 06	348.36	0.00
	353.80	81.82
Unit 07	351.45	0.00
	355.00	42.61
Unit 08	349.27	0.00
	354.70	107.02
Unit 08 North	352.96	0.00
	355.30	52.14
Unit 09	354.00	0.00
	356.70	40.76
Unit 09 North	353.25	0.00
	356.80	14.37
Unit 10	354.73	0.00

	357.40	44.74
Unit 10 North	354.78	0.00
	358.40	14.90
Unit 11 South	353.39	0.00
	357.10	5.22
Unit 11 North	353.87	0.00
	357.40	60.60
Unit 12 South	352.46	0.00
	355.60	18.27
Unit 12 North	354.48	0.00
	356.10	67.51
Unit 13	353.80	0.00
	355.90	95.29
Unit 14	352.47	0.00
	356.40	14.72
Unit 14MS	354.77	0.00
	357.40	6.24
Unit 15	352.66	0.00
	357.20	64.35
Unit 15MS	354.66	0.00
	357.70	9.21
Unit 16 East	352.98	0.00
	357.40	66.23
Unit 16MS East	354.74	0.00
	357.70	9.05
Unit 16 West	354.24	0.00
	357.60	56.69

Unit 16MS West	355.36	0.00
	357.90	4.46
Unit 17	353.83	0.00
	357.90	34.67
Unit 17MS	355.59	0.00
	358.70	13.06
Unit 19	355.95	0.00
	357.00	3.25
Unit 20 North	354.88	0.00
	357.20	5.71
Unit 20 South	354.47	0.00
	356.80	13.66
Unit 21	354.55	0.00
	357.10	151.06
Unit 26	357.10	0.00
	358.60	31.32
Unit 27	354.43	0.00
	357.80	70.08

2 HYDRAULIC MODELING OF EXISTING CONDITIONS

The three major components of the hydraulic model include topographic data, land cover data, and gravity drain data. The topographic data and the land cover data were discussed above. These two types of data were entered into the computer program HEC-RAS. Water control structure data was also entered into HEC-RAS. A schematic taken from the HEC-RAS geometric data editor showing the two-dimensionally modeled area is given in FIGURE 8. The boundaries of the existing management units are evident in the figure. Along some of the management unit boundaries, red and blue lines are shown. These lines indicate two-dimensional flow area boundaries, which can be thought of as the berms that separate the management units. In the modeling, these two-dimensional flow area boundaries also include data pertaining to the WCSs that pass through the berms. Thus, the two-dimensional flow area boundaries are comprised of berm data and WCS data. The two-dimensional flow area boundaries facilitate the passage of water over and through the berms. The gridded pattern within the management units indicates that these areas are two-dimensionally modeled.

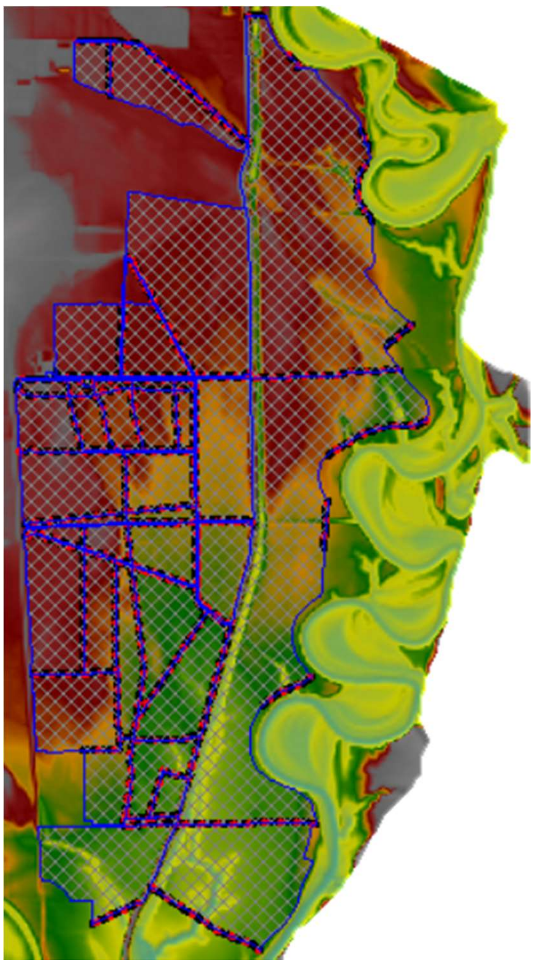


Figure 8 – Schematic from HEC-RAS Geometric Data Editor Showing Two-Dimensionally Modeled Area

It can be noted in FIGURE 8 that areas outside of OBGTR are two-dimensionally modeled, as indicated by the gridded pattern in these areas. These areas outside of OBGTR had to be included in the modeling so that the exiting of water from the OBGTR could be simulated. Also, bordering some of these areas outside of the OBGTR are two-dimensional flow area boundaries and two-dimensional flow area boundary conditions (both indicated by red and blue lines). The two-dimensional flow area boundaries facilitate the passage of water over and through berms, embankments and roadways. The two-dimensional flow area boundary conditions allow water to leave or to enter the modeled area. In the case of this modeling effort, the two-dimensional flow area boundary conditions are located on the eastern and southern edges of the modeled area.

Two-dimensional modeling in the HEC-RAS computer program is based upon partitioning the terrain into a gridded pattern of computational cells. The user requests cell dimensions and the program creates the gridded pattern. The cell shape and dimensions vary near berms and levees. A schematic from the HEC-RAS geometric data editor showing two-dimensional cells is given in FIGURE 9. A depiction of the berm between Unit 08 and Unit 06 is shown in the upper left portion of this figure as a red and black line. A depiction of the Degognia and Grand Tower Levee System is shown in the right portion of this figure as a red and black line. One of the gravity drains that passes through the Degognia and Grand Tower Levee System is depicted as a narrow black line perpendicular to the levee. The colors in FIGURE 9 depict varying terrain elevations. A small stream leading toward the Degognia and Grand Tower Levee System is depicted in yellow. The relatively large height of the Degognia and Grand Tower Levee System is depicted in gray. A bayou on the right side of the Degognia and Grand Tower Levee System is depicted by light green.

The cell size chosen for the terrain within the management units was 100 feet, whereas the cell size chosen for the terrain outside OBGTR was 200 feet. A smaller cell size yields more detailed calculations, and more detailed calculations were desired within the OBGTR than for areas outside of it. While simulations of water flow are being executed, calculations are made for all faces of each cell that is used in the modeling. Typically, a cell will have four faces but some cells have more than four faces. For each cell, an elevation-volume relationship is calculated for it based upon the underlying terrain.

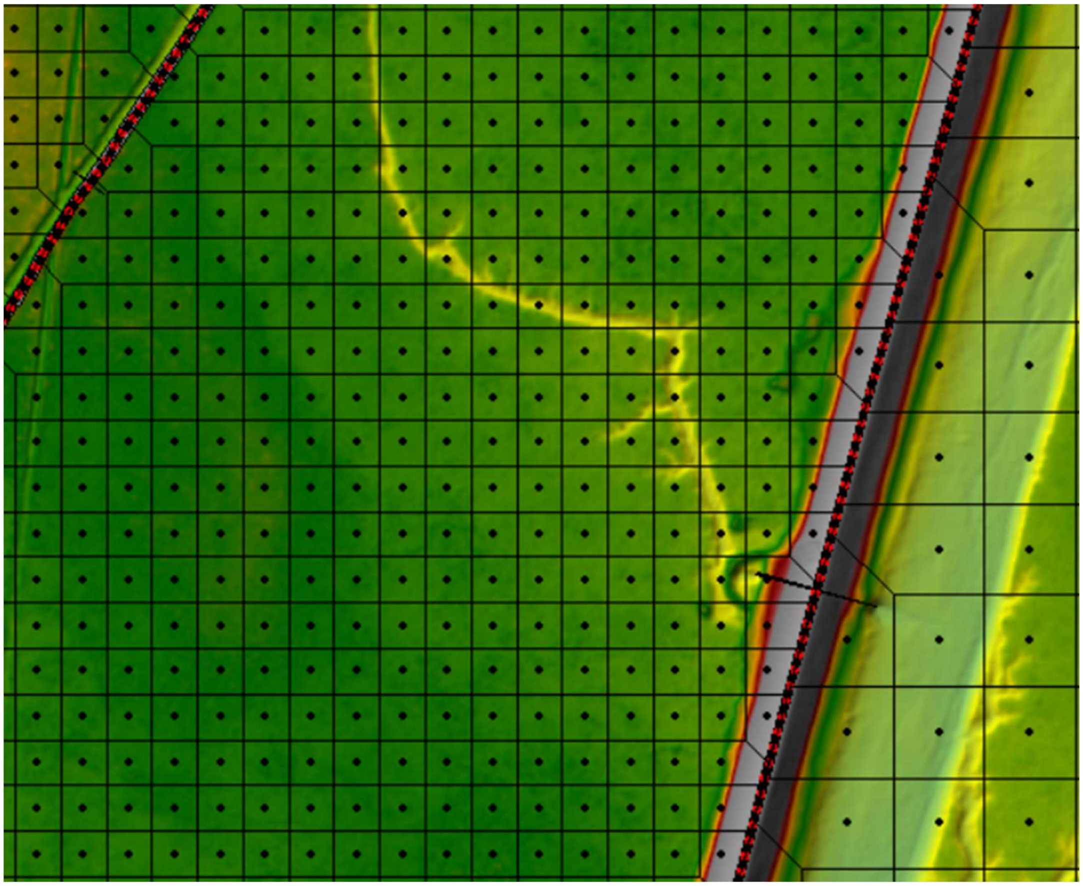


Figure 9 – Schematic from HEC-RAS Geometric Data Editor Showing Two-Dimensional Cells

A schematic taken from the HEC-RAS geometric data editor showing the berm between Unit 08 and Unit 06 is given in FIGURE 10. The berm, which was given the abbreviation “cn U08 U06” for the computer program, is shown as if the reader is looking from Unit 08 at the berm into Unit 06. The elevation of the centerline of the berm in units of feet NAVD88 is depicted in the figure. Also shown in the figure are the three WCSs that pass through this berm, depicted by three vertical lines. The top and the bottom of these vertical lines depict the top elevation and the invert elevation, respectively, of each of the three WCSs.

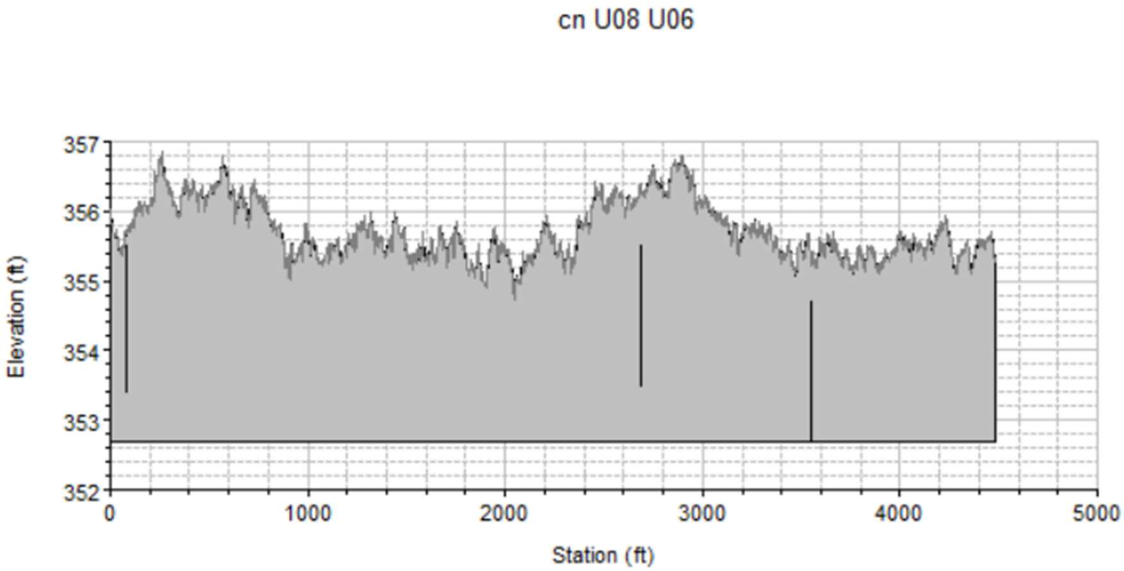


Figure 10 – Schematic from HEC-RAS Geometric Data Editor Showing Berm between Unit 08 and Unit 06

A zoomed portion of the schematic from the HEC-RAS geometric data editor, plus the culvert data editor for the berm, is given in FIGURE 11. In the HEC-RAS computer program, zooming in upon the schematic shown in FIGURE 10 at the left-most vertical line will produce the image shown on the right side of FIGURE 11. Zooming in upon the left-most vertical line shows the WCS that passes through the berm at that location. In the culvert data editor to the left of the schematic, the upstream invert elevation is shown to be 353.5 feet NAVD88 and the downstream invert elevation is shown to be 353.4 feet NAVD88. In the schematic, the upstream cross section of the WCS is shown by a solid line in the form of a round pipe (with its upstream invert elevation of 353.5 feet NAVD88) and the downstream cross section is shown by a dashed line in the form of a round pipe (with its downstream invert elevation of 353.4 feet NAVD88). A characteristic of WCSs is that they are often sloped and thus have varying invert elevations at their upstream and downstream ends, and HEC-RAS is able to model the varying invert elevations.

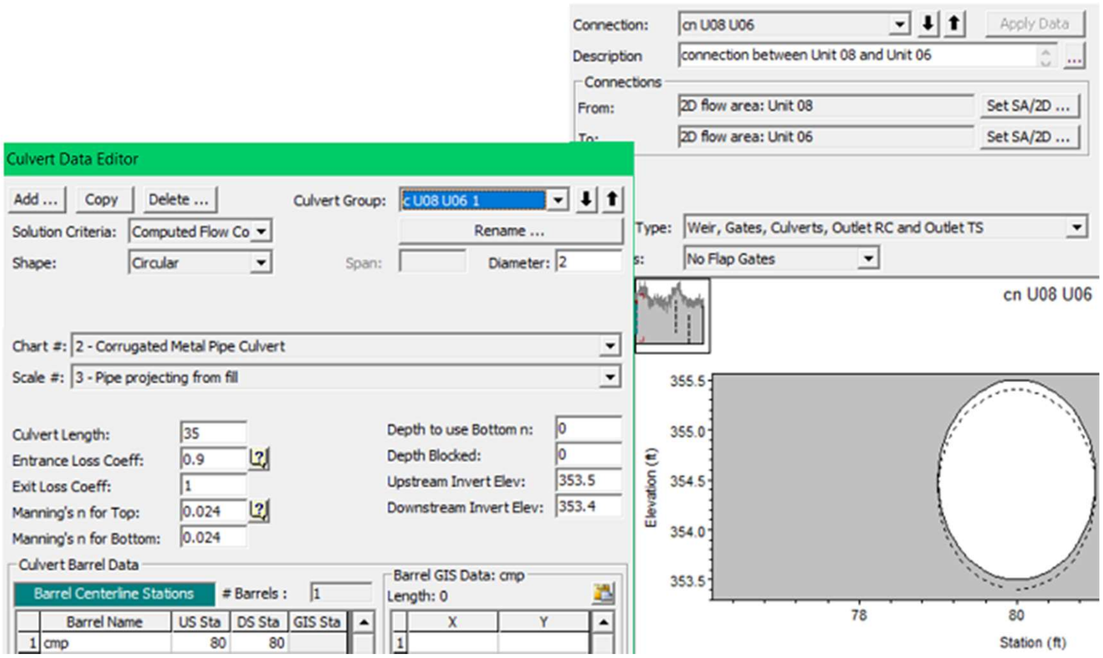


Figure 11 – Zoomed Portion of Schematic from HEC-RAS Geometric Data Editor plus Culvert Data Editor

The information depicted in the previous three figures, and the discussion accompanying these figures was meant to show typical data used in the two-dimensional hydraulic modeling. The many berms, WCSs, and other portions of the Degognia and Grand Tower Levee System were all modeled similarly. The end result was a two-dimensional hydraulic model that was capable of simulating gravity draining, and filling by pumping, of the Green Tree Reservoir. Two-dimensional flow modeling is an advanced form of unsteady flow modeling. In unsteady flow modeling, the flow of water during a specified period is simulated and the movement of water is able to change directions during the simulation based upon the various factors affecting the flow. For each simulation, reasonable assumptions of initial conditions for water-surface elevations and water flow rates are made or these initial conditions are based upon historical conditions or calculations made specifically for the simulation. Various types of boundary conditions are also specified for each simulation. These boundary conditions involve water-surface and flow rate hydrographs, specifications for operation of gated structures, water body or hydraulic structure operational rules, and precipitation.

2.1 Existing Conditions Modeling Assumptions

2.1.1 All scenarios

- Due to time and budget constraints, it has been assumed in all scenarios that all WCSs were fully open and were functioning without any deficiencies. It is understood that this makes the water move more freely than real-life.
- No adjustment or manipulation of the water control gates occurred; they were fully open or fully closed for the full simulation. (not valid for 2018 filling scenario)
- The computer program HEC-RAS presently is not able to simulate infiltration of water, so all rainfall is assumed to become runoff and water that would be absorbed by the soil and trees was assumed to remain within OBGTR. (Ultimately, the use of rainfall in the modeling for existing conditions was not important to the work and it was not pursued. If it would have been pursued, accounting for rainfall losses would have been included in the analysis.)
- "Full" for the management unit means that the water level within it was as high as possible, while at the same time no water was flowing over any of the berms encompassing the unit.

2.1.2 Filling by Well Pumps

- The pipeline that exists in the southern berm of the MSUs was used.
- Gravity drains through the Degognia and Grand Tower Levee System are closed to prevent water from the Big Muddy River from entering the reservoir.
- At the beginning of the simulation, OBGTR was completely empty of water.
- All well pumps were continuously operating at full capacity.

2.1.3 Draining by Gravity through the Levee System

- At the beginning of the simulation, OBGTR was at a fully flooded state.
- All gravity drains that pass through the Degognia and Grand Tower Levee System were fully open and were functioning without any deficiencies, and that no backwater effects from the Big Muddy River existed upon these structures.

2.2 Results of Hydraulic Modeling of Existing Conditions

For existing conditions, four scenarios were simulated for the OBGTR with the two-dimensional hydraulic modeling. Brief descriptions of these scenarios are as follows:

1. The first was draining the reservoir. In addition to intentional flooding from well pumps, the reservoir is periodically flooded by rainfall runoff from the watershed upstream of the reservoir. This flooded condition was such that water was about 0.5-2.5 feet above the berms within the reservoir as the simulation began.

2. The second was filling reservoir to its capacity by well pumps. It was intended that

no water be flowing over berms at the end of this simulation.

3. The third scenario was draining OBGTR for the plan of operation that occurred during 2018. During 2018, some of the management units were not flooded. Leaving some of units dry and flooding others occurs during most, if not all, years. Therefore, it was intended to minimize or eliminate water flowing over berms as the simulation began.

4. The fourth scenario was filling the reservoir by pumping from well pumps for the plan of operation that occurred during 2018. Again, it was intended that no water be flowing over berms at the end of this simulation.

The first scenario simulated was draining the entirely flooded reservoir. Rainfall on OBGTR and vicinity was included in the simulation. The entire two-dimensionally modeled area was assumed to have 1.0 inch of rain during both the first and second 24-hour periods of the simulation, and 0.5 inch during the fourth 24-hour period of the simulation. Both 1.0-inch rainfalls were assumed to occur over a six-hour period, and the 0.5-inch rainfall was assumed to occur over a four-hour period. The simulation showed that the vast majority of the water in OBGTR had drained within two weeks. As shown in FIGURE 12 and as was evident throughout the Green Tree Reservoir, water only remained in some small, isolated areas at three weeks into the simulation. The same general appearance of the Green Tree Reservoir occurred for drainage simulations that did not include rainfall, thus showing that rainfall was not a large factor in the modeling results and therefore was not pursued further in the HEC-RAS draining simulations.

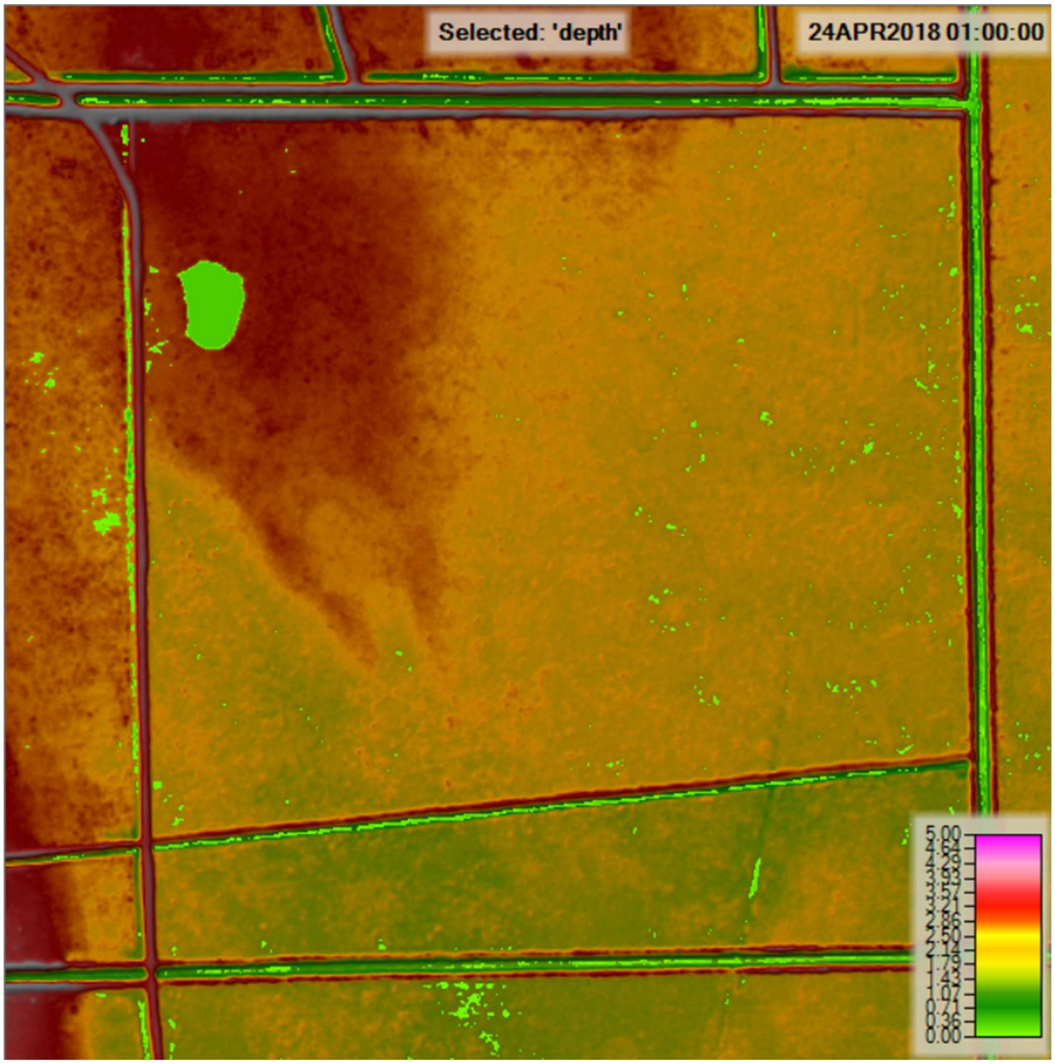


Figure 12 – Unit 12 after 3 weeks of the draining simulation

The second scenario simulated was filling the reservoir to its capacity by well pumps. It was intended that no water be flowing over berms within OBGTR at the end of this simulation. No rainfall on OBGTR and vicinity was included in this simulation. All 10 pumps that existed at the OBGTR when the simulation was developed were used during the simulation. Some pumps were operated at full capacity throughout the simulation, others were "turned on and off" periodically, and others were not used. The simulation showed that the extent of areas covered by pumped water gradually increased during the first two weeks of the simulation. Thereafter, the extent of areas covered by pumped water increased very slowly and eventually stagnated. The depth of some areas covered by pumped water continued to increase beyond the depth needed or desired for operation of OBGTR. The depth of water in some ditches became excessive. The results of this simulation proved that manipulation of WCSs within OBGTR, and the management of distribution of pumped water, is necessary to achieve the flooding that is desired for operation. The results of this simulation also demonstrated the model was able to verify the complexity and challenges of the existing hydraulic situation at OBGTR. The approach taken in this simulation (i.e., pumping at full capacity with all pumps with no adjustment of WCS gates) was shown to be inadequate to achieve the desired flooding.

It was believed that using the hydraulic model to simulate operations that occurred during 2018 would be a good test of the model. As a result, no attempt was made to improve the filling scenario described in the previous paragraph. It was planned that the lessons learned from the filling scenario described in the previous paragraph would be applied to the scenario of simulating the filling that occurred during 2018. Also, since leaving some of units dry and flooding others occurs during most (if not all) years is the method of operation, this planned simulation would be more realistic than the one described in the previous paragraph.

During 2018, some of the management units were not flooded. Leaving some of units dry and flooding others occurs during most, if not all, years. Flooding of OBGTR that occurred during 2018 is shown in FIGURE 13. Units 01, 02, 03, 10 North, 11, 15, 17, 19, 27, and 28 were not flooded during 2018. The remainder of the units were flooded.

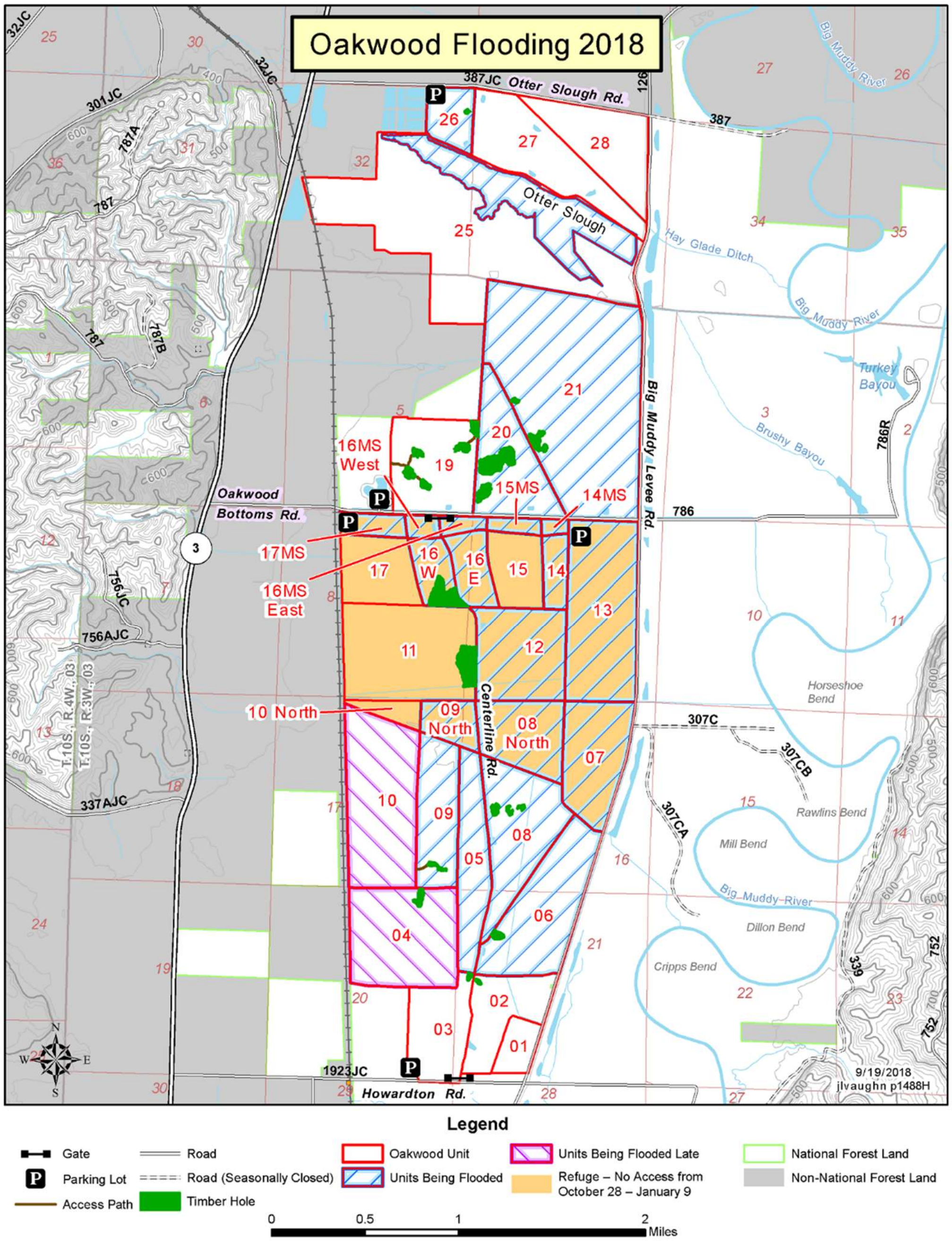


Figure 13 – Flooding of Green Tree Reservoir during 2018

The first simulation to be developed of operations during 2018 was that of draining the units that were flooded. For each unit that was flooded for the management season, it was assumed that all WCSs within berms that encompass the unit were closed during the season. These structures were then all simultaneously fully opened at the start of the simulation (with the exception of those connected to units that were kept dry during the season) and functioned without any deficiencies. To facilitate drainage of the reservoir, water was allowed to drain through three units which had not been flooded for the 2018 management season. These units were Unit 01, Unit 02, and Unit 03. This course of action was followed because, without using the Degognia and Grand Tower Levee System gravity drains within and near these units, the OBGTR would not have been able to be fully drained. As with the first simulation of draining the OBGTR described above, rainfall on the OBGTR and vicinity was included in the simulation. The entire two-dimensionally modeled area was assumed to have 1.0 inch of rain during both the first and second 24-hour periods of the simulation, and 0.5 inch during the fourth 24-hour period of the simulation. Both 1.0-inch rainfalls were assumed to occur over a six-hour period, and the 0.5-inch rainfall was assumed to occur over a four-hour period. The simulation showed that the vast majority of the water in the OBGTR had drained within two weeks, but this is a “best case” scenario with near perfect conditions which is overly optimistic considering known draining times communicated by USFS personnel. The results of this model showed where the water traveled and the inefficiencies associated with the existing conditions. Water only remained in some relatively small, isolated areas at three weeks into the simulation. In terms of time needed to drain the reservoir, this simulation and the draining simulation discussed previously were comparable. A smaller volume of water was drained with this simulation than with the previous one, but a smaller number of WCSs were available for draining with this simulation than the previous one. With this simulation, structures within berms that encompassed the units left dry were not available for draining.

The second simulation to be developed of operations during 2018 was that of flooding of the units that were selected to be flooded. A large amount of effort was made to adjust and manipulate the gates of various WCSs to achieve flooding of the units that were selected to be flooded. In some cases, gates were initially left closed and opened later to allow water to enter certain units. No rainfall on the Green Tree Reservoir and vicinity was included in the simulation. All 10 pumps that existed at the Green Tree Reservoir when the simulation was developed were used during the simulation. Some pumps were operated at full capacity throughout the simulation, others were “turned on and off” periodically, and others were not used. A simulation with a duration of two weeks and six days was developed. Numerous iterations of this simulation were executed, each iteration reflecting various adjustments made to the previous one. Numerous adjustments were made to WCS gates, pumps and pipeline system valves in an attempt to achieve the best simulation. The result of the work was that some units were filled or had water within their entire surface area by the end of the simulation, whereas others required more time and adjustments to achieve the same result. The work showed that the simulation of filling that occurred during 2018 could eventually be achieved with a longer execution time and more adjustments of key components of the system. It is recognized that the limitation of being unable to account for infiltration or evaporation of pumped water is significant. Future versions of the computer program HEC-RAS may be able to account for these factors or approximate them.

Several teleconferences were conducted with USFS personnel during which the results of the hydraulic modeling of existing conditions were displayed. The computer program HEC-RAS has a mapping and animation utility named RAS Mapper, and this utility was used during the conference calls. USFS personnel communicated that filling and draining times were much lengthier in real life and required a lot of manpower to operate the many WCS. Their comments were greatly appreciated, and served to improve the modeling as it progressed and to put the modeling in perspective. Their field experience in operating the project was very valuable as the modeling effort progressed.

The hydraulic modeling for existing conditions formed the basis, and laid the groundwork, for hydraulic modeling of proposed conditions. It was planned to incorporate lessons learned during the hydraulic modeling for existing conditions into the hydraulic modeling for proposed conditions.

3 PROPOSED PROJECT FEATURES

Within the current configuration, the OBGTR takes approximately 45 days for both filling and draining. The management team is not only trying to operate almost 100 WCS structures to drain the area, but many of the existing ditches and pumps are also undersized.

For the proposed hydraulic modeling, three computer programs were used; USACE HEC-RAS, USACE HEC-GeoRAS and ESRI ArcMap 10. The same two-dimensional unsteady flow regime as existing conditions was used to model the proposed alternatives.

3.1 Terrain Formation for Hydraulic Modeling

Before the proposed modeling could take place, a proposed terrain needed to be created. Three computer programs were used to accomplish this task; Bentley OpenRoads Designer Connect, Blue Marble Geographics Global Mapper 19, and ESRI ArcMap 10. Changes were made using cross sections and corridors to create small terrains of each berm modification which were then merged with the existing Lidar, provided by St. Louis USACE Geospatial branch. Once the complex terrain was created, the file was exported out as a LandXML and brought into Global Mapper 19. Next, the terrain was converted into a GRID format and exported once again. Finally, the terrain could be imported into ArcMap 10 where the complex terrain could be merged with the existing Lidar for east of the Degognia and Grand Tower Levee System. Once this merge was complete, the terrain was ready to be used for proposed hydraulic modeling.

3.2 Proposed Conditions Modeling Assumptions

3.2.1 All Scenarios

- Due to time and budget constraints, it has been assumed in all scenarios that all WCSs were fully open and were functioning without any deficiencies. It is understood that this makes the water move more freely than real-life.
- No adjustment or manipulation of the water control gates occurred; they were fully open or fully closed for the full simulation.
- The computer program HEC-RAS presently is not able to simulate infiltration of water, so all rainfall is assumed to become runoff and water that would be absorbed by the soil and trees was assumed to remain within OBGTR.
- “Full” for the management unit means that the water level within it was 1 foot beneath the lowest berm.

3.2.2 Filling by Well Pumps

- The pipeline that exists in the southern berm of the MSUs was used.

- Gravity drains through the Degognia and Grand Tower Levee System or the WCS within the ring berms around each gravity drain are closed to prevent water from the Big Muddy River from entering the reservoir.
- At the beginning of the simulation, OBGTR was completely empty of water.
- All well pumps were continuously operating at full capacity.

3.2.3 Draining by Gravity through the Levee System

- At the beginning of the simulation, OBGTR was at a fully flooded state.
- All gravity drains that pass through the Degognia and Grand Tower Levee System were fully open and were functioning without any deficiencies, and that no backwater effects from the Big Muddy River existed upon these structures.

3.3 Results of Hydraulic Modeling of Proposed Conditions

Originally, seven alternatives were proposed; Forest Service Preferred, Maximum, Minimum, Non-Structural, Natural Regeneration, Water Management Flexibility, and No Action. A few of the alternatives were not modeled due to the fact that there were no proposed changes in infrastructure to physically model. Of the four remaining alternatives, two proposed models were chosen to be created; the Forest Service Preferred Alternative and the Minimum Alternative. As many changes were made throughout the process of creating the models, not every detail was captured, but they provided a strong representation of both alternatives. The Maximum Alternative was not modeled because assumptions were able to be made using the other two alternatives, such as, WCS sizes, WCS locations, and berm heights. The No Action Plan was not modeled since it would be the same as the existing conditions. Modeling was performed to determine sizes, quantities, and locations of WCS such that OBGTR was able to be drained in a shorter and more efficient way. A brief description of all scenarios are as follows:

1. The first scenario was the draining of OBGTR through the gravity drains within the Degognia and Grand Tower Levee System. This scenario was completed for both alternatives discussed above. **Error! Reference source not found.**, Figure 3, and Figure 4 show the Forest Service Preferred Alternative at various times during the scenario. As you can see in Table 1, the berm elevations for OBGTR were raised to hold water at higher than existing elevations which would result in a greater area within each unit being covered by water.

2. The second scenario assumed the Big Muddy River stage was high enough to cause the closure of all the gravity drain structures through the Degognia and Grand Tower Levee System and water needed to drain by gravity to the southeast corner of the OBGTR, where the proposed pump station is located, to be pumped out of OBGTR ~~over the levee. The areas north of Otter Slough were unable to drain without~~

extradrainage channels which have not yet been designed. This issue will be further addressed in Feasibility Level of Design.

3. The third scenario, a filling model, was also performed for both alternatives to determine capacities and quantity of deep well pumps such that the OBGTR was able to be filled in a shorter more efficient manner (Figure 5 and Figure 6). These models also assumed there was no precipitation during the filling period. The pumps ran for various times depending on the size of the unit, number of pumps per unit, and pump capacity. The pumps would be turned off once the water was close to reaching its maximum WSE.

Table 1 – Minimum Berm Heights and Maximum WSE for the draining scenario which water flows through gravity drains within the Degognia and Grand Tower Levee System

Subunit	Minimum Berm Height (ft)	Maximum WSE (ft)
F-1A	358.5	357.5
F-1B	359	358
F-1C	358.5	358
F-2A	358.5	357.5
F-2B	358.5	357.5
F-2C	358.5	357.5
F-3	358.5	357.5
F-3MS	359	358
F-4	357.5	356.5
F-4MS	358	357
F-5A	356.5	355.5
F-5B	356.5	355.5
F-6	355.75	354.75
F-7	356.75	355.75
F-8	358.5	357.5
F-X	355.5	354.5

*The berms in unit F-1C were previously raised by Duck's Unlimited, but very little water will be in the unit if we keep 1 full foot of freeboard between max WSE and top of minimum berm elevation.

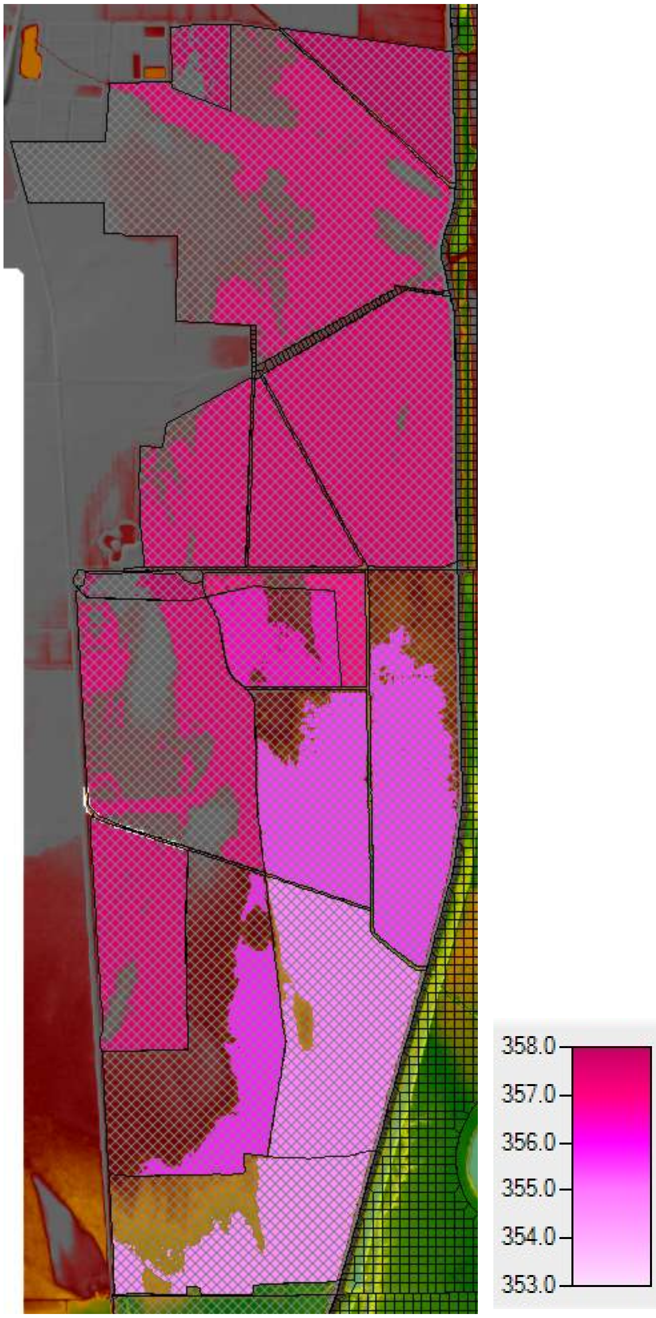


Figure 2 – Forest Service Preferred Alternative with maximum WSE at beginning of draining scenario (Day 0)

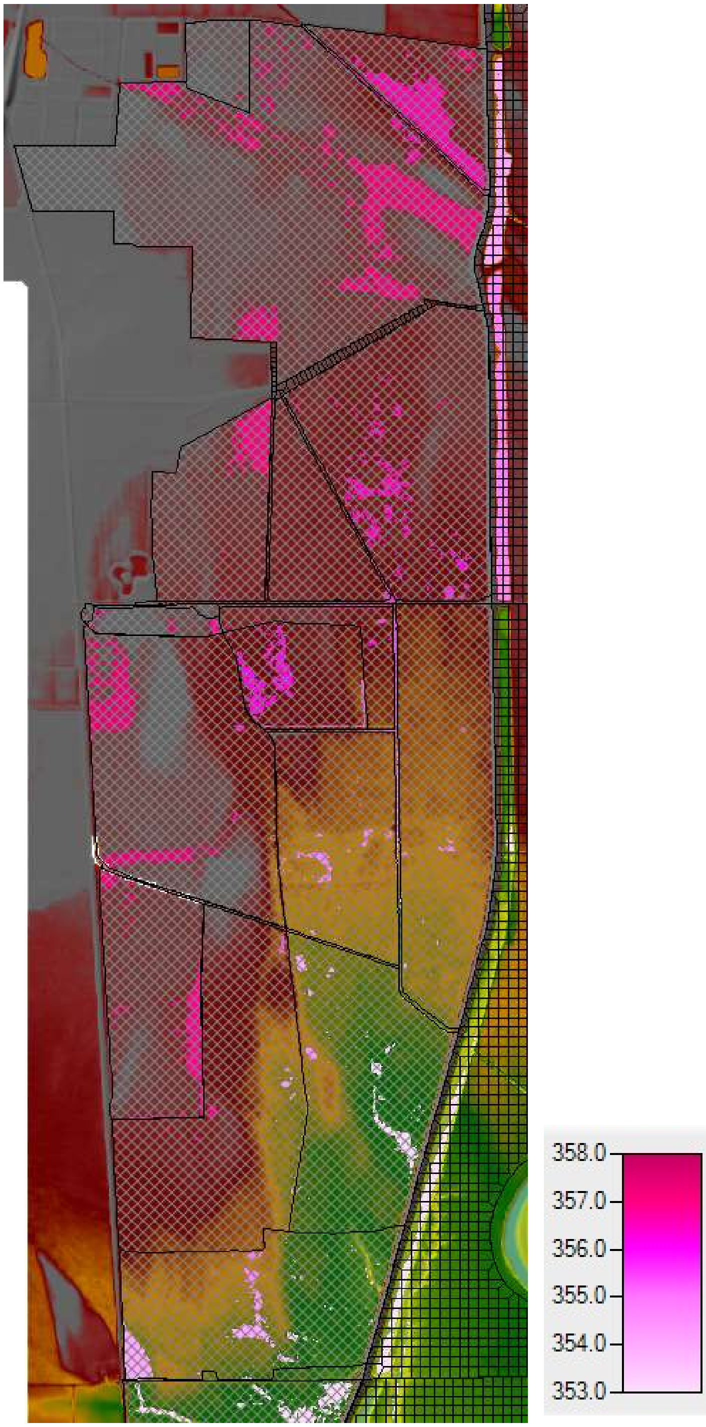


Figure 3 – Forest Service Preferred Alternative after 7 days of draining scenario

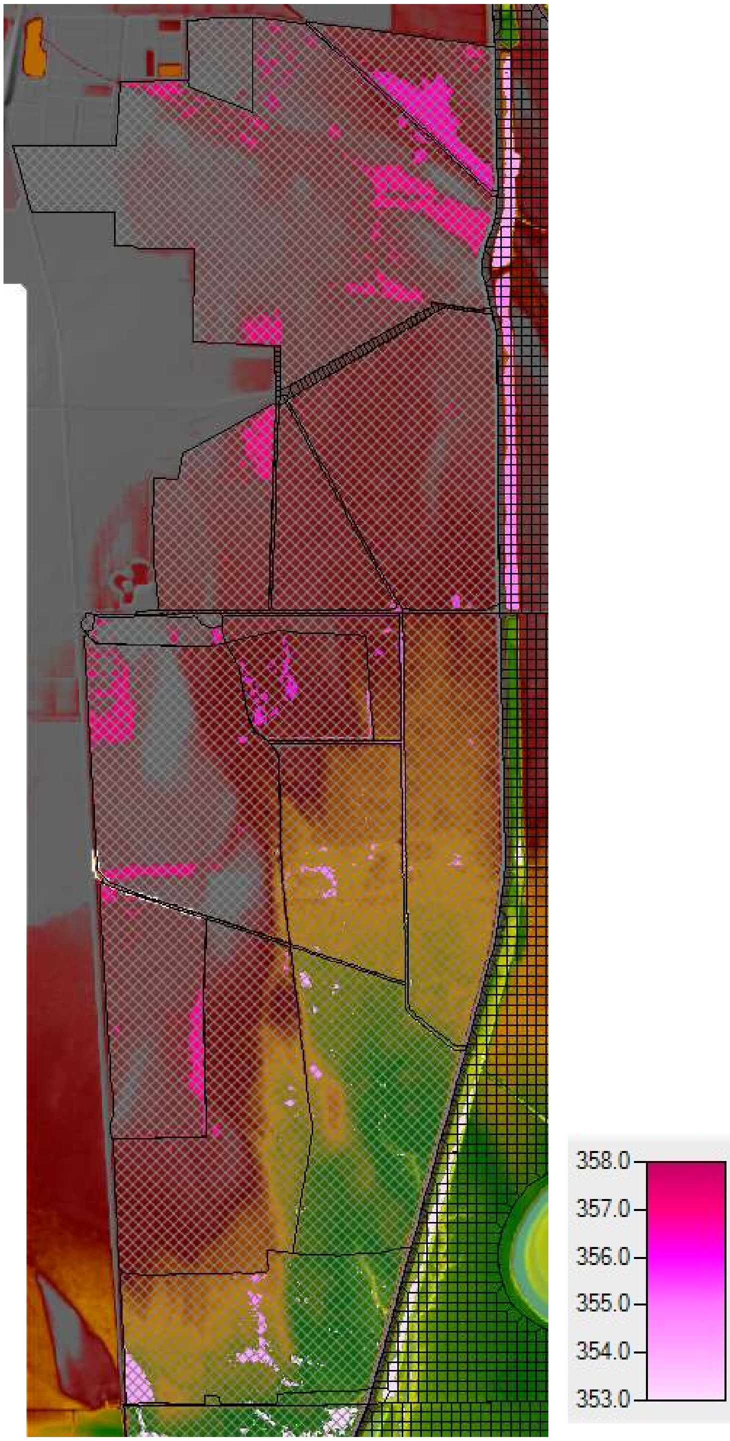


Figure 4 – Forest Service Preferred Alternative after 14 days of draining scenario

Figure 5 – Forest Service Preferred Alternative 7 days into filling scenario

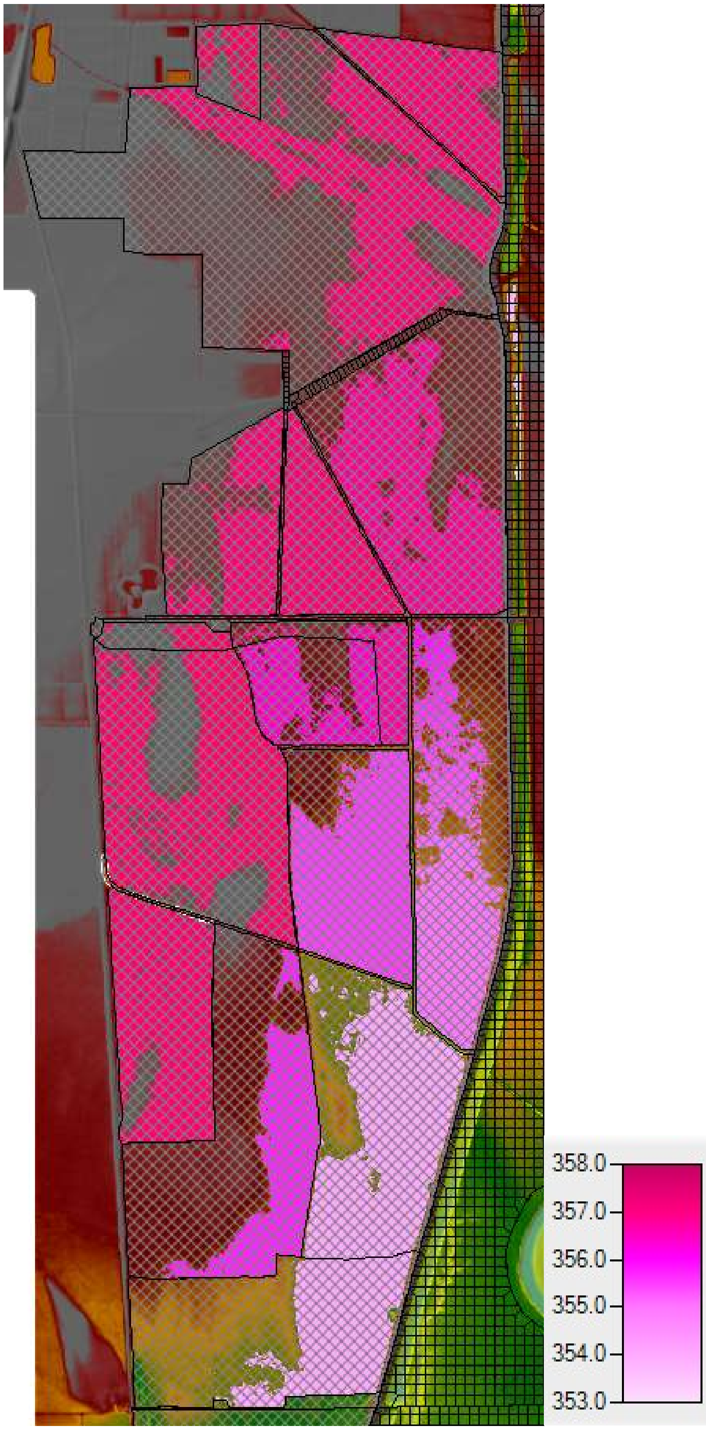


Figure 6 – Forest Service Preferred Alternative 14 days into filling scenario

4 CLIMATE CHANGE

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. The OBGTR project is an ecosystem restoration project so the environmental business line was considered. While this assessment does not change the numerical results of the alternatives evaluated, it helps to inform alternative selection by providing information on possible trends in flood flows with time.

Climate change characteristics that could impact OBGTR project reliability include temperature, precipitation, stream flow and changes in seasonality.

4.1 Current Climate

Carbondale, Illinois has a continental climate characterized by cold winters and hot summers. The average annual rainfall is 47.17 inches with May and November being the months of highest rainfall (U.S. Climate Data, 2020). However, precipitation is highly variable from year-to-year with the statewide average ranging as low as 25.52 inches in 1901 and as high as 51.18 inches in 1993. The driest 5-year period in history was from 1952 to 1956 and the wettest 5-year period ranged from 2007 to 2011. The average annual snowfall is 11 inches with the majority falling in December through February (monthly average 3 to 4 inches). Figure 7 shows the monthly climate patterns for Carbondale, Illinois (U.S. Climate Data, 2020).

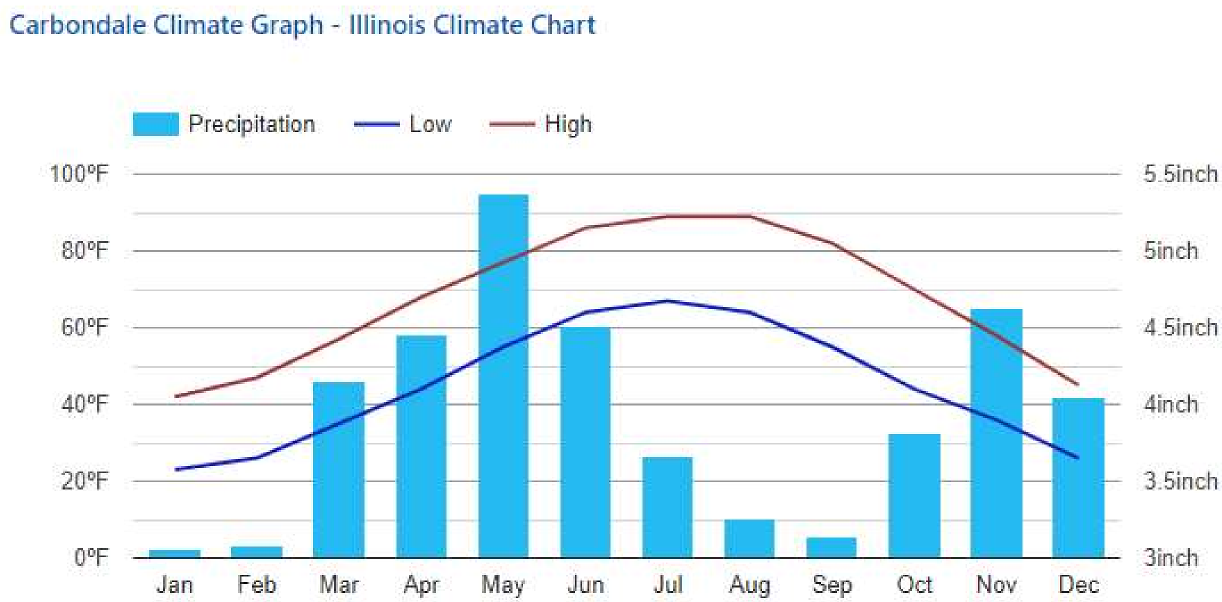


Figure 7 – Current Climate

4.2 Observed Climate Trends

The *Climate Science Special Report from the Fourth National Climate Assessment* (USGCRP, 2017) and the USACE *Recent US Climate Change and Hydrology Literature Applicable to US Army Corps of Engineers Missions Upper Mississippi Region 7* (USACE, 2015) were referenced for observed trends in precipitation, temperature, stream flow, and changes in seasonality.

Figure 8 shows that annual temperature in the study area has increased over time and that the largest increases have been in the winter opposed to the summer. Water is generally held within the management units over the winter months and the warmer temperatures can cause water quality concerns.

Figure 10 shows the annual mean precipitation in the study area has increased. The largest increase in the spring and fall. Management units are filled in the fall and drained in the early spring. Higher amounts of precipitation during these months can cause concerns with these processes.

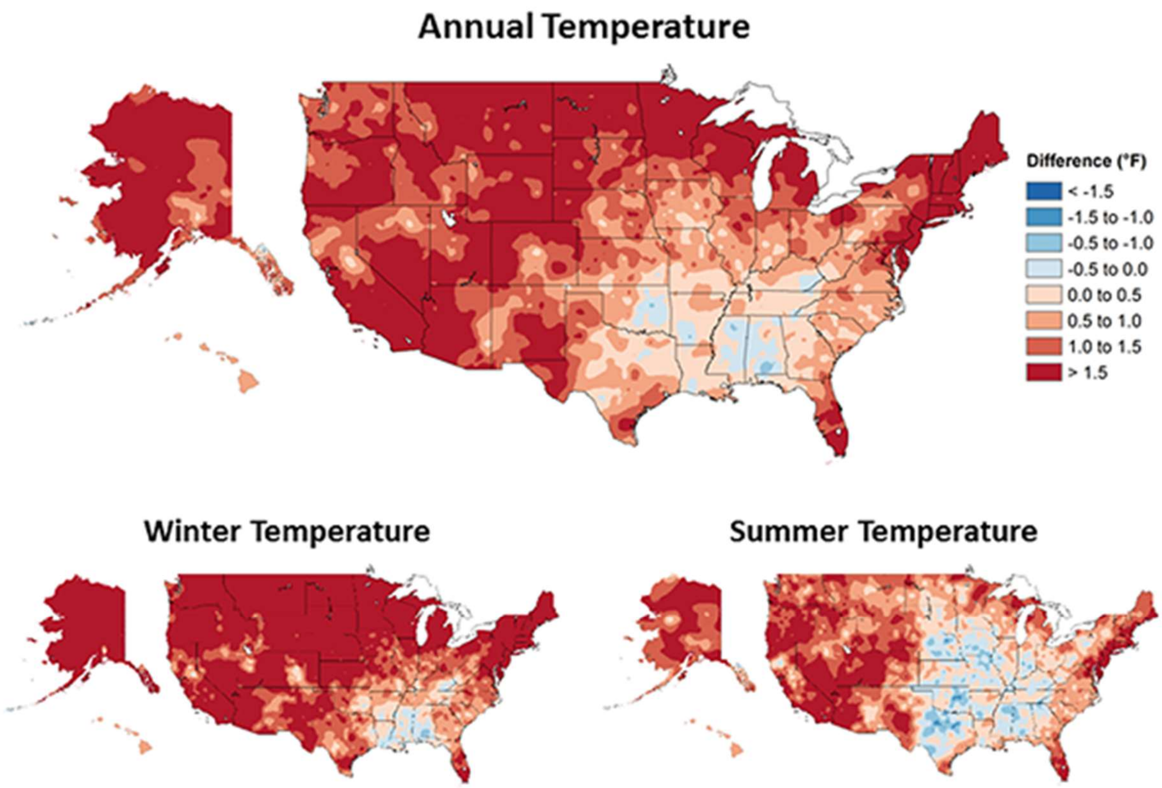


Figure 5. Observed changes in annual, winter, and summer temperature (°F). Changes are the difference between the average for present-day (1986–2016) and the average for the first half of the last century (1901–1960 for the contiguous United States, 1925–1960 for Alaska and Hawai'i). Estimates are derived from the nClimDiv dataset (Vose et al. 2014, Vose et al. 2017) (NCA Vol 2 Figure 6.1, Figure source: NOAA NCDC / NCEI).

Figure 8 – Observed changes in temperature

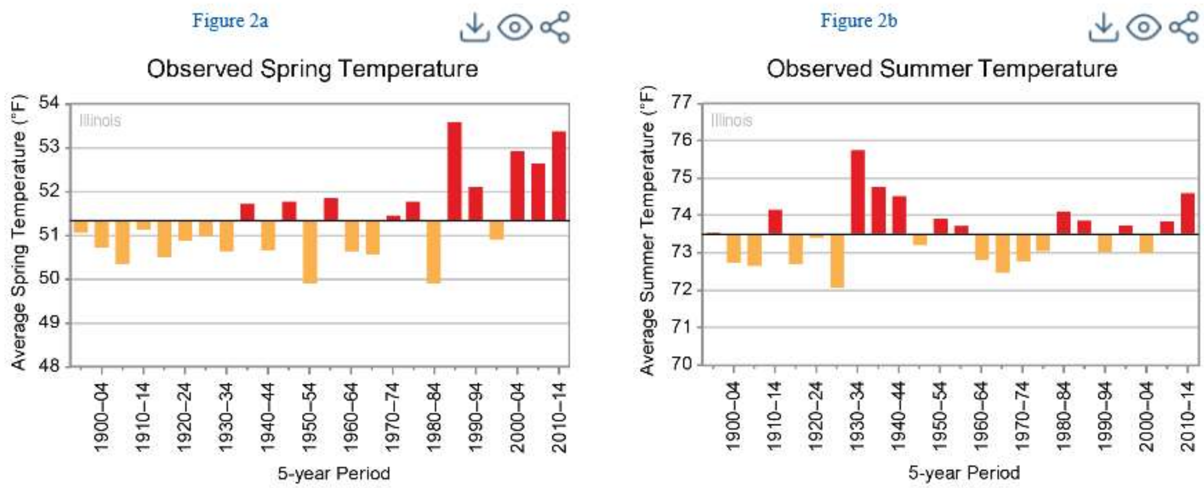
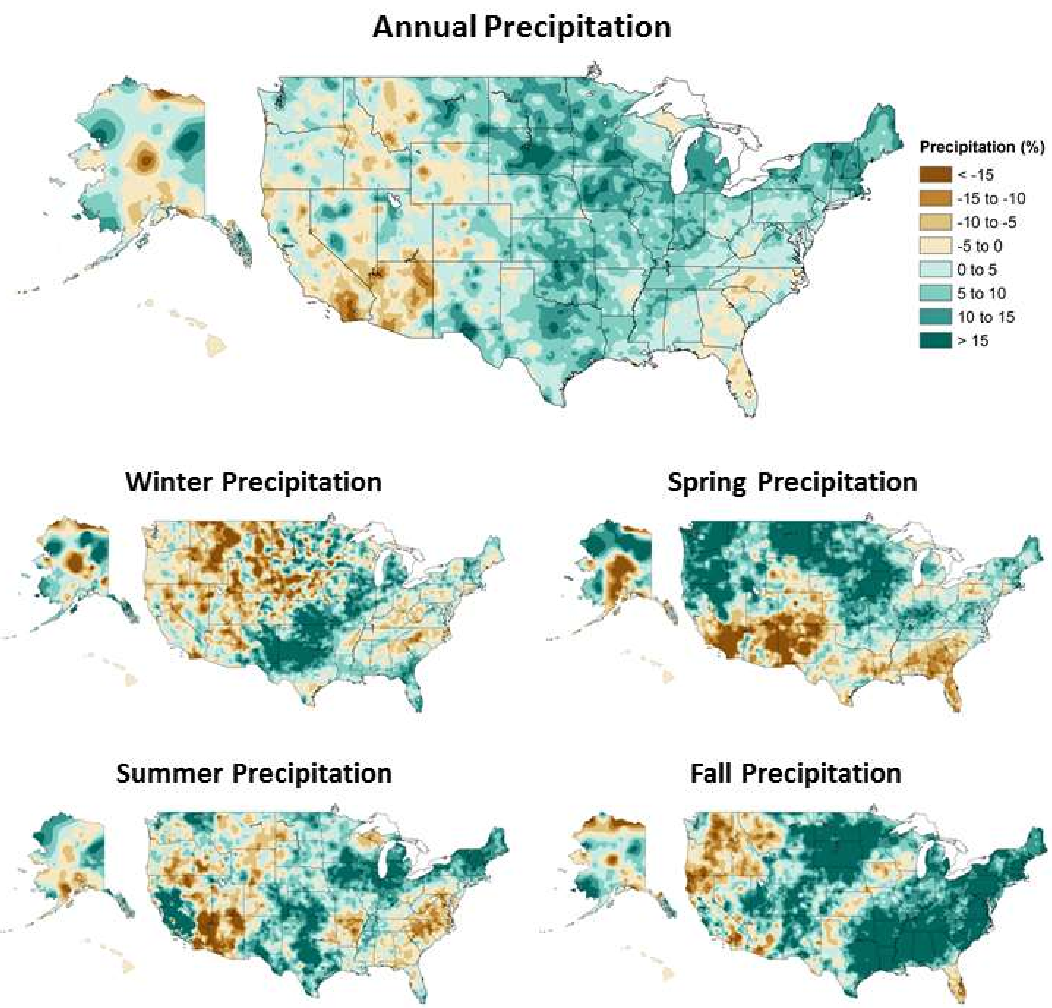


Figure 2: The observed spring and summer temperatures across Illinois for 1895–2014, averaged over 5-year periods; these values are from NCEI's version 2 climate division dataset. The dark horizontal lines represent the long-term average. Over the past three decades, Illinois has experienced the highest springtime temperatures in the historical record. Summer temperatures during the most recent 5-year period (2010–2014) have reached the highest level since the extreme heat of the 1930s Dust Bowl era. The dark horizontal line on each graph is the long-term average (1895–2014) of 51.3°F (spring) and 73.5°F (summer). Source: CICS-NC and NOAA NCEI.

Figure 9 - Observed Spring and Summer Temperatures (U.S. Climate Data, 2020)



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 10 – Observed changes in precipitation

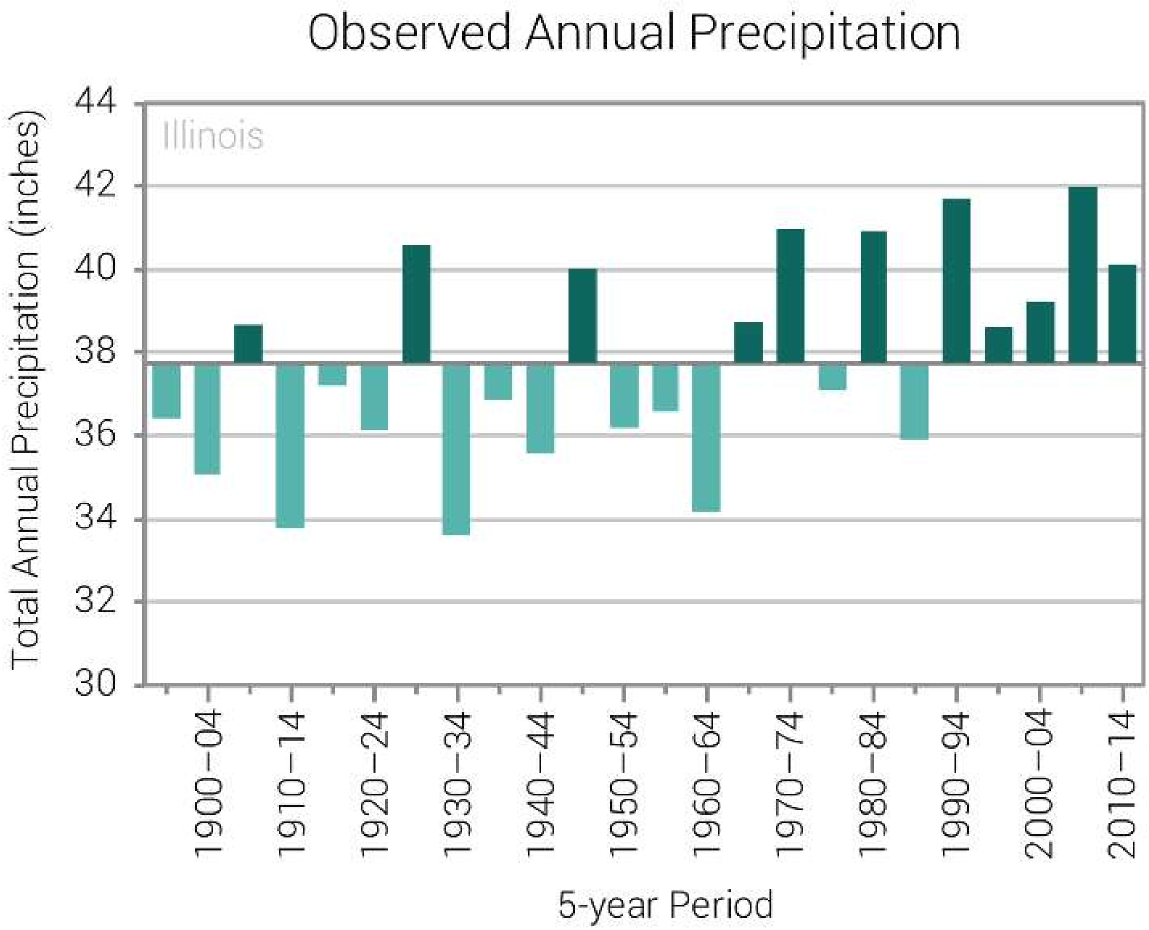


Figure 11 - Observed Annual Precipitation for the State of Illinois (U.S. Climate Data, 2020)

4.3 Literature Review Conclusions

Based on the observed trends mentioned above, important hydrologic variables for OBGTR which may be impacted by climate change include intensity, duration, and frequency of precipitation events as well as air temperatures. Changes in these variables may cause impacts to the OBGTR project. It is therefore appropriate to investigate the potential impacts of global climate change on OBGTR.

The literature review indicates that:

- The general consensus in recent literature points toward moderate increases in temperature and precipitation in the Upper Mississippi Region over the past century.

- In some studies and some locations, statistically significant trends have been quantified. In other studies and locales within the Upper Mississippi Region, apparent trends are observed graphically, but are not statistically quantified.
- Some evidence points to an increased frequency in the occurrence of extreme storm events (Villarini et al., 2013).
- Multiple authors identified a transition point in climate data trends in 1970 where rates of increase changed significantly.

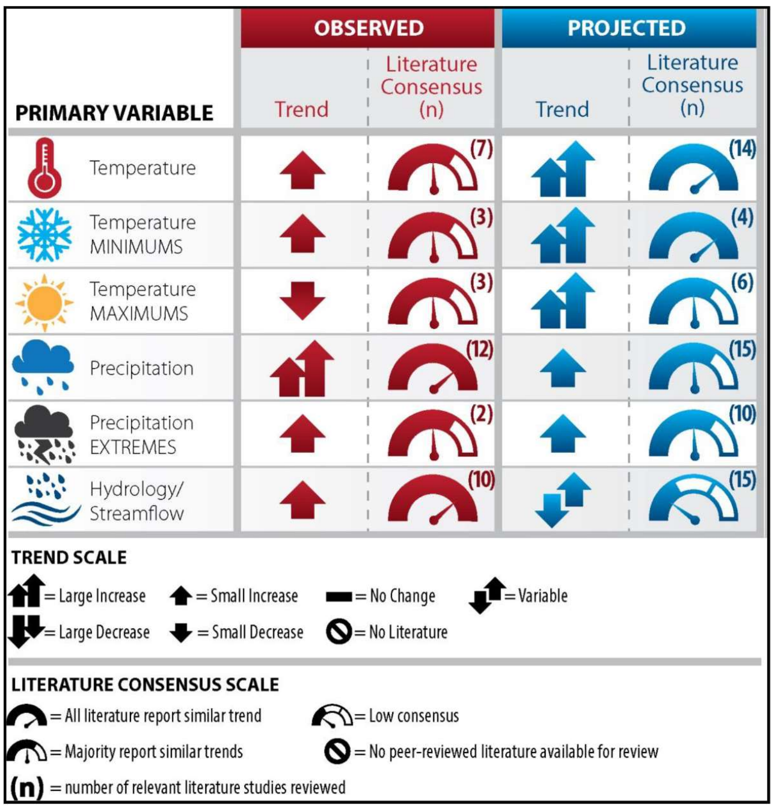


Figure 12 – Summary matrix of observed and projected regional climate trends and literature consensus (USACE, 2015)

4.4 Climate Projections

There is strong consensus in the literature that air temperatures will increase in the study region, and throughout this country and over the next century. The studies reviewed here generally agree on an increase in mean annual air temperature of approximately 2 to 6 ºC (3.6 to 10.8 ºF) by the latter half of the 21st century in the Upper Mississippi Region. Reasonable consensus is also seen in the literature with respect to ~~projected increases in extreme temperature events, including more frequent, longer,~~ and more intense summer heat waves in the long term future compared to the recent past.

Increased air temperatures and increased frequencies of drought, particularly in the summer months, will result in increased water temperatures. This may lead to water quality concerns, particularly for the dissolved oxygen levels, which are an important Climate Change Assessment for Water Resources Region 07 Upper Mississippi Region USACE Institute for Water Resources 43 June 26, 2015 water quality parameter for aquatic life. Increased air temperatures are associated with the growth of nuisance algal blooms and influence wildlife and supporting food supplies.

Projections of precipitation found in a majority of the studies forecast an increase in annual precipitation and in the frequency of large storm events. However, there is some evidence presented that the northern portion of the Upper Mississippi Region will experience a slight decrease in annual precipitation. Additionally, seasonal deviations from the general projection pattern have been presented, with some studies indicating a potential for a decrease in precipitation in the summer. Lastly, despite projected precipitation increases, droughts are also projected to increase in the basin as a result of increased temperature and [evapotranspiration] rates.

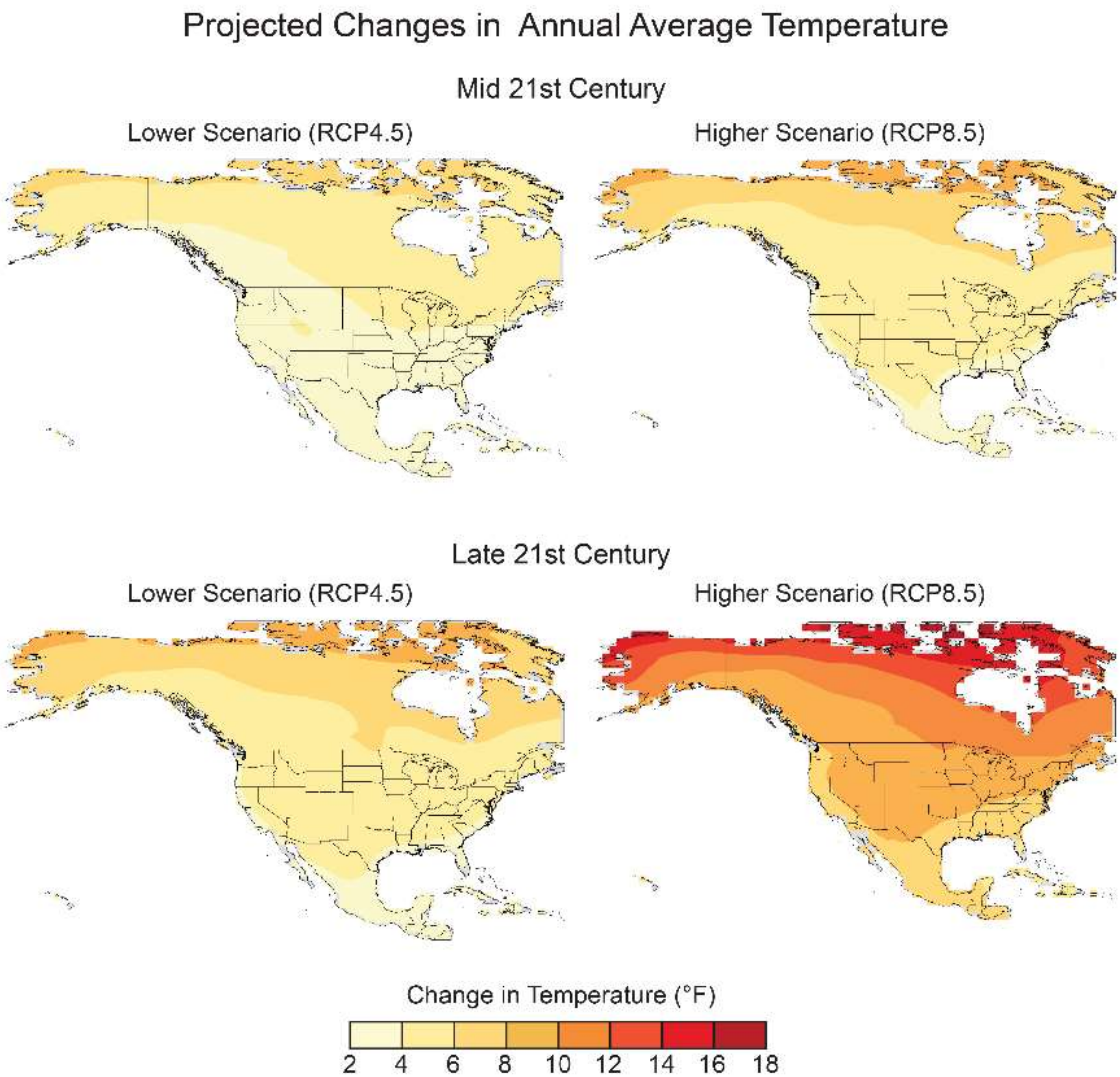
Figure 13 and Figure 15 show projected trends in temperature and precipitation for difference emission scenarios. Temperature at the project site are projected to increase in all emission scenarios and time projections, from 2-4 degrees F for the low emission scenario by Mid 21st Century and from 8-10 degrees for the high emission scenario by Late 21st Century.

Precipitation projections shown in Figure 15 from this source are less confident. Precipitation is forecasted to increase in all seasons except summer but the confidence of the results is not strong and, in the case of fall and summer, may not be stronger than the natural variability of the site’s climate. Increases in spring precipitation are the strongest. This could impact the site because OBGTR generally drains its management units during late winter and early spring. If there is more precipitation during this time, water will take longer to remove from the Oakwood Forest which will impact the growing season.

A clear consensus is lacking in the hydrologic projection literature. Projections generated by coupling [Global Climate Models] with macro scale hydrologic models in some cases indicate a reduction in future streamflow but in other cases indicate a potential increase in streamflow. Of the limited number of studies reviewed here, more results point toward reduction than increase, particularly during the summer months.

Increased mean annual precipitation in the region may pose complications to planning for ecosystem needs and lead to variation in flows. This may be particularly true during dry years, when water demands for conflicting uses may outweigh water supply. During wet years, flooding may raise particular ecological concerns and may threaten ecosystems.

Given the high degree of variability and uncertainty in weather patterns in general and in predictions of future weather patterns in particular, quantifying future project impacts is inexact.



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 13 – Projected Changes in Temperature

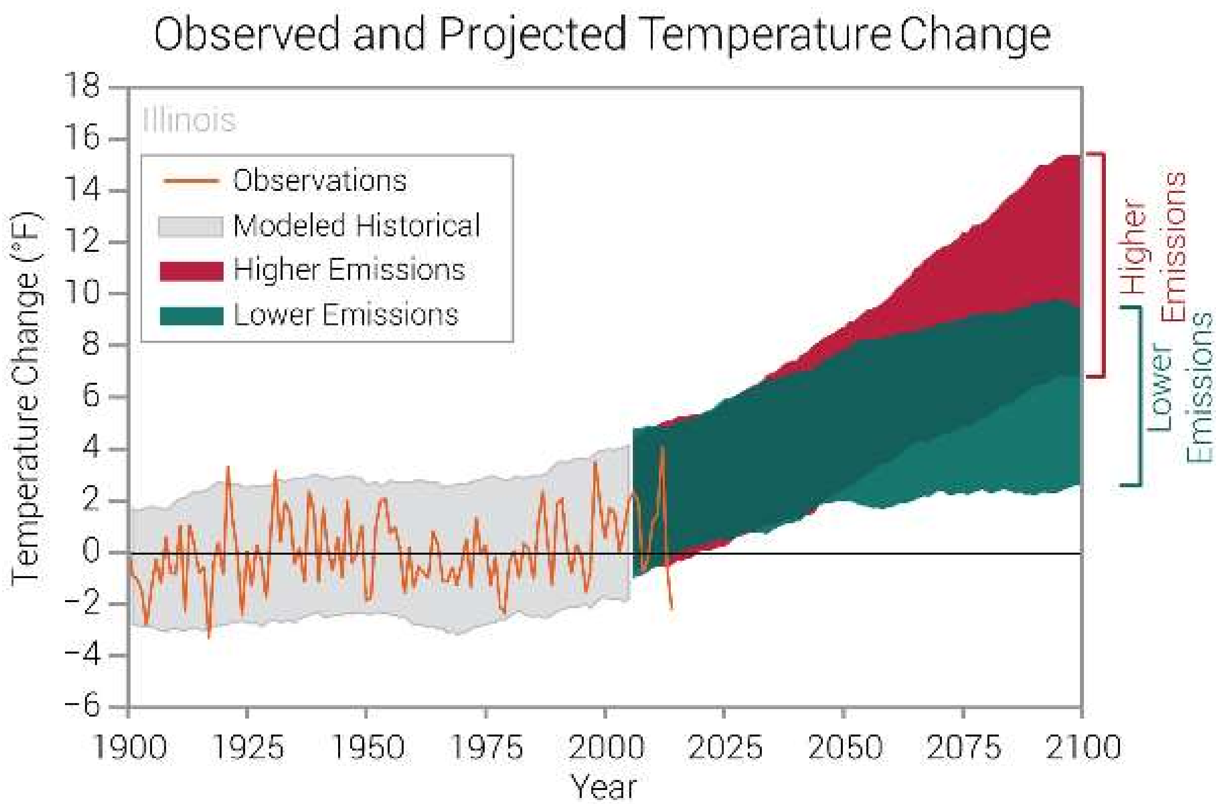
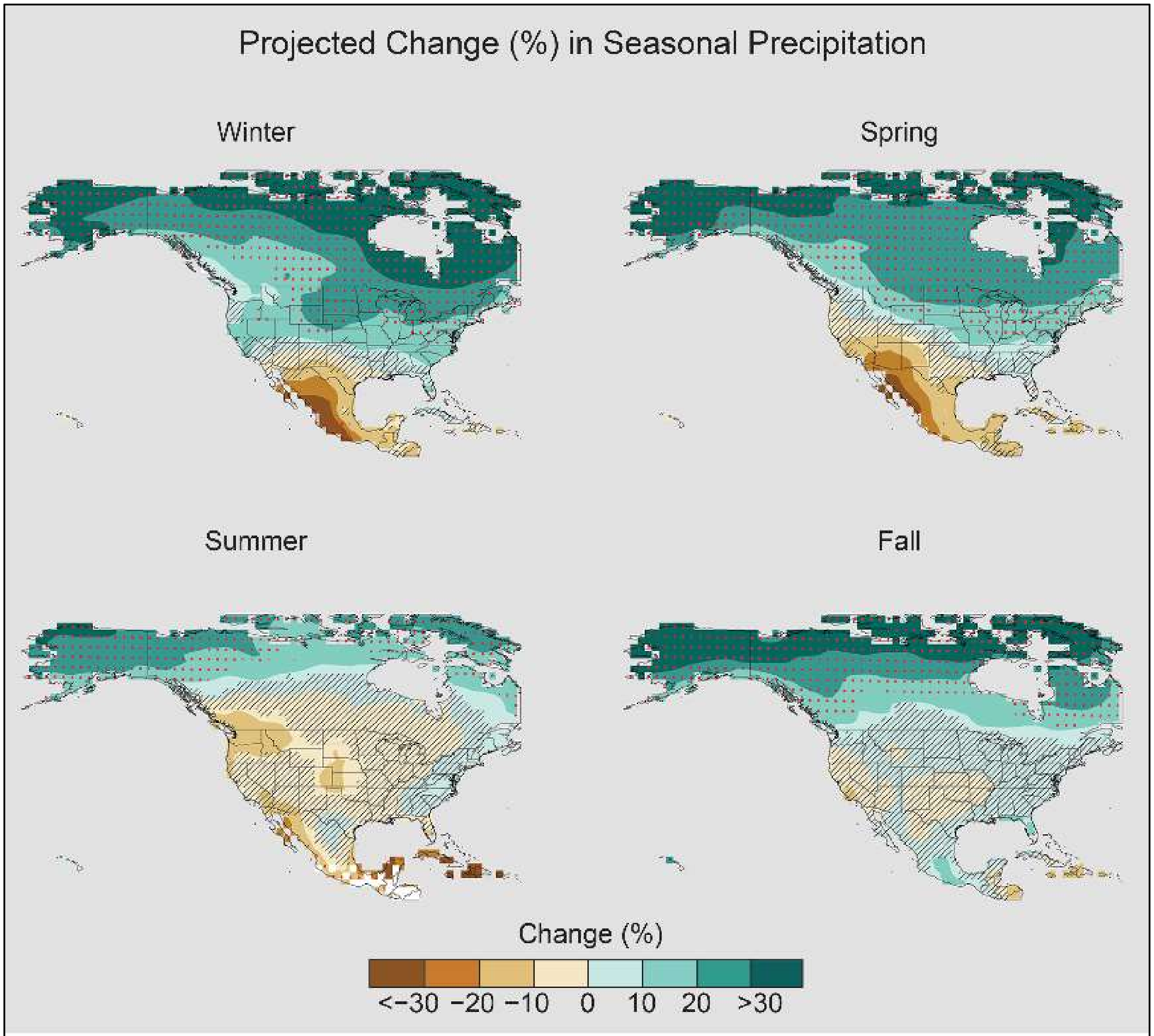


Figure 1: Observed and projected changes (compared to the 1901–1960 average) in near-surface air temperature for Illinois. Observed data are for 1900–2014. Projected changes for 2006–2100 are from global climate models for two possible futures: one in which greenhouse gas emissions continue to increase (higher emissions) and another in which greenhouse gas emissions increase at a slower rate (lower emissions). Temperatures in Illinois (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 hottest year in the historical record; green shading) and more warming under a higher emissions future (the hottest years being about 10°F warmer than the hottest year in the historical record; red shading). Source: CICS-NC and NOAA NCEI.

Figure 14 - Observed and Projected Temperature Change for Illinois (U.S. Climate Data, 2020)



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 15 – Projected Changes in Precipitation

4.5 Observed Local Trends

The USACE Climate Hydrology Assessment Tool was used to examine observed first-order streamflow trends in the vicinity of the project area. The tool only has capability to assess the annual peak instantaneous streamflow; additional hydrologic variables of interest will be added in the future. The p-value is for the linear regression fit drawn; a smaller p-value would indicate greater statistical significance. There is no recommended threshold for statistical significance, but typically 0.05 is used as this is associated with a 5% risk of a Type I error or false positive.

Table 2 shows the USGS stream gauges used in this analysis and Figure 16 shows a map of their locations. The hydrologic time series of annual peak instantaneous streamflow was generated at Murphysboro, Plumfield, and Marion gauges. These gauges were chosen because they were the 3 closest gauges to the OBGTR.

The historical streamflow was observed at these three gauges and summarized in Table 3. The analysis from the gage at Murphysboro, IL had an upward trend but the trend was not statistically significant (p-value = 0.2). It is possible that a combination of land use change a climate charge are causing this upward trend. This trend is shown in Figure 17. Figure 18 shows that Plumfield exhibited a decreasing trend over the whole available POR and has statistical significance (p-value = 0.037). The Plumfield gauge is 19.4 miles downstream of Rend Lake reservoir where flows have been regulated since October 1970. This is likely the cause of the downward trend at this gauge. Due to the nonstationarity around this time period, the POR was shortened. In Figure 19, the new positive trend for Plumfield can be observed. In comparison, the gauge at Murphysboro is 67.8 miles downstream of this dam and has no strong nonstationarities. Based on this information, it is likely Rend Lake Dam is causing the strong nonstationarity at the Plumfield gauge but has become more muted by the time it reaches Murphysboro. The Marion gauge displays an increasing trend in annual peak instantaneous streamflow (Figure 20); however, the positive trend at Marion is more statistically significant than the negative trend at Plumfield as indicated by the low p-value (p = 0.0033). After using the Nonstationarity Detection Tool on the Marion gauge, the POR needed to be shortened. With only a 20 year POR, the Climate Hydrology Assessment Tool displayed a decreasing trend with no statistical significance (Figure 21).

The Climate Hydrology Assessment Tool can be found here: https://maps.crrel.usace.army.mil/projects/rcc/portal.html.

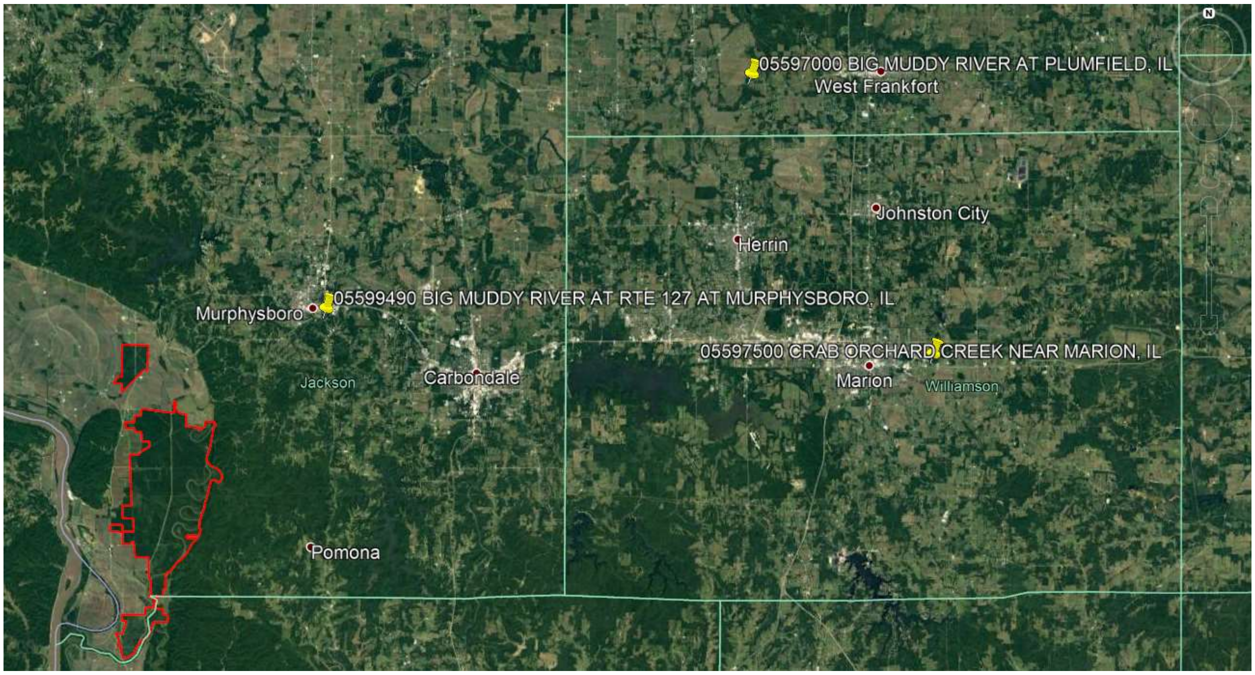


Figure 16 – Map of stream gauges used in study

Table 2 - Nearest USGS Stream Gauges

Stream Gauge	Station ID	Upstream Area (sq mi)	Period of Record (POR)	Observed Years
Big Muddy River at Rte 127 at Murphysboro, IL	05599490	2,159	1916-1917, 1919, 1931-2014	87
Big Muddy River at Plumfield, IL	05597000	792.0	1909-1912, 1915-2014	104
Crab Orchard Creek Near Marion, IL	0597500	31.7	1952-2014	63

Table 3 - Stream Flow Trends

Stream Gauge	Station ID	Adopted Period of Record	P-Value	General Trend	Statistically Significant
Big Muddy River at Rte 127 at Murphysboro, IL	05599490	1916-2014	0.208	Upward	No
Big Muddy River at Plumfield, IL	05597000	1909-2014	0.037	Downward	Yes
Crab Orchard Creek Near Marion, IL	05597500	1952-2014	0.0003	Upward	Yes

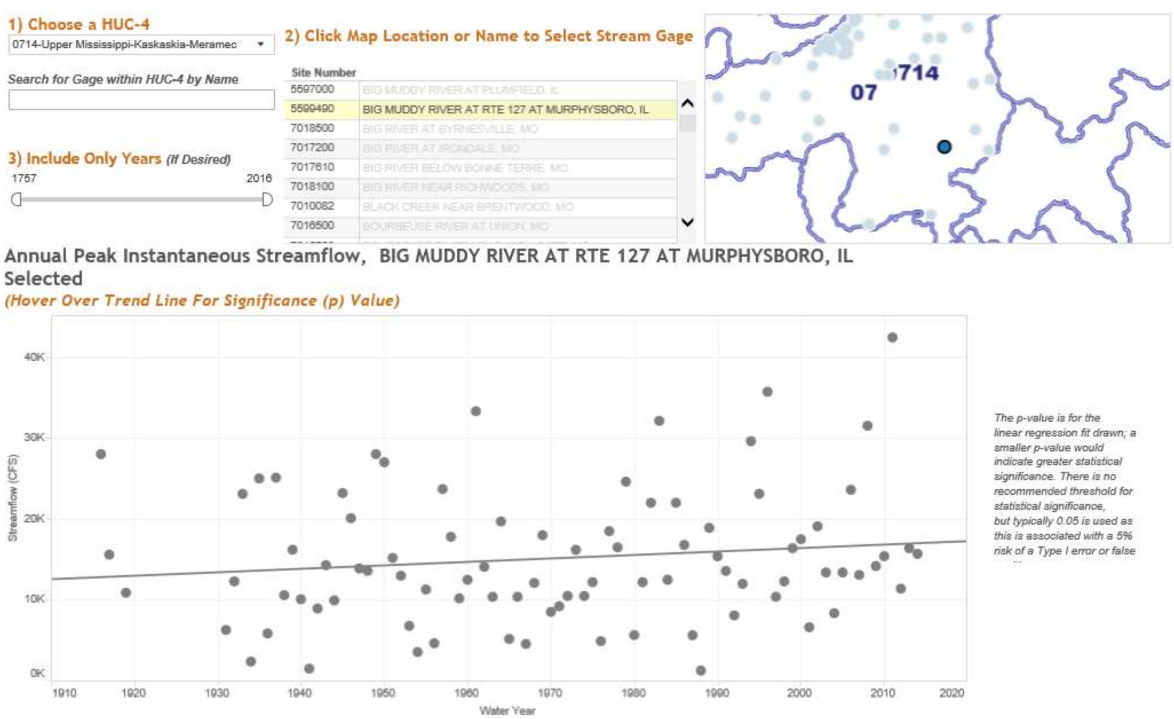


Figure 17 – Annual Peak Instantaneous Streamflow, Big Muddy River at Rte 127 at Murphysboro, IL, Trendline Equation: Q = 42.7062 * (Water Year) – 69006.1, p = 0.207718.

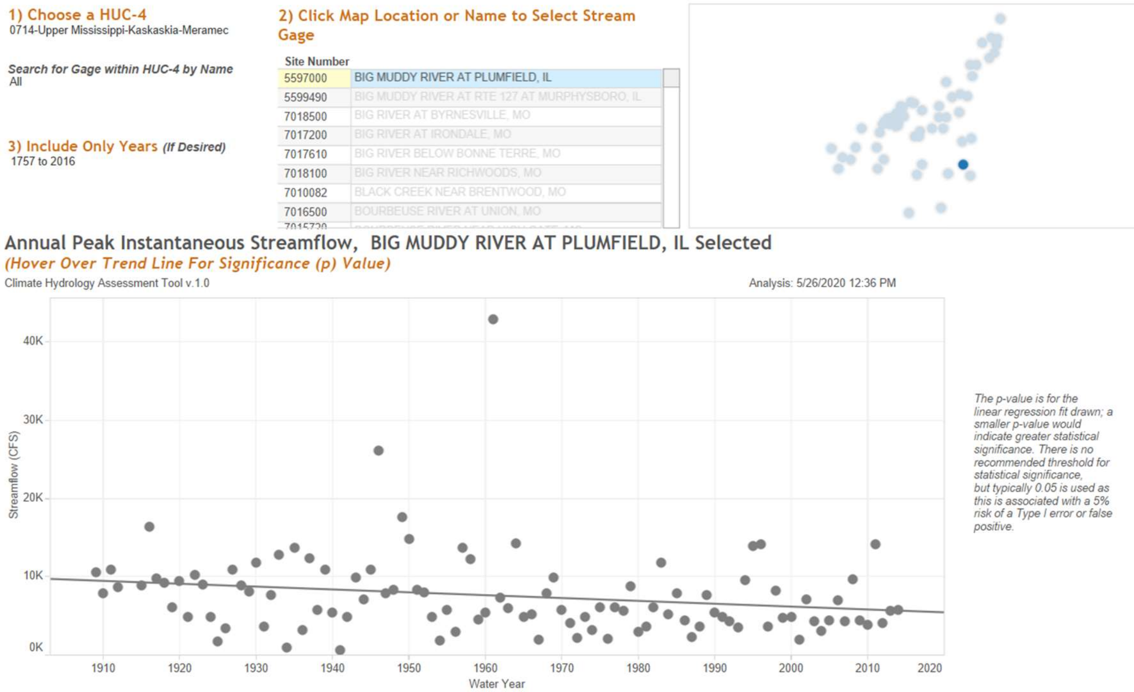


Figure 18 – Annual Peak Instantaneous Streamflow, Big Muddy River at Plumfield, IL. Trendline Equation: Q = -36.5248 * (Water Year) + 79219.5, p = 0.0374231.

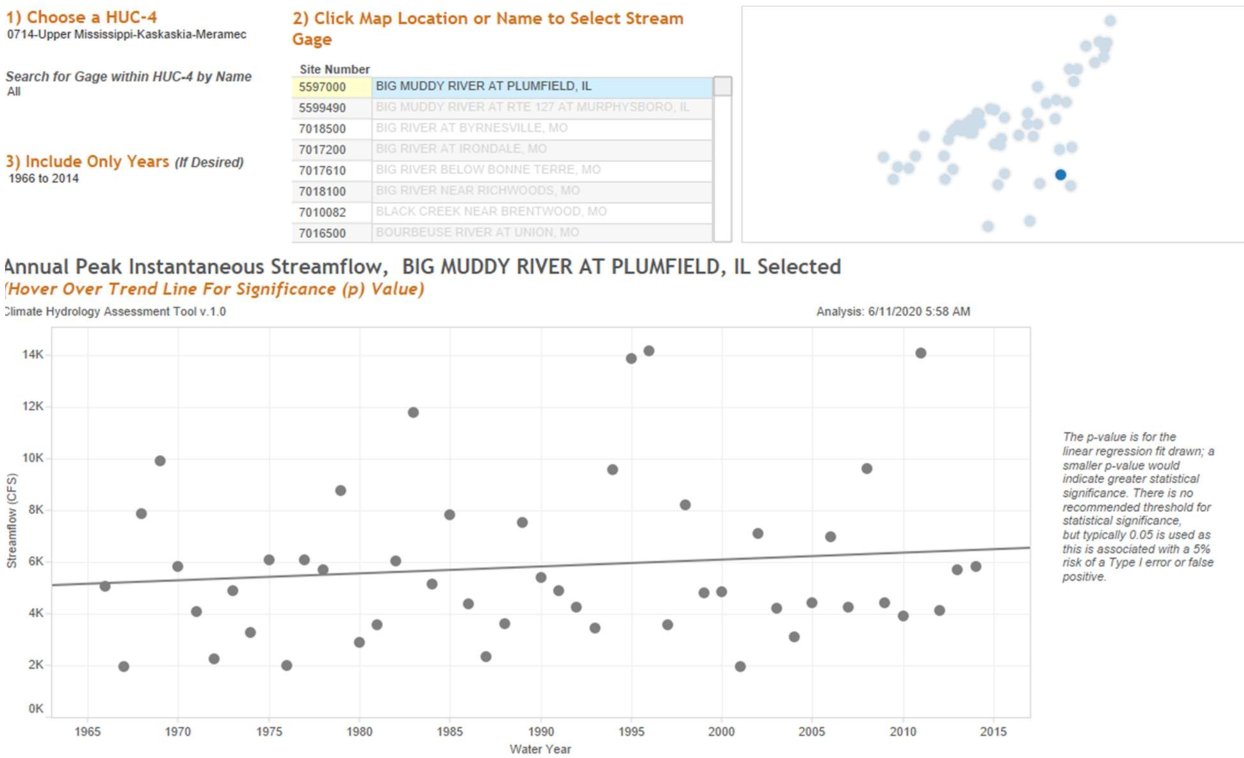


Figure 19 – Annual Peak Instantaneous Streamflow, Big Muddy River at Plumfield, IL. Trendline Equation: Q = 26.7755 * (Water Year) – 47448.2, p = 0.394523. (Shortened POR)

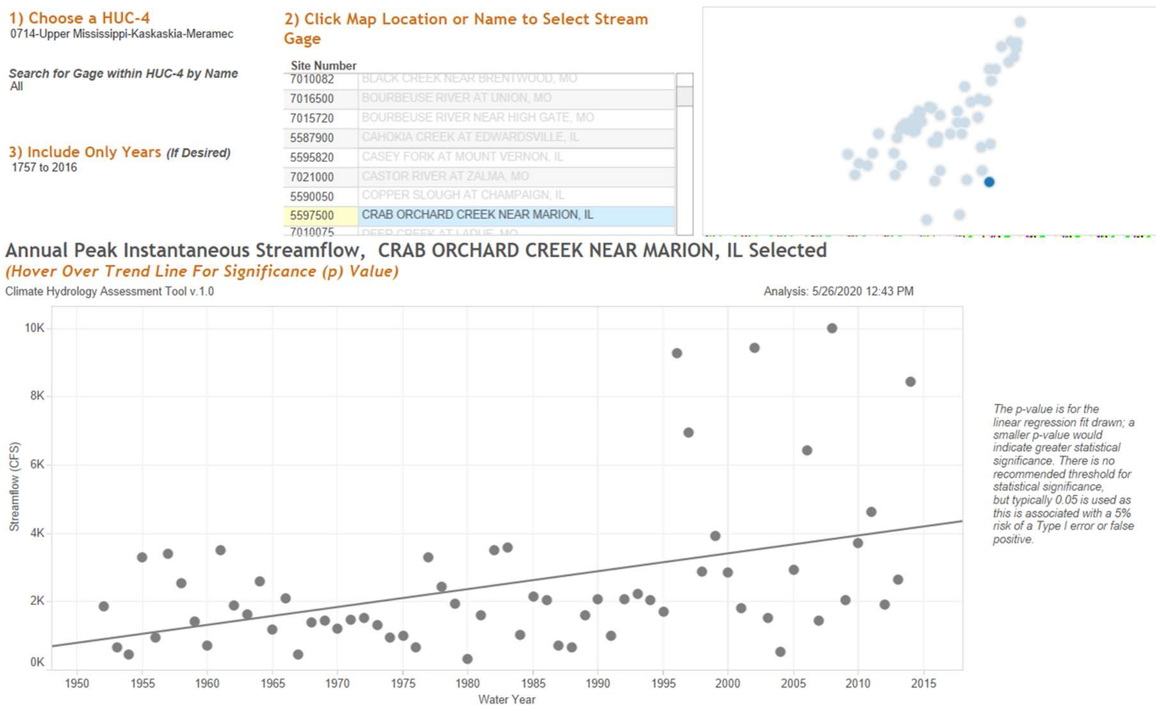


Figure 20 – Annual Peak Instantaneous Streamflow, Crab Orchard Creek Near Marion, IL. Trendline Equation: Q = 52.3526 * (Water Year) - 101291, p = 0.0003318.

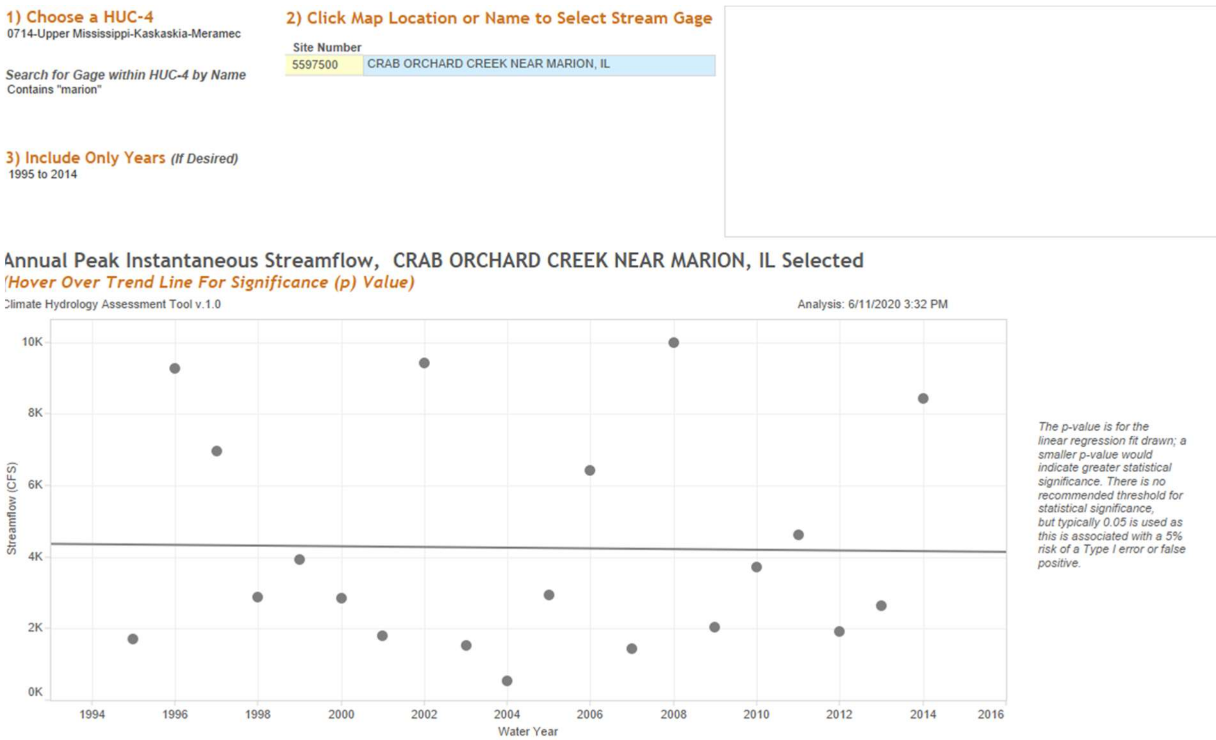


Figure 21– Annual Peak Instantaneous Streamflow, Crab Orchard Creek Near Marion, IL. Trendline Equation: Q = -9.72932 * (Water Year) + 23758.4, p = 0.93674. (Shortened POR)

4.6 Projected Regional Trends

The USACE Climate Hydrology Assessment Tool was used to examine observed and projected trends in watershed hydrology to support the qualitative assessment. This tool was used on the greater upper Mississippi-Kaskaskia-Meramec Rivers Hydrologic Unit Code (HUC). As expected for this type of qualitative analysis, there is considerable but consistent spread in the projected annual maximum monthly flows (Figure 22). The overall projected trend in annual peak instantaneous streamflow increases over time (Figure 23). This increase is statistically-significant (p-value <0.0001). This finding suggests that there may be potential for higher peak streamflows in the future. The default year of 2000 separates where emissions were held constant (1950-1999) and where the projected pathway of emissions is being applied (2000-2099) in the Global Circulation Models (GMC). The projected hydrology used 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 22. 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.

The USACE Watershed Vulnerablility Assessment Tool was used to examine the vulnerability of the project area to ecosystem decline (Figure 24). 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 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.

Upper Mississippi-Kaskaskia-Meramec Watershed (HUC 0714) is not among the top 20% of HUCs at greatest risk for ecosystem decline under either a wet or dry climate scenario. While the watershed is not among the top 20% of greatest risk, it is still vulnerable to climate change. The driving indicators to this vulnerability are listed in

Table 4 - Vulnerability results and indicators for 2050 Epoch

2050 Epoch	**HUC 0714 - Not Vulnerable**			
Indicator	**Dry**		**Wet**	
	WOWA Cont.	% Cont.	WOWA Cont.	% Cont.
8 Percent of freshwater plant communities at risk	27.96	39.74%	27.67	39.32%
65L Local mean annual runoff	4.09	5.82%	3.06	4.35%
156 Change in sediment load due to change in future precipitation	1.39	1.97%	2.15	3.06%
221C Cumulative monthly CV of runoff	6.30	8.95%	6.14	8.73%
277 Percent change in runoff divided by percent change in precipitation	14.51	20.63%	14.20	20.19%
297 Macroinvertibrate index of biotic condition	10.14	14.41%	10.03	14.26%
568C Cumulative flood magnification factor	2.13	3.03%	4.47	6.35%
568L Local flood magnification factor	0.89	1.26%	1.10	1.57%
700C Cumulative low flow reduction	2.95	4.20%	1.54	2.19%
Total WOWA Vulnerability Score:	**16.6**		**16.2**	

Table 5 - Vulnerability results and indicators for 2085 Epoch

2085 Epoch	**HUC 0714 - Not Vulnerable**			
Indicator	**Dry**		**Wet**	
	WOWA Cont.	% Cont.	WOWA Cont.	% Cont.
8 Percent of freshwater plant communities at risk	27.96	39.62%	27.67	39.24%
65L Local mean annual runoff	4.09	5.79%	3.06	4.34%
156 Change in sediment load due to change in future precipitation	1.41	2.00%	2.28	3.24%
221C Cumulative monthly CV of runoff	6.37	9.02%	6.53	9.26%
277 Percent change in runoff divided by percent change in precipitation	14.51	20.57%	13.83	19.62%
297 Macroinvertibrate index of biotic condition	10.14	14.37%	10.03	14.23%
568C Cumulative flood magnification factor	2.23	3.16%	4.52	6.42%
568L Local flood magnification factor	0.88	1.25%	1.05	1.49%
700C Cumulative low flow reduction	2.98	4.22%	1.53	2.17%
Total WOWA Vulnerability Score:	**16.6**		**16.1**	

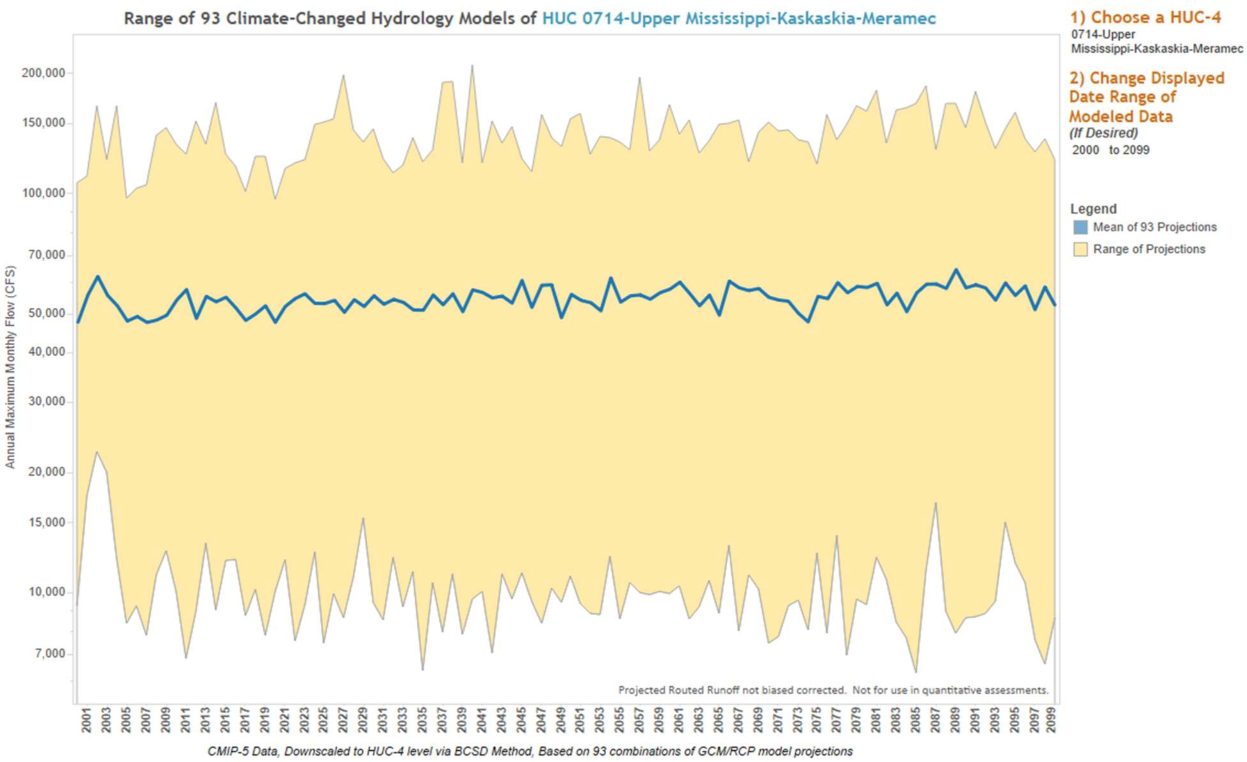


Figure 22 – Range in the Projected Annual Maximum Monthly Flows, HUC 0714 Upper Mississippi-Kaskaskia-Meramec

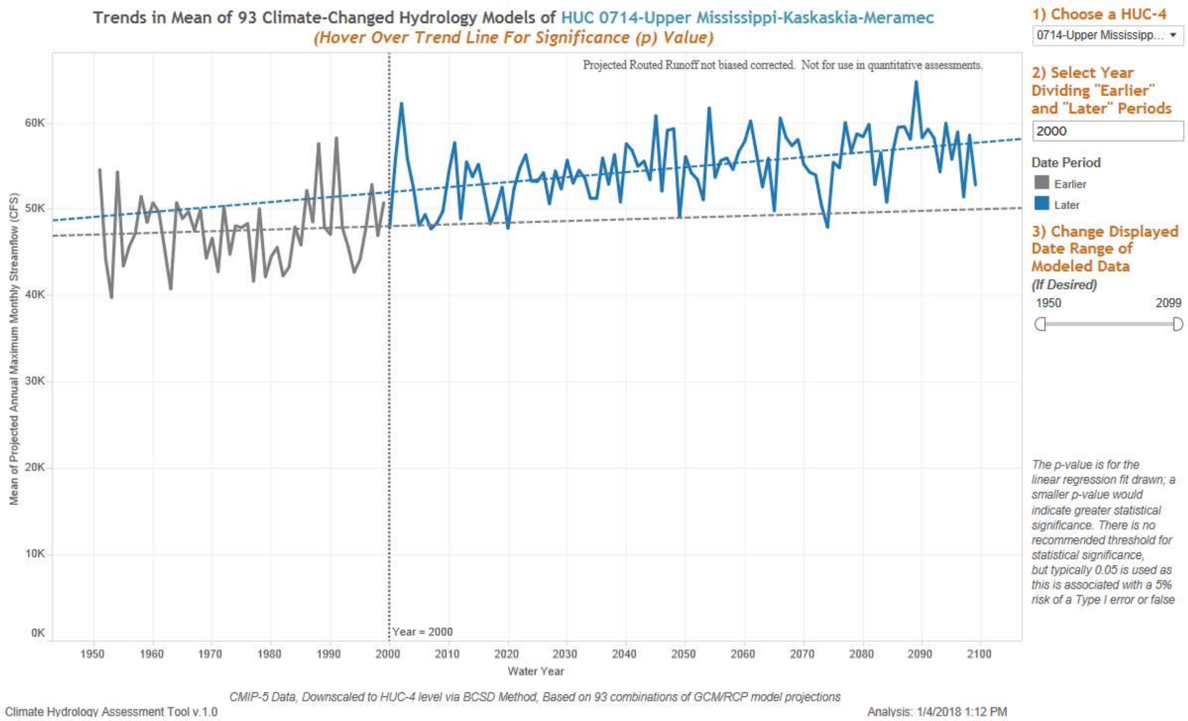


Figure 23 – Mean Projected Annual Maximum Monthly Streamflow, HUC 0714 Upper Mississippi-Kaskaskia-Meramec. Trendline Equation: Q = 57.5719 * (Water Year) – 63194.8, p < 0.0001

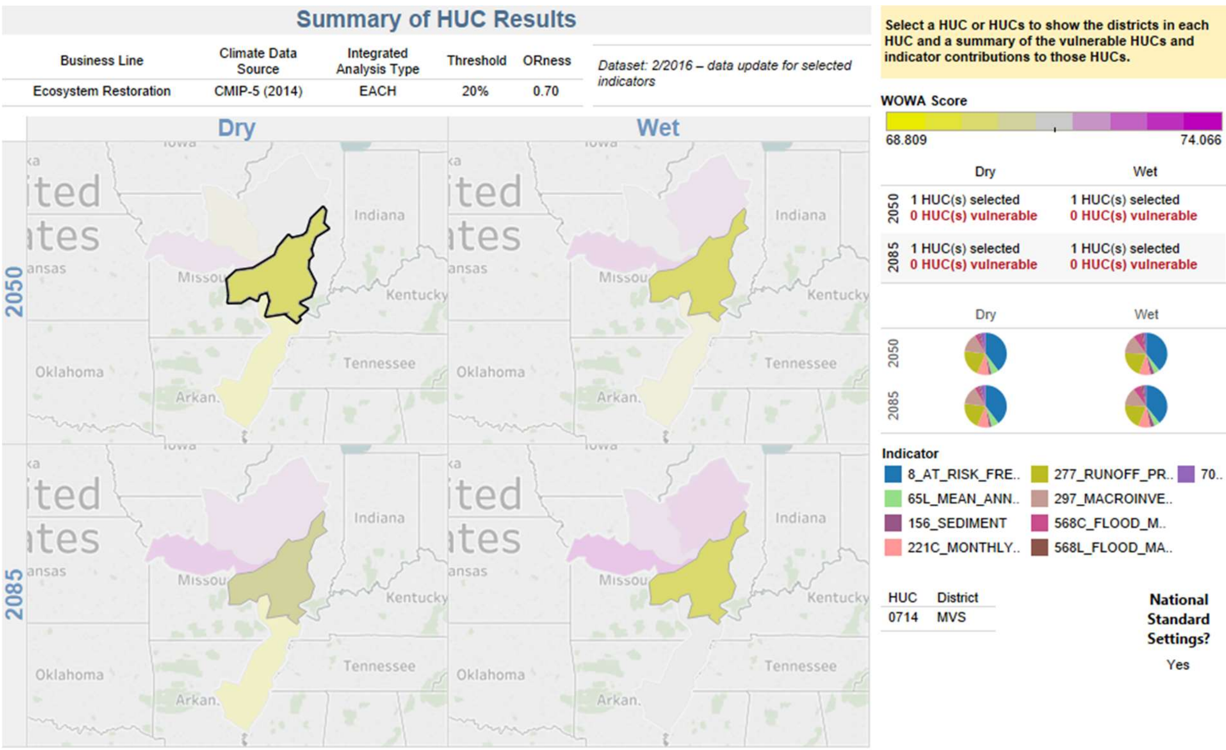


Figure 24 – Projected Vulnerability for the Upper Mississippi-Kaskaskia-Meramec (HUC 0714) with respect to Ecosystem Restoration.

4.7 Period of Record and Flow Regulation

The Nonstationarity Detection Tool (NSD) was used to determine if the stream gauge records needed to be limited to a specific period to be considered homogeneous and stationary. 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 NSD 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. The monotonic trend analysis portion of the NSD tool was used to check for statistically significant trends in the data.

For a trend to be considered statistically significant, it should typically have a P-value of 0.05 or less, based on the default values for the Pettitt sensitivity test in the tool. From the USACE literature, “P-values are probabilities of Type I errors, or the probability of accepting an alternative hypothesis when the null hypothesis is true. In this context, it is the probability of incorrectly asserting that there is a nonstationarity when in fact there is none. The default value for the Pettitt sensitivity in the tool is 0.05, but the user can change this to 0.01 or 0.1. Because they represent accepted probabilities of Type I errors, these values are typically selected as the standard significance threshold within statistical literature” (USACE, 2017a).

Note that statistical analyses on the data should not just adopt the homogenous record, especially if analysis on the homogenous record results in less conservative results. If the gauge is impacted by a dam or other anthropogenic change an effort should be made to re-homogenize the record or create an unregulated-regulated rating relationship.

Figure 25 through Figure 30 show the results of the Non-Stationary Detection Tool. Results at the Big Muddy River at Plumfield gauge show a nonstationarity around 1965. This nonstationarity is considered strong because it triggered two tests for mean and two additional tests for distribution and variance. The largest flow event observed in the continuous period of record occurred in 1961 and likely played a role in triggering the nonstationarity detected in the early 1900s.The Monotonic Trend analysis for the Plumfield gauge shows a statistically significant trend in both the Mann-Kendall and Spearman Rank Order Tests. This means the time series still does not meet the assumption of stationarity. Results at the Big Muddy at RTE 127 at Murphysboro show a nonstationarity around 1975. This nonstationarity is not considered strong because it doesn’t trigger 2 of the same type of statistical test; it only triggered one test for mean and one for distributional. According to the Monotonic Trend Analysis, there is no significant trend which means the data can be considered homogrneous. Looking at the gauge metadata, the main driver of nonstationarities in the case of these two Big Muddy gauges is Rend Lake 19.4 miles upstream of Plumfield and 67.8 miles upstream of Murphysboro. This is the reason a strong stationarity was found at the Plumfield gauge. The dam’s regulation becomes muted by the time it gets to the Murphysboro gauge where there are no strong nonstationarities triggered. The results at Crab Orchard Creek near Marion show a Nonstationarity around 1991. It is considered strong because it triggered 2 tests for mean and another for distribution. Flows started having significantly higher peaks with a more positive trend starting in 1996 which likely played a role in triggering the nonstationarity. The Monotonic Trend analysis for the Marion gauge shows a statistically significant trend in both the Mann-Kendall and Spearman Rank Order Tests. This means the time series still does not meet the assumption of stationarity.

~~The Nonstationarity Detection Tool can be found here:~~

https://maps.crrel.usace.army.mil/projects/rcc/portal.html.

Table 6 - Adopted Period of Record

Stream Gauge	Station ID	Full POR	Adopted Period of Record	Adopted No. of Years	Nonstat. Detected	Record Adjustment Notes
Big Muddy River at Rte 127 at Murphysboro, IL	05599490	1916-1917, 1919, 1931-2014	1931-2014	84	One test triggered in 1975	Record shortened due to missing data
Big Muddy River at Plumfield, IL	05597000	1909-1912, 1915-2014	1966-2014	49	Variance in 1960 Mean 1963 Mean 1964 Distributional 1965	Shortened record to obtain homogenous POR
Crab Orchard Creek Near Marion, IL	05597500	1952-2014	1995 -2014	20	Distributional 1982 Mean 1990 Mean 1991 Distributional 1995	Shortened record to obtain homogenous POR

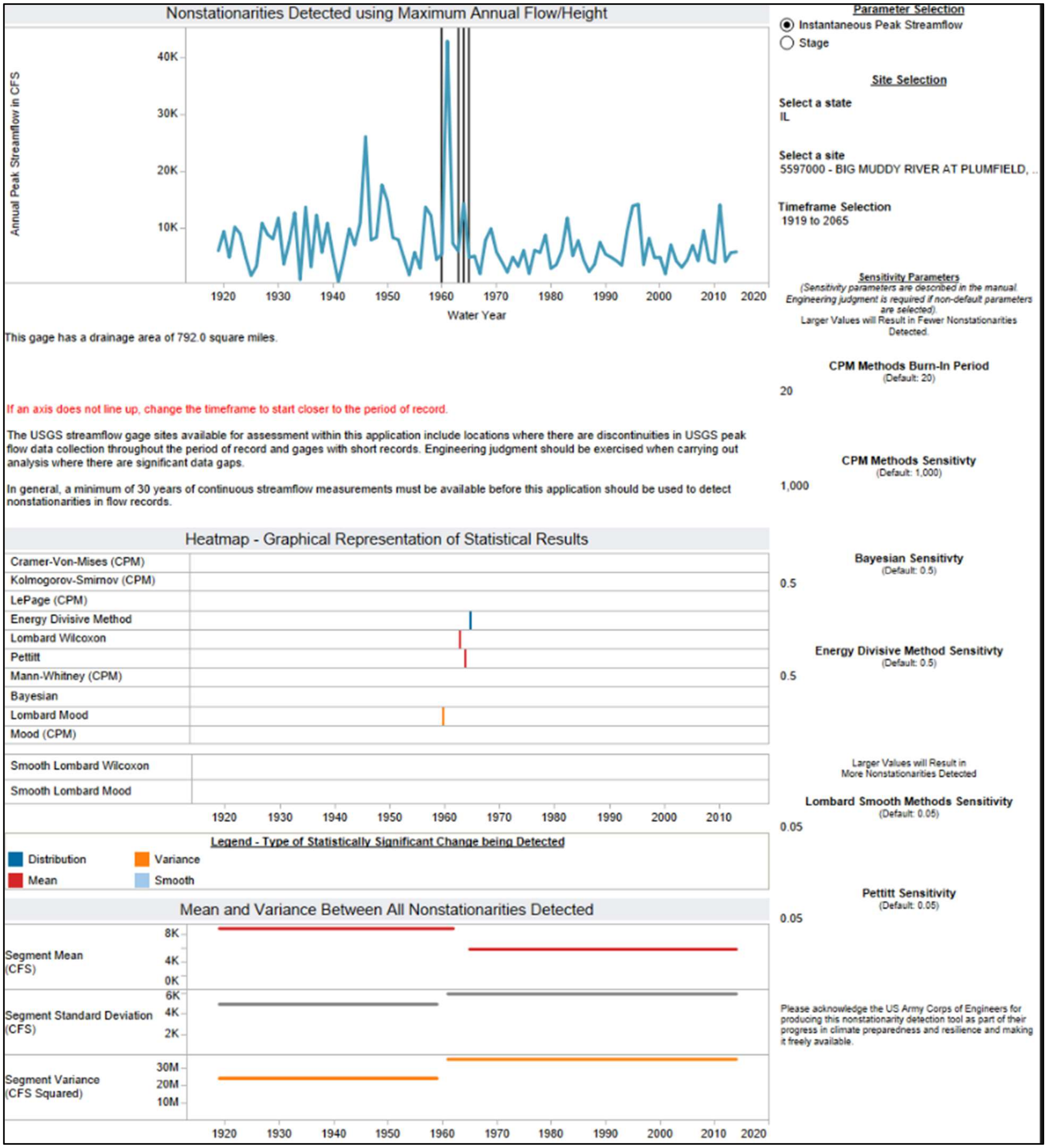
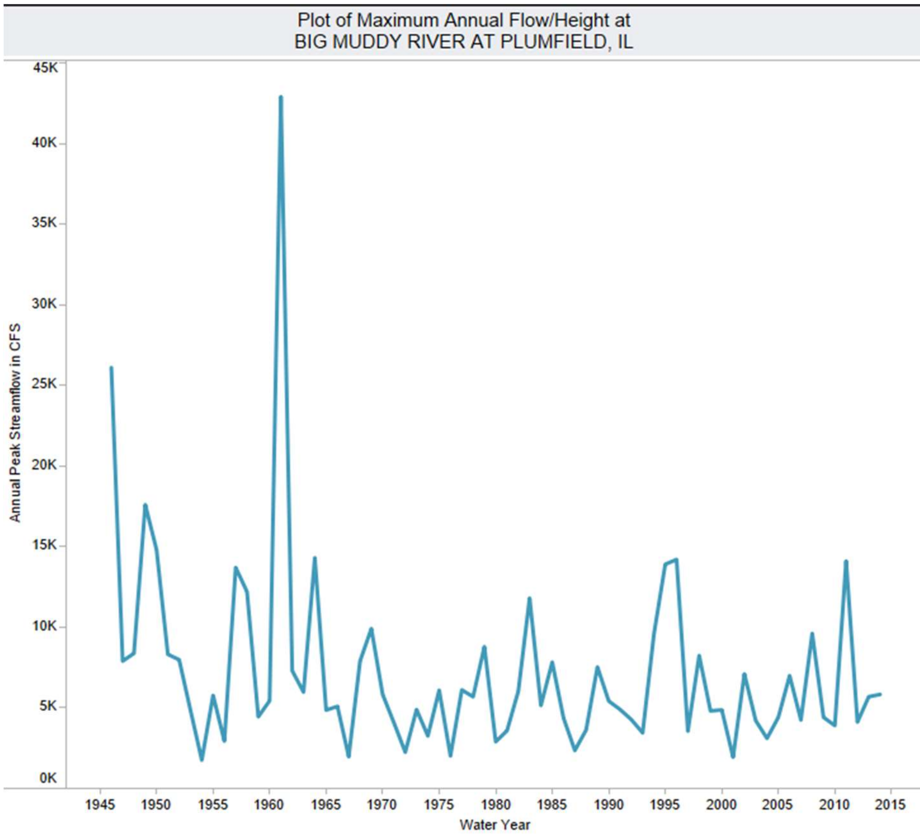


Figure 25 – Nonstationarities for Big Muddy at Plumfield



Timeframe Selection
1946 to 2065

Monotonic Trend Analysis

Is there a statistically significant trend?
Yes, using the Mann-Kendall Test at the .05 level of significance. The exact p-value for this test was 0.043.
Yes, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.037.

What type of trend was detected?
Using parametric statistical methods, **a negative trend** was detected.
Using robust parametric statistical methods (Sen's Slope), **Null** 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 26 – Maximum Annual Flow at Big Muddy at Plumfield

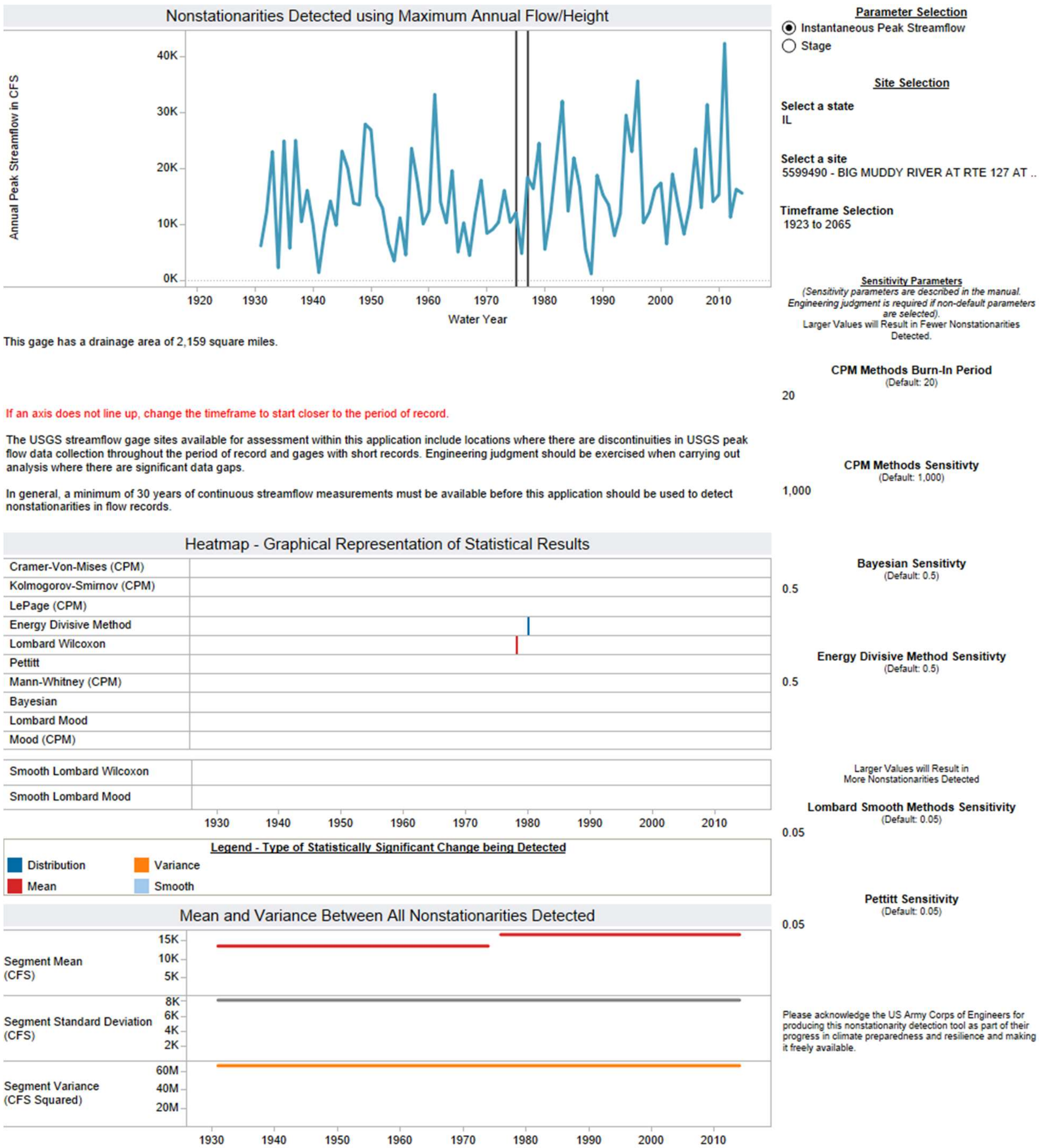
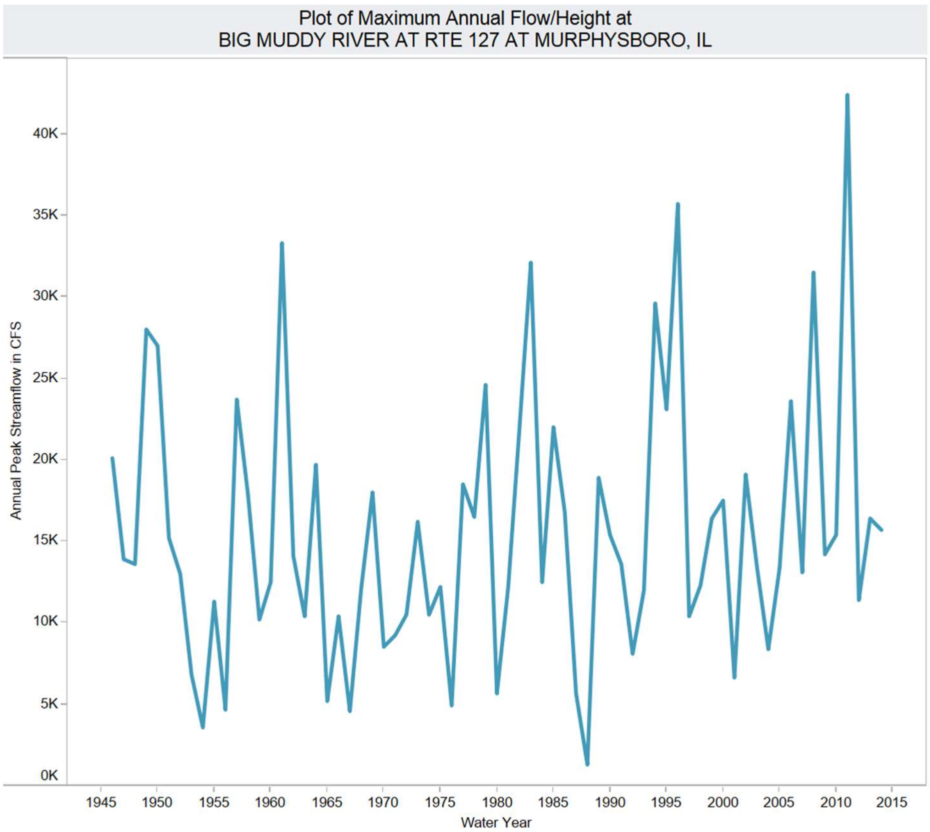


Figure 27 – Nonstationarities for Big Muddy at Big Muddy River at RTE 127 at Murphysboro



Timeframe Selection
1946 to 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 0.233.
No, using the Spearman Rank Order Test at the .05 level of significance. The exact p-value for this test was 0.252.

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 28 – Maximum Annual Flow at Big Muddy at Big Muddy River at RTE 127 at Murphysboro

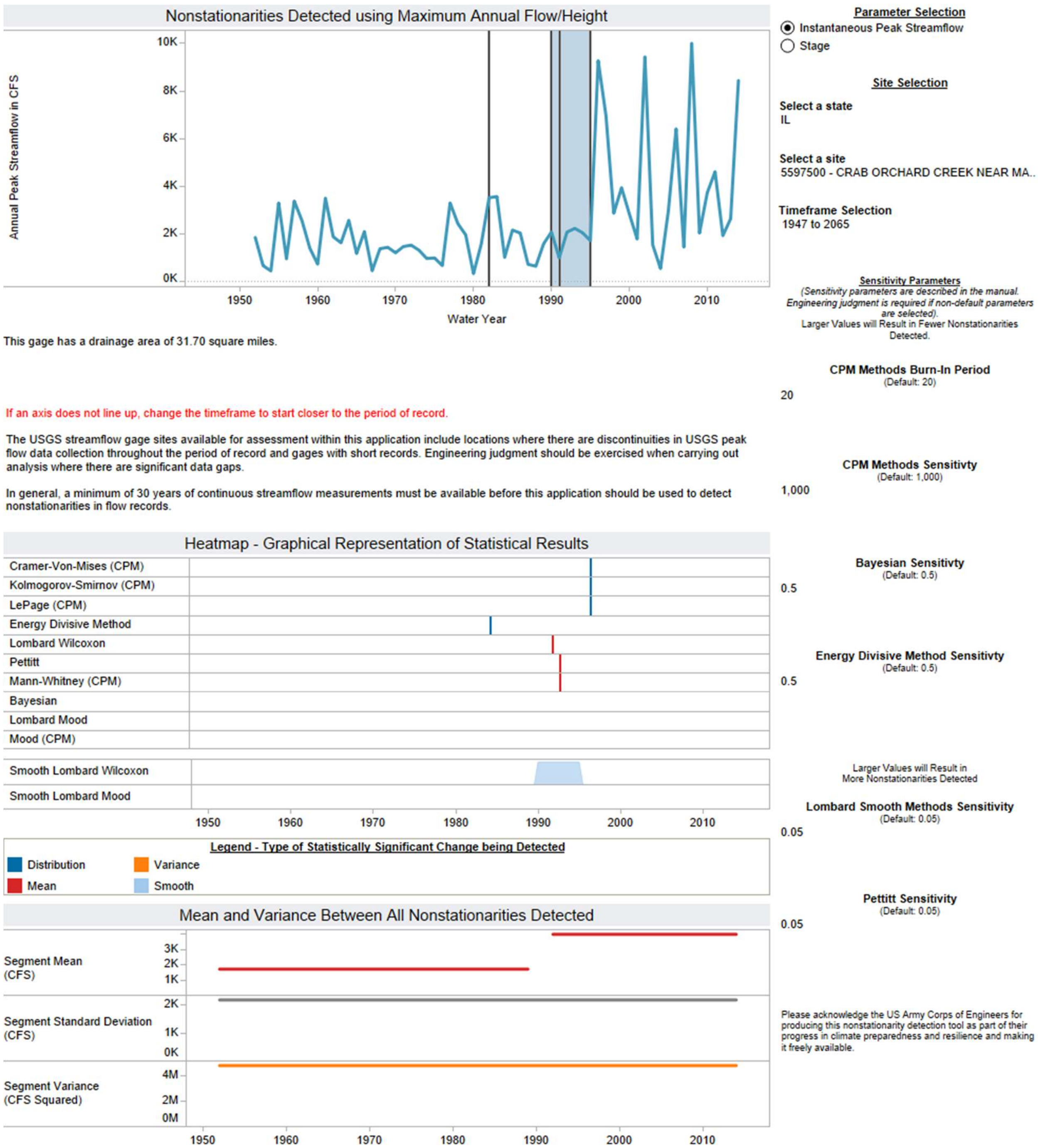


Figure 29 – Nonstationarities for Crab Orchard Creek near Marion

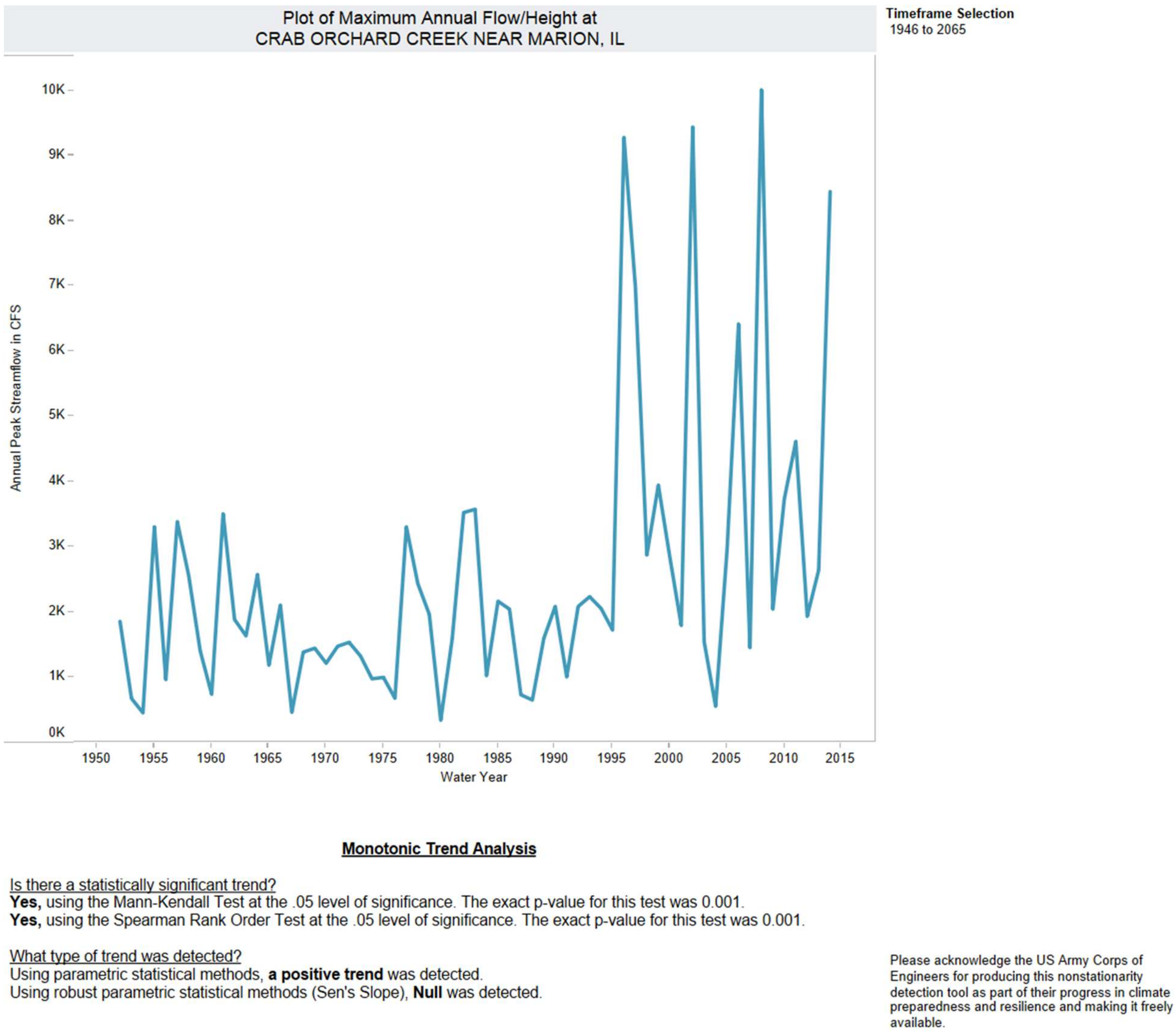
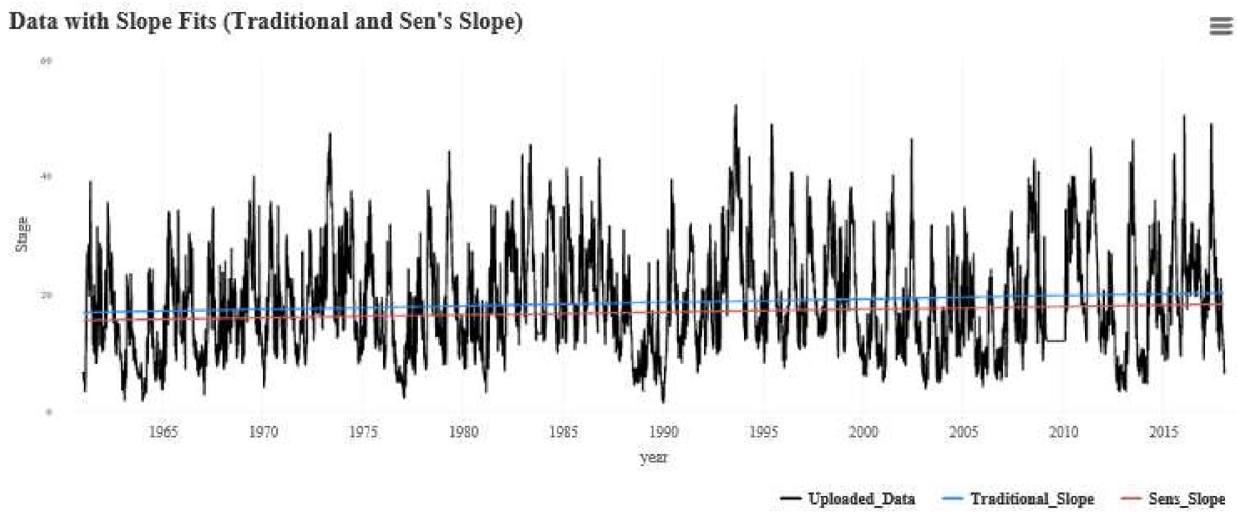


Figure 30 – Maximum Annual Flow at Crab Orchard Creek near Marion

4.8 Analysis of Trends in Daily Flow Data

The Time Series Toolbox was used to analyze the trends in the daily stage data used in the duration analysis. The three gauges used for this analysis and their POR are discussed in section 1.6. The Mississippi River at Grand Tower gauge shows a positive (0.058941) slope and is statistically significant because the P-Values are less than 0.05 in all three tests (Figure 31). The Mississippi River at Moccasin Springs gauge also shows a positive (0.057693) slope and is statistically significant because the P-Values are less than 0.05 in all three tests (Figure 32). Since the duration analysis was conducted in early 2018, the data for the Big Muddy at Sand Ridge has been removed from the USACE St. Louis District's Water Manager CWMS 3.0 Production Server. Once this data is able to be retrieved, the data will be uploaded and analyzed in the Time Series Toolbox.



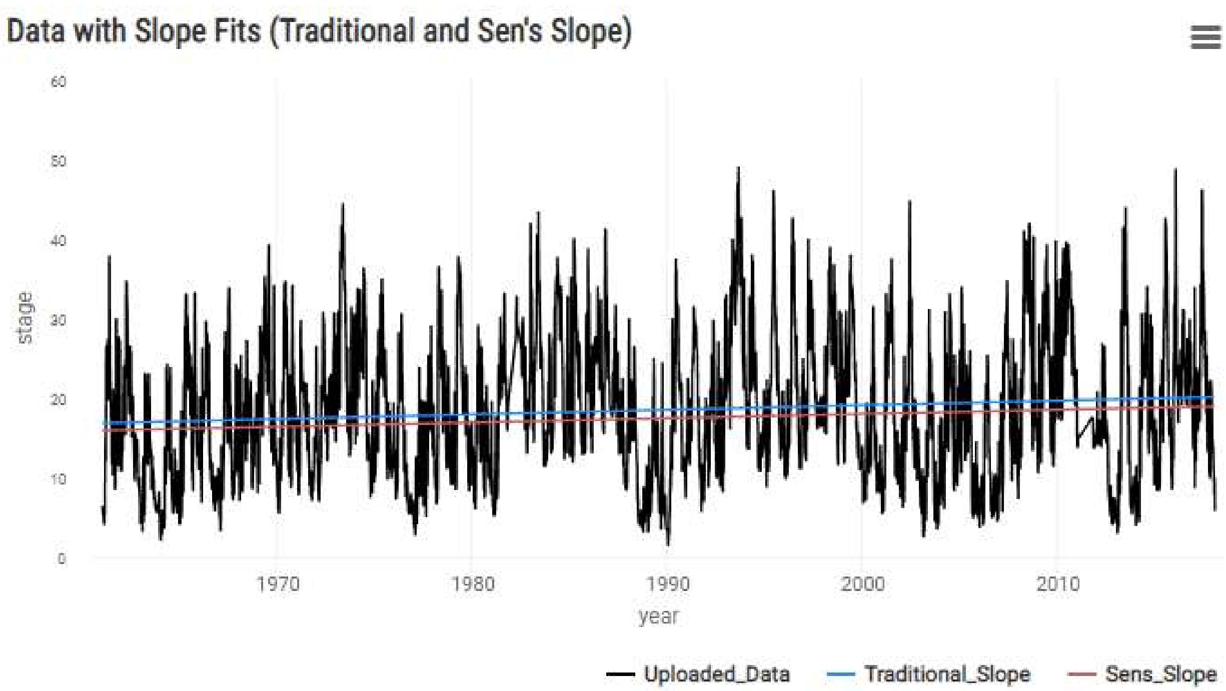
Trend Line Coefficients

Method	Slope	Intercept
Linear Regression Slope	0.058941	-98.815
Sens Slope	0.048317	-79.328

Test	P.Value
t-Test	4.9939e-55
Mann-Kendall	< 2.2e-16
Spearman Rank-Order	1.1398e-41

- **A statistically significant trend (at the alpha = .05 level) was detected by the Mann-Kendall Test.**
- **A statistically signifnicant trend (at the alpha = .05 level) was detected by the Spearman Rank-Order Test.**

Figure 31 - Mississippi River at Grand Tower Trend Analysis



Trend Line Coefficients

Method	Slope	Intercept
Linear Regression Slope	0.057693	-96.333
Sens Slope	0.053268	-88.588

Test	P.Value
t-Test	9.1878e-57
Mann-Kendall	< 2.2e-16
Spearman Rank-Order	5.5339e-48

Figure 32 - Mississippi River at Moccasin Springs Trend Analysis

4.9 Climate Change Conclusions

The literature review indicates:

1. The general consensus in recent literature points toward moderate increases in temperature and precipitation in the Upper Mississippi Region over the past century.
2. In some studies and some locations, statistically significant trends have been quantified. In other studies and locales within the Upper Mississippi Region, apparent trends are observed graphically, but are not statistically quantified.
3. Some evidence points to an increased frequency in the occurrence of extreme storm events (Villarini et al., 2013).
4. Multiple authors identified a transition point in climate data trends in 1970 where rates of increase changed significantly.

Project specific results generated using USACE tools indicate the following:

1. Nonstationarity analysis and monotonic trend analysis of annual peak streamflow records observed at sites in the vicinity of the project area indicate two “strong” nonstationarities.
2. The Plumfield gauge is 19.4 miles downstream of Rend Lake reservoir where flows have been regulated since October 1970. This is likely the cause of the statistically significant downward trend at this gauge. The statistically significant upward trend for the Marion gauge could indicate increasing flows due to climate change.
3. The HUC4 containing the OBGTR is relatively vulnerable to climate change impacts for the Ecosystem Restoration Business Line in all future scenarios tested (2050-dry, 2050-wet, 2085-dry, and 2085-wet). The primary indicator variable driving the vulnerability score is the percent of freshwater plant communities at risk.
4. Two of the observed stream gauge records showed statistically significant results ($p < 0.05$). One displayed an upward trend and the other a negative trend. Climate change and land use runoff are potential drivers for the upward trends while the upstream reservoir is a possible inhibitor or the downward trend.

Future, Without Project Conditions could be impacted by changes in climate at some indeterminate point in the future. An upward trend in precipitation and possibly stream flow in the OBGTR would cause larger amounts of interior flooding with no way to remove the water from behind the levee. This would continue to destroy the Oakwood populations. Additional resiliency was built into the project by selecting the alternative with a pump station on the southern end of the project site to be used in dewatering the area during extreme conditions.

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