Three Rivers Southeast Arkansas Study

Appendix B: Hydrologic and

Hydraulic Analysis

THREE RIVERS SOUTHEAST ARKANSAS

Introduction

The Three Rivers Study, which encompasses the confluence of the Arkansas and White rivers with the Mississippi River in southeast Arkansas, is being conducted by the U. S. Army Corps of Engineers (USACE) to study the McClellan-Kerr Arkansas River Navigation System (MKARNS) in an effort to seek a long-term sustainable navigation system that promotes the continued safe and reliable economic use of the MKARNS.

There is a risk of breach of the existing containment structures near the entrance channel to the MKARNS on the White River. During high water events, water backing up the Mississippi can create significant head differentials between the Arkansas and the White rivers. The existing containment structures are subject to damaging overtopping, flanking and seepage that could result in a catastrophic breach. The uninhibited development of a breach, or cutoff, has the potential to create various navigation hazards, increase the need for dredging, and adversely impact an estimated 200 acres of bottomland hardwood forest in the isthmus between the Arkansas and White rivers.

Stage of Planning Process

This is a feasibility study. A planning Charette was conducted in September 2015, and an Alternatives Milestone Meeting was completed in December 2015. The study is in the Alternative Formulation and Analysis Phase. Utilizing a reasonable level of detail, the PDT has analyzed, compared, and evaluated the array of alternatives to identify a Tentatively Selected Plan.

Study Authority

Section 216, Flood Control Act of 1970 (Public Law 91-611) authorizes a feasibility study due to examine significantly changed physical and economic conditions in the Three Rivers study area. The study will evaluate and recommend modifications for long-term sustainable navigation on the MKARNS. Section 216 of the Flood Control Act of 1970 (Public Law 91-611) states:

> *"The Secretary of the Army, acting through the Chief of Engineers, is authorized to review the operation of projects the construction of which has been completed and which were constructed by the Corps of Engineers in the interest of navigation, flood control, water supply, and related purposes, when found advisable due to significantly changed physical or economic conditions, and to report thereon to Congress with recommendations on the advisability of modifying the structures or their operation, and for improving the quality of the environment in the overall public interest."*

Non-Federal Sponsor

The Arkansas Waterways Commission is the non-federal sponsor for the Three Rivers Southeast Arkansas Study. An amended feasibility cost-sharing agreement was executed in June 2015.

Purpose

Based on the Section 216 authority, the study is investigating alternatives that would minimize the risk of cut off development, including reducing the cost of maintence associated with preventing cutoff development, while minimizing impacts to the surrounding ecosystem.

Three Rivers: Mississippi River, Arkansas River, and White River
Two-Dimensional Hydraulic Modeling

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1 Study Background and Introduction

1.1 Problem statement

A natural cutoff (or interconnecting, uncontrolled channel between two water courses) historically existed between the lower White River and the Arkansas River. The natural cutoff resulted from hydrologic interactions near the confluence of three river systems: the Arkansas, Mississippi and White Rivers. Over time this interaction promoted overland erosion creating a free flowing channel connecting the Arkansas and White Rivers. During the development of the McClellan-Kerr Arkansas River Navigation System (MKARNS) in the mid-1960s, the natural cutoff was identified as an impediment to the reliability of navigation and was closed by constructing a non-overtopping dike named the Historic Closure Structure. The Historic Closure Structure has increased the head differential between the White River and the Arkansas River during overtopping events across the isthmus, the narrow strip of land that separates the Arkansas River from the White River, resulting in higher energy differences and increased erosion. Additional cutoffs have been developing through the isthmus as a response to the higher energy differences attempting to restore the natural hydrologic relationship between the systems. This geomorphic process continues to threaten the MKARNS with increasing and more frequent maintenance costs. The uninhibited development of these cutoffs has the potential to create navigation hazards, increase the need for dredging, and adversely impact an estimated 110 acres of bottomland hardwood forest in the isthmus between the Arkansas and White Rivers.

The Dale Bumpers White River National Wildlife Refuge, (The Refuge) established in 1935, contains approximately 160,000 acres of prime bottomland hardwood habitat located within the floodplain of the lower White river and is adjacent to the navigation channel. The bottomland hardwood forest is frequently flooded and is a forest type highly affected by land and water elevation relationship. An uncontrolled breach through the isthmus would cause the development of a head cut (an abrupt degradation of the channel bed) that would proceed up the White River. This would cause bank caving along the main channel and subsequent head cutting up tributaries that would result in oxbow lakes losing their form and function. If this continued unchecked, there could be a drop in the water table which would cause the bottomland hardwoods to become disconnected from the ground water table. Repairing the breach through the isthmus would stop further head cutting up the White River and would eventually cause aggradation of the channel bed, but the rate of aggradation might be insufficient to catch up with the head cutting nick point before bank caving and loss of some oxbows occurs.

1.2 Site Description

The study focuses on preserving the integrity and long term dependability of the entrance channel to the *McClellan-Kerr Arkansas River Navigation System (MKARNS)*, while providing environmental benefits to the bottomland hardwoods, wetlands, and oxbow functions in the isthmus and in the *US Fish and Wildlife Dale Bumpers White River National Wildlife Refuge* (Refuge) as shown in Figure 1-1 and Figure 1-2. Tows traveling to the Arkansas River from the Mississippi River enter the MKARNS at the White River's mouth, travel 10 miles up the White River to Lock 01 (Norrell), lock into the Arkansas Post Canal, and navigate the canal to the Arkansas River.

Figure 1-1: General Map of MKARNS Entrance Channel Location

The immediate study area is loosely bounded on the north by the Phillips and Desha County Lines, on the east by levees and the Mississippi River, on the west by levees, and on the south just downstream of the Arkansas River confluence with the Mississippi River. See Figure 1-2: Study Area

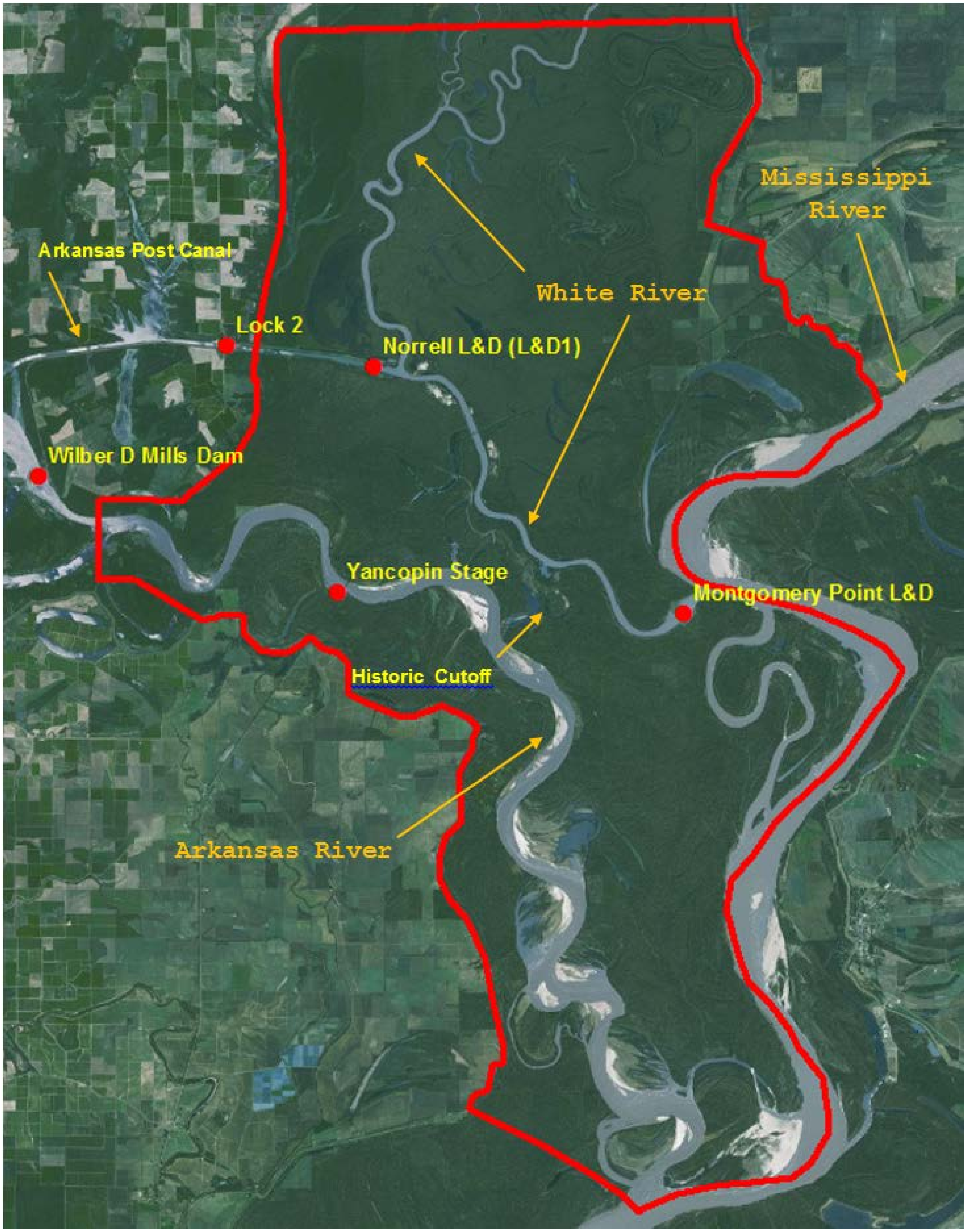

Figure 1-2: Study Area

1.4 History

The confluence of the Arkansas and the White Rivers with the Mississippi River is an area of complex and evolving flow patterns. Early European explorers and cartographers[1] noted there was a channel connecting the lower White and the lower Arkansas Rivers. The channel was either unnamed or called a cutoff. The cutoff was so named because it could be used as a shortcut for some river traffic depending on its destination. It is now called the Historic Cutoff. The Historic Cutoff was deep enough that it connected the lower Arkansas and White Rivers for all known conditions; hence the land between the cutoff and the Mississippi River came to be known as Big Island (360 Sq. Mi.).

When building the MKARNS, the designers were concerned about the high cost of stabilizing the lower Arkansas River. To maintain a stable navigation channel, many stone structures had been placed in the lower Arkansas River with varying degrees of success. To avoid the tricky and expensive proposition of challenging the inherently unstable deltaic channel[2], the designers chose to construct a canal connecting the Arkansas River to the stable Lower White River. The Historic Cutoff, however, presented two possible problems.

Sometimes dangerous cross currents in the White River were reported to occur when flow passed through the cutoff between the rivers. Additionally, the Arkansas River carries more sediment load than the White River. The designers suspected the Historic Cutoff would continue to contribute sediment into the White River Entrance Channel at a high rate. So, in 1964, the Historic Cutoff was closed, Closure *Structure*, to avoid the possible navigation risk and lower the dredging cost[3].

This arrangement worked well until 1973, the year of the first unusually high water on the Mississippi following construction of the MKARNS[4]. Afterwards, a new, small *headcut* was identified on the Arkansas River, running up through the isthmus. Over the next two decades, the headcut grew whenever Mississippi River stages at the mouth of the White River produced backwater high enough to push flow across the isthmus into the Arkansas River. Little Rock District personnel became alarmed at the headcut's rate of acceleration in the 1980s.

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[1] Hutchins, Thomas, *The Western Parts of Virginia,* (1778); Collot, George Henri Victor, *A Journey in North America* (1796); Cramer, Zadok, *The Navigator,* (1817). This span of maps brackets any possible impacts of the 1811-1812 New Madrid earthquakes.

[2] Saucier, Roger T., *Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley*, (Vicksburg, MS: US Army Corps of Engineers, 1994).

[3] Franco, J. J., et al., *Technical Report No. 2-795: Arkansas River Navigation Entrance – Hydraulic Model Investigation*, (Vicksburg, MS: U.S. Army Engineer Waterways Experiment Station, 1967).

[4] Arkansas City Gauge reached 47.6 feet on 13MAY73 and Helena reached 50.2 feet three days earlier.

The headcut channel came to be known as the *Melinda Corridor*. In 1989, the district moved to arrest the headcut by constructing three structures. The *Melinda Headcut Structure (Melinda)* was the first phase of the three structure plan; the other two structures were the *Owens Lake Weir* and the *Containment Structure*. Before the project's construction was finished Melinda was damaged, and the district repaired Melinda twice. In 1992, the Corps completed the Owens Lake Structure. By 2000, Melinda had been severely damaged and repaired three more times, while the Melinda Corridor continued to widen and deepen. By 2002, the Arkansas River (*House Bend*) migrated northward to capture *J. Smith Lake*; following the opening of this new flow path, the Containment Structure near J. Smith Lake's north end had to be protected and repaired. The district responded with an experimental geotube structure to act as sacrificial protection for the Containment Structure. Contractors finished placing the geotubes in 2004. In the winter of 2005, the geotubes were breached, Melinda was damaged again, but the containment structure held. Soil cement repairs at Melinda were completed in 2012 from damages obtained from at least two prior floods, 2008 and 2011. Melinda and Jim Smith were repaired again due to flanking erosion that threatened to bypass these containment structures.
Maintenance costs have risen as new failure paths have developed – leading many observers to suspect the Historic Cutoff was not a geologic relic, but an important connection in governing the water surface behavior at the confluence of the three rivers.

1.5 Mechanism of Cutoff

Isthmus erosion happens in two ways: lateral migration of the rivers, and overtopping of the land mass by a flooding river into the other river's channel. Locations where overland sheet flows converge receive the greatest damage. That convergence becomes channelized flows. The greatest concern is a system failure, which is defined to be: an uncontrolled channel (cutoff) by which flows are exchanged between the White and Arkansas River, significantly impeding navigation.

1.5.1 Meandering

The first erosion mechanism, meandering, relates mostly to the Arkansas River since the White River maintains a stable plan form and Big Island separates the Mississippi from the isthmus. A limited geomorphic study of the lower Arkansas focused on the reach adjacent to the isthmus, identified the bank migration pattern as, primarily, downstream movement of the bends. This migration has eroded natural high ground alongside the river, making new cutoff paths possible (primarily through ox-bow lakes on the isthmus).[5] The Mississippi separation from the isthmus means that its migration does not directly impact the land mass – having said that, the westward movement of the Mississippi during the channel shortening period (in response to 1927 and 1937 floods)

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[5] Pinkard, C. Fred, et al., *Arkansas –White Rivers Preliminary Geomorphic Assessment*, (Vicksburg, MS: U.S. Army Corps of Engineers -- Engineering Research and Development Center – Coastal and Hydraulics Laboratory, 2003)

resulted in the Mississippi contributing more flow into the White River for the cutoff formation process.

1.5.2 Overland Erosion

The second forming mechanism, overland erosion, is direct erosion from overtopping. The primary provider of the overtopping flows is the Mississippi. The Mississippi will rise putting a backwater condition in the White and that backwater takes relief over the isthmus into the Arkansas. The westward movement of the Mississippi during the shortening period has increased the impact of the backwater condition by shortening the White River by several miles[6] and relocating the mouth of the White about nine miles farther upstream on the Mississippi. These changes allow the White River to carry more flow between the Mississippi and the Cutoff, and allow the Mississippi to deliver high backwater conditions to the White River's mouth. Secondly, the Arkansas River, more rarely, will overtop the isthmus into the White. For simplicity, the conditions of overtopping are described in two ways, White to Arkansas and Arkansas to White. The area begins overtopping when a river's water surface exceeds the Owens Lake Weir crest at elevation 145 feet (NGVD). Figure 1-3: Absolute Head Differentials, shows that for White and Arkansas River water surfaces below 137, the Arkansas is higher more than the White; but, for conditions above 137 the White River is more likely to overtop into the Arkansas River.[7] The flow volume contributed to the system by the White River is comparatively small.[8]

The difference between the water surface elevation on the White River and the Arkansas River is defined as the head differential. That head differential is analogous to the energy input to the land surface as frictional and turbulence loses. The higher the head differential the more turbulence and violent the water's passing between the rivers. The more violent flow exchange the more erosion and cutoff formation are likely.

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[6] White River was shortened by about 10 miles.
[7] Mississippi controlled condition.
[8] A major flood on the White River might contribute enough flow to raise the Mississippi by one foot in the vicinity of the mouth of the White River.

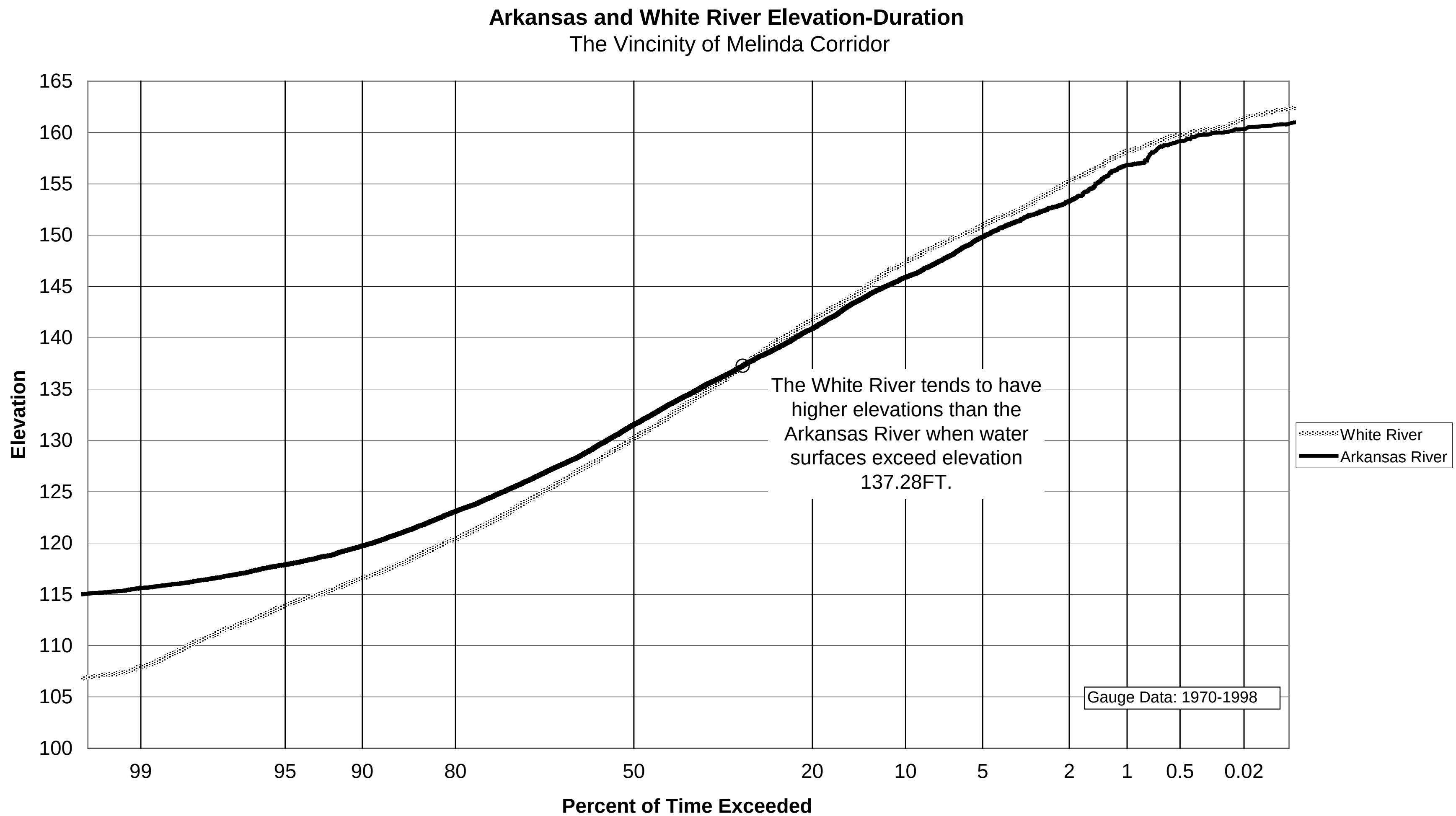

Figure 1-3: Absolute Head Differentials

1.5.3 Failure Paths

An FTN study, published in 2000, ranks four major failure paths, see Figure 1-4, through the isthmus as follows:

(1) Melinda Channel – Owens Lake corridor, by flanking or rupture of the Owens Lake control structure; the Melinda Structure.

(2) Melinda Channel – Owens Lake slough, a breach through the containment structure where the structure is built to elevation 152';

(3) LaGrues Lake corridor, with elements of the Owens lake and/or Melinda outflow channel being utilized in the failure path; and

(4) J Smith Lake corridor.

The Melinda Channel-Owens Lake corridor was selected as the most likely location for a cutoff to occur because (1) it is the current primary flow pathway between the Arkansas and White Rivers, (2) it presents the pathway of least hydraulic resistance, (3) it is the pathway exhibiting the most damage from existing flows between the two river systems, and (4) it presents the area with the potential to experience the greatest head differential coupled with high flow rates.[9]

The failure paths have since been updated to account for new developments such as nick points and the meandering of the Arkansas River. As of 2016 the risk of failure list is ordered in the following manner:

(1) Melinda Channel – Owens Lake corridor, by flanking or rupturing of the Owens Lake control structure, the Melinda Structure.

(2) J Smith Lake corridor, the Arkansas River's House Bend's east by east-west movement captured the lake effectively making the J Smith Lake corridor the shortest, most damaged, and least hydraulically resistant flow path between the White and Arkansas Rivers.

(3) Historic Cutoff: Two sink holes have appeared in the Historic Structure, one in 2014 and one just recently at the end of 2016. The appearance of the sink holes is indication of a growing seepage path through the historic structure. As the seepage path erodes away soil under the Historic Structure, the structural stability of the soil is compromised and collapses in on the seepage path. When this soil loss gets large enough, sink holes will appear at the surface. If this continues unchecked, there is a possibility that the Historic Cutoff Structure will collapse due to this internal erosion.

(4) J Smith Lake – Historic Cutoff Corridor, a lengthy headcut and nick point has been identified moving through the woods from the Historic Cutoff toward J Smith Lake.

(5) LaGrues Lake corridor, with elements of the Owens Lake and/or Melinda outflow channel being utilized in the failure path, a nick point has developed moving along a swale toward LaGrues Lake.

(6) Melinda Channel – Owens Lake slough, a breach through the containment structure where it is built to elevation 152.'

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[9] *Feasibility Study Report for the Arkansas-White River Cutoff Project*. September 29, 2000.

(7) Webfoot Lake – Historic Cutoff corridor, nick points have developed in the east side of Webfoot Lake. The head cut would move across Big Island and connect to the White River about 2 miles upstream of its confluence with the Mississippi River.

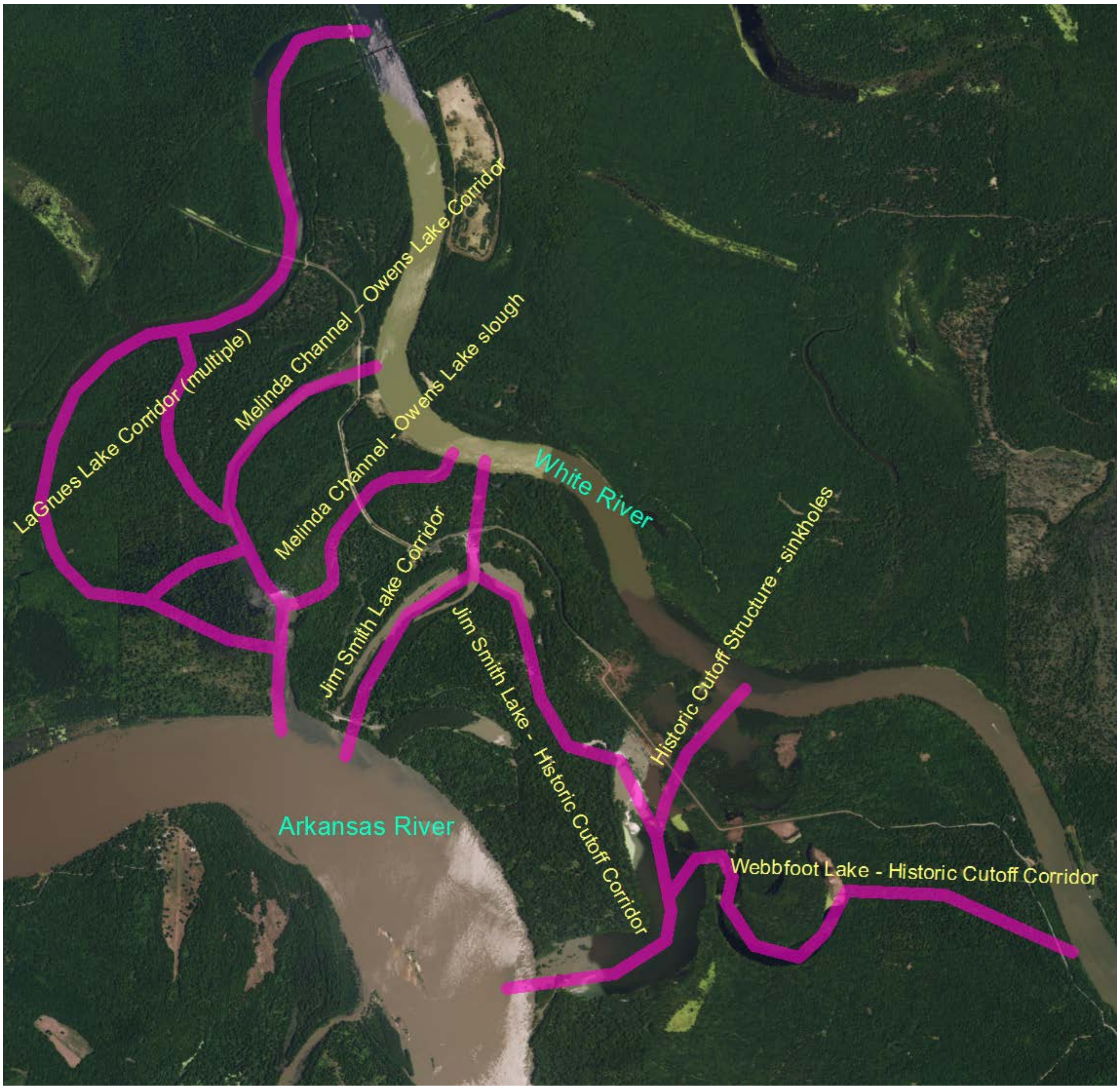

Figure 1-4: Failure Paths

1.6 Design Criteria

Six major design criteria were used in alternative formulation. The alternative formulation strove to meet a varied combination of these design criteria.
The criteria are:

1. Isthmus velocities
2. Hydraulic head differentials
3. Duration of head differentials
4. Location of overtopping
5. Duration of flooding
6. Safe navigation

Spatial coordinate projection file is NAD83 UTM Zone 15, U.S Feet and vertical projection is NAVD88, U.S. Feet.

The measure of the head differential and the duration of the head differential during flow exchanging events are measured in two primary corridors: along the Historic Cutoff and the Melinda Corridor (see Figure 1-4: Measured Head Differentials locations). The head differential is measured as the modeled water surface elevation differences at the confluence with the White and the Arkansas Rivers for each respective corridor. The duration of the absolute head differential was measured above elevation 145 feet when overtopping occurs for existing conditions.

The Hydrologic Engineering Center – River Analysis System (HEC-RAS) program has the ability to produce georeferenced gridded hydrologic velocity maps of the entire area. These velocity maps are an extremely useful tool in pinpointing locations in the isthmus that scour is most likely to occur. Identification of these potential scour locations increases the effectiveness of alternative formulation by developing measures that target those problem areas.

Controlled locations of overtopping events would include armoring the relief channel(s) against erosion and could consist of multiple step-down structures to minimize the damaging head differentials across each structure. Severe damage has not been observed for events with head differentials less than four feet so reducing the head differential to less than four feet or minimizing the duration of those damaging head differentials would reduce head cutting erosion across the isthmus.

The goal to maximize navigation benefits was to meet a varied combination of reducing the maximum head differential, reducing isthmus velocities, reducing the duration of the extreme values during overtopping events, and controlling the location of overtopping events.

Figure 1-5: Measured Head Differentials

Environmental benefits for terrestrial and aquatic habitat health, form, and function are directly related to the timing and location of flood duration. For aquatic habitat, several stage duration analyses were performed at selected locations to determine potential changes in oxbow recharge, fish passage capabilities, and in-channel changes across the alternatives. Terrestrial habitat and bottomland hardwood health is dependent on overland flood duration and the location of the flooding. In addition to the elevation duration analysis, HEC-RAS 5.0.1 was used to develop "Percent Time Inundated" grids, based on the growing season starting on 15 March and ending on 15 November for each of the alternatives. These grids were used to compare each alternative's effects on the duration of flooding in The Refuge with respect to existing conditions. This identified locations that would experience the greatest change in hydrology for each alternative.

The final consideration is the impact of cross-currents on navigation. The specific configuration of an alternative could have a significant effect on the safety of the shipping lane. A two-dimensional mathematical model can provide velocity details in-channel, but variables like tow boat capabilities, barge number and configuration, and ship captain experience need to be investigated further for those alternatives that have a potential of producing dangerous cross-currents. If the Tentatively Selected Plan (TSP) includes a relief channel, a ship tow simulator would need to be completed to minimize the impacts of dangerous cross-currents.

1.7 Description of Alternatives:

Existing Conditions and future without project. These two conditions were considered hydraulically identical. The future without project conditions defines the most likely future conditions that will exist in the study area if action is not taken as a result of this study. Traditionally, the future conditions relates to a problem where federal action has not taken place, however, this study relates to a continuation of piecemeal repairs, and major rehab, if necessary, to maintain an authorized navigation system.

Containment structure at elevation 157 feet. The Containment Structure, See Figure 1-5: Alternative C157HC145, would be approximately 2.5 miles long and begin on natural high ground just south and west of the existing Melinda Weir located on the south side of Owens Lake. It would continue east and cross south of the existing Melinda Weir and then head northeast and connect to the existing soil cement containment structure north of J. Smith Lake. The Containment Structure would then follow the existing containment alignment and terminate at the Historic Cutoff Containment Structure. This alternative would incorporate the use of existing and natural high ground in the project area which will result in minimal disturbance to the terrain and to the natural hydrology of the land. It would also provide an opportunity to restore form and function to oxbow lakes in the isthmus while providing a long-term solution for reducing the risk of a breach between the Arkansas and White Rivers by reducing the frequency, duration, location, and damaging head differentials of overtopping events. Variations of this alternative includes the addition of a relief channel ranging from 500 feet to 1,000 feet wide, at elevation 145 feet, through the Historic Cutoff Containment Structure. This is the current elevation that the White and Arkansas Rivers exchange flow through the Melinda Corridor. This will further reduce damaging head differentials across the isthmus, but may introduce dangerous cross-currents into the shipping lane for widths larger than 500 feet.

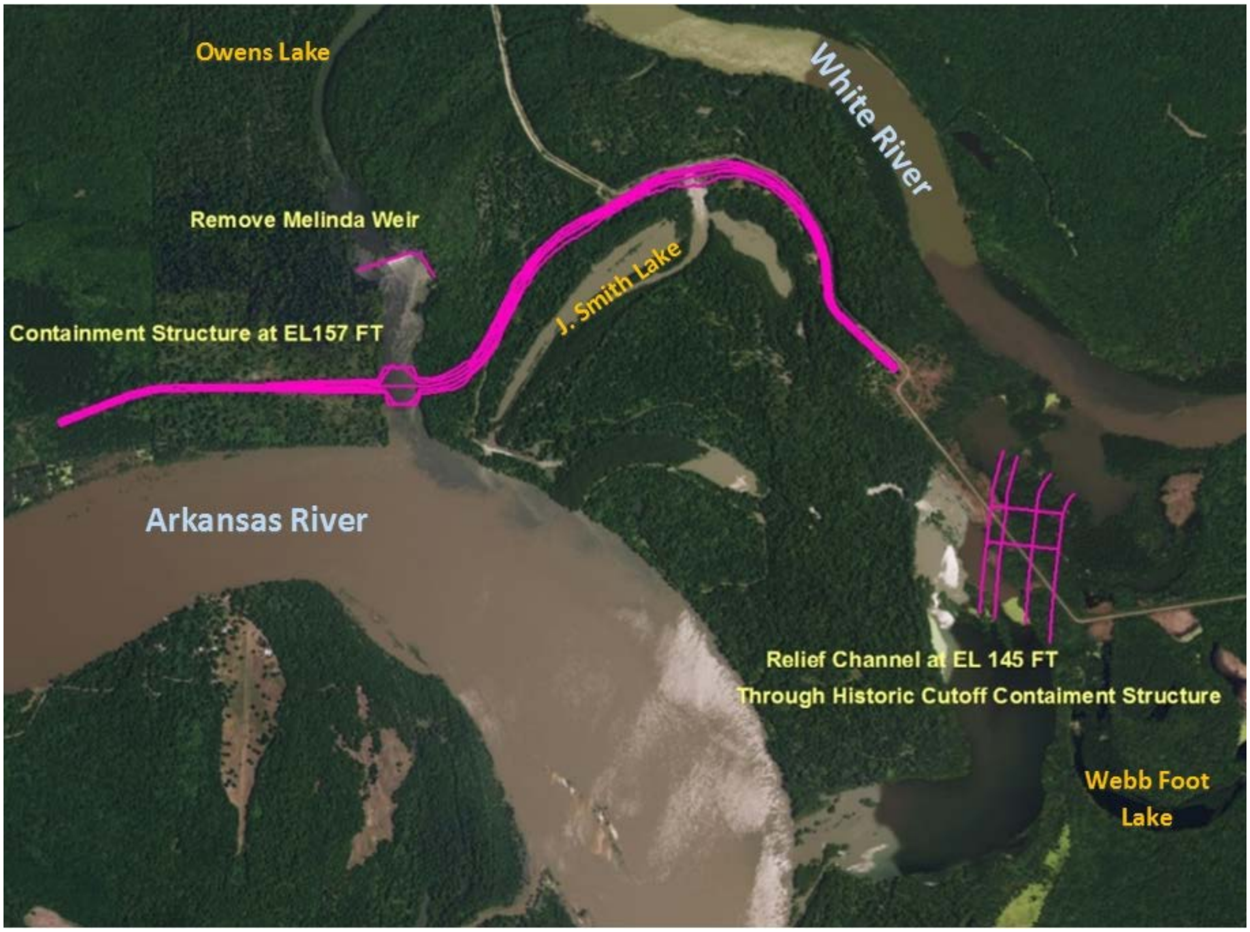

Figure 1-6: Alternative C157HC145

The Multiple Openings Alternative. This alternative would utilize the existing footprints of oxbow lakes in the isthmus and the Historic Cutoff as multiple relief openings, See Figure 1-6: Alternative M135 for approximate locations of structures. Several step-down structures would be placed in Owens Lake, Historic Cutoff, and possibly J. Smith Lake that would facilitate the exchange of water at an environmentally optimized elevation between 115 feet and 135 feet. This alternative would restore some of the pre-Historic Cutoff Containment Structure hydrology between the Arkansas and the White Rivers and therefore restore some historic ecological conditions. The Arkansas River carries a larger sediment load than the White and therefore a sediment transport model will be needed to identify changes in deposition and scour in both rivers. This alternative would provide a long-term solution for reducing the risk of a breach between the Arkansas and White Rivers by minimizing the duration and controlling the location of damaging head differentials during overtopping events. More investigations will be needed to determine the effects of cross-currents on navigation.

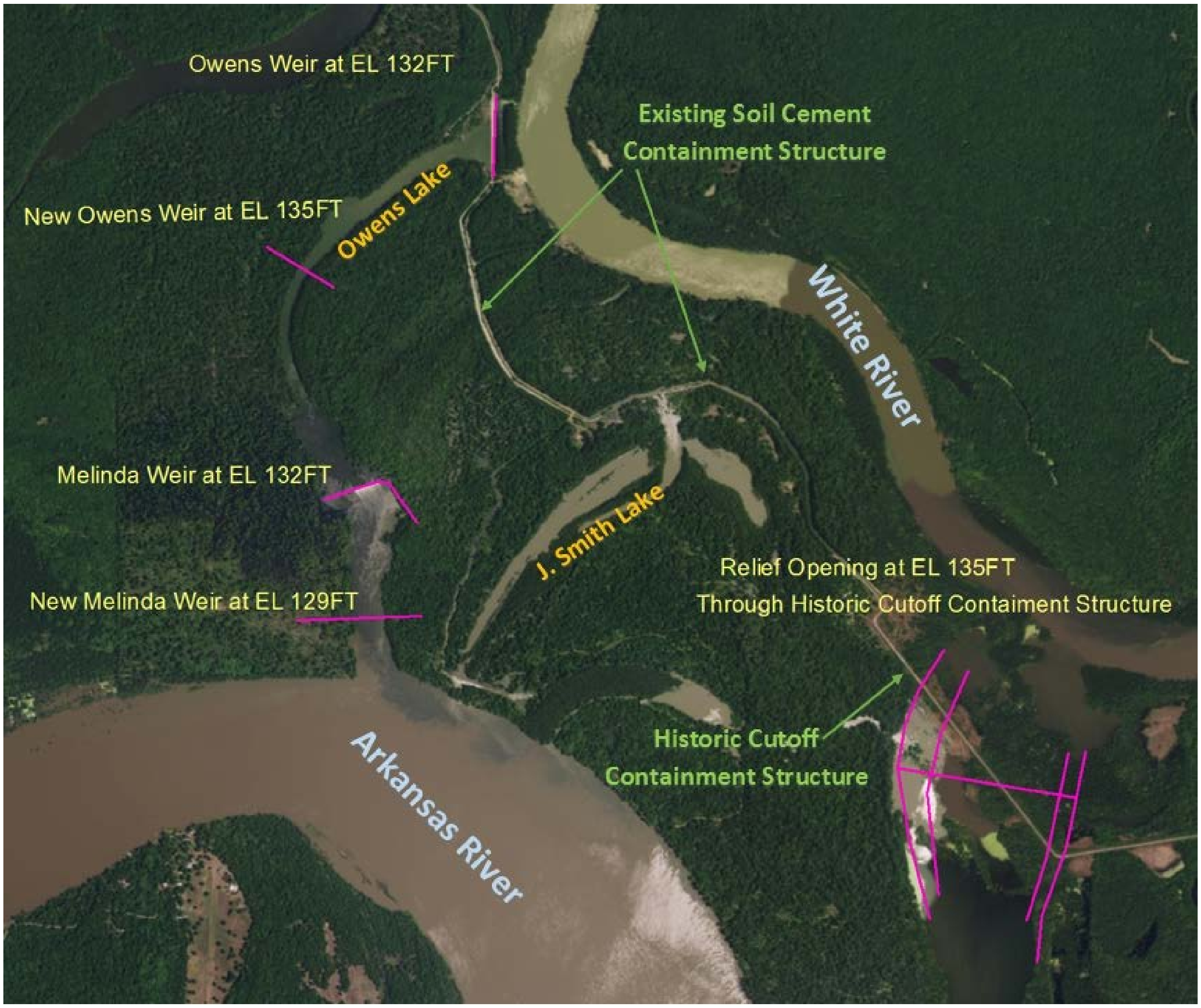

Figure 1-7: Alternative M135

The following table lists the short names utilized in this report for all of the alternatives, and their variations. See Table 1-1: Alternative Short Names.

Table 1-1: Alternative Short Names

SHORT NAME	ALTERNATIVE
EXIST or E	Existing Conditions
C157	Containment Structure at Elevation 157 feet
C157HC145_500ft	Containment Structure at Elevation 157 feet with Relief Channel through Historic Structure at Elevation 145 feet and 500 feet wide
C157HC145_1000ft	Containment Structure at Elevation 157 feet with Relief Channel through Historic Structure at Elevation 145 feet and 1000 feet wide
M115	Multiple Openings at Elevation 115 feet: Melinda Corridor and Historic Cutoff
M125	Multiple Openings at Elevation 125 feet: Melinda Corridor and Historic Cutoff
M135	Multiple Openings at Elevation 135 feet: Melinda Corridor and Historic Cutoff

2 HEC RAS Model Development

2.1 HEC-RAS Model Limits

The HEC-RAS model limits, see Figure 2-1: HEC RAS Model Limits, are located at the following gages:

Upstream limits, Discharge hydrograph:
- Mississippi River at Helena, MS
- White River at St. Charles, AR
- White River Entrance Channel at Lock 2, AR
- Arkansas River at Wilbur D Mills (Dam 2), AR

Downstream limit, Rating Curve:
- Mississippi River at Greenville, MS

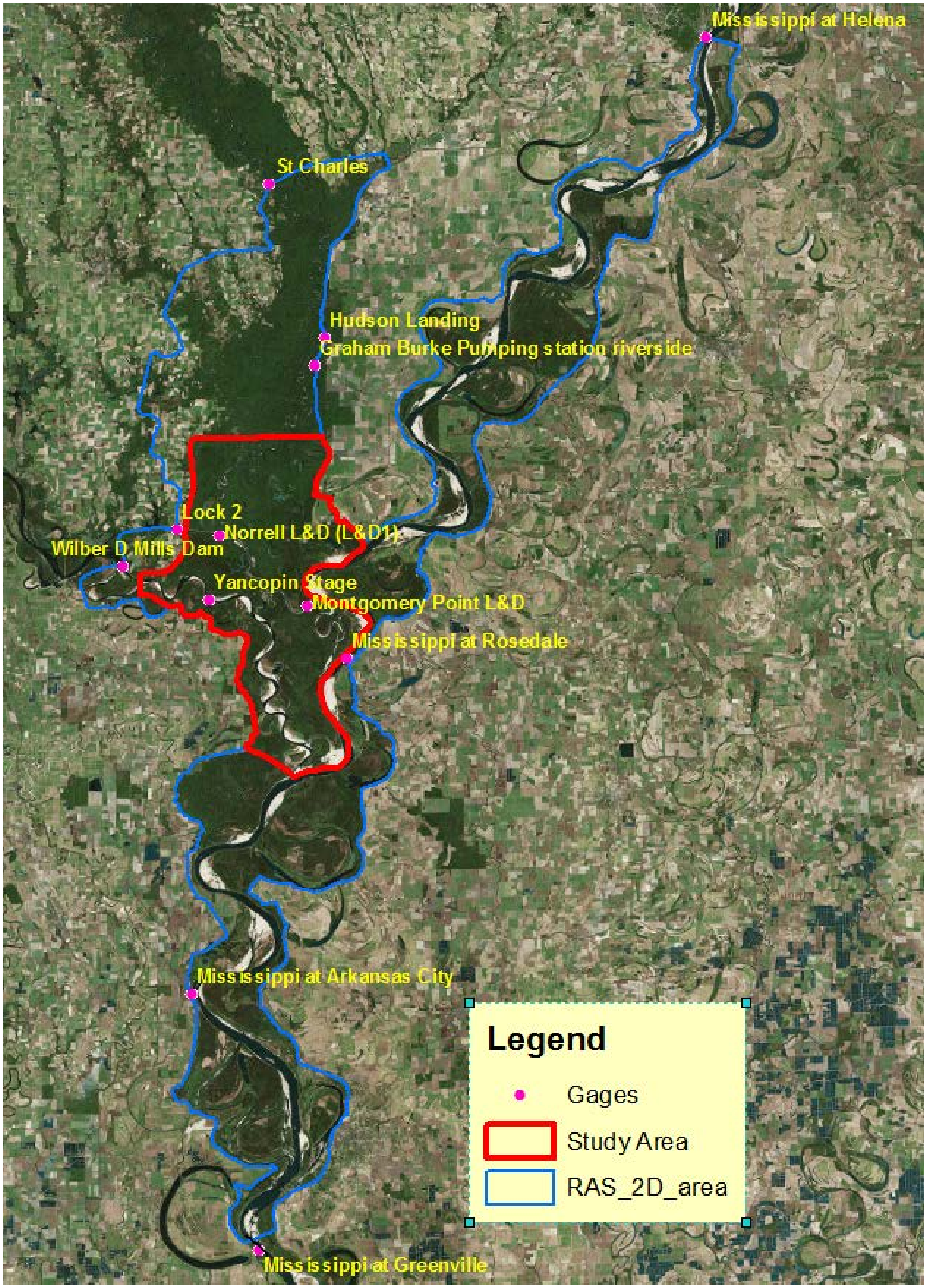

Figure 2-1: HEC RAS Model Limits

2.2 Flow and Stage Gage Data

The period of record simulated was 01 January 2000 to 31 December 2014. Observed discharge hydrographs, stage hydrographs, and rating curves were obtained from the Little Rock, Vicksburg, and Memphis District Water Management Sections. The two year and five year flow data was obtained from the previous 2007 Ark-White study. Elevation data in the rating curves and stage hydrographs was converted into NAVD88 elevations for the calibration efforts. The conversion to NAVD88 is approximately equal to NGVD29 minus 2.5 inches in the study area.

The upstream boundary conditions are discharge hydrographs from Mississippi at Helena gage, White River at St. Charles gage, Lock 2 tail water leakage, and Dam 2 releases. The downstream boundary condition is the rating curve at Greenville, Mississippi gage.

The elevation hydrographs at St Charles, Hudson Landing, Graham Burke Pumping station, Norrell L&D (L&D1), Montgomery Point Lock and Dam (MPLD), Wilber D. Mills (Dam 2), Yancopin, Helena, Rosedale, Arkansas City, and Greenville were used in the calibration effort. More emphasis was placed on the gages closer to or within the study area. See Figure 2-1: HEC-RAS Model Limits for gage locations.

2.3 Terrain

2.3.1 LiDAR and Bathymetry

Spatial coordinate projection file is NAD83 UTM Zone 15, U.S Feet and vertical projection is NAVD88, U.S. Feet.

Mississippi River bathymetry from the mouth of the White River up to Helena (2015) was obtained from Memphis District. Pool 1 (2015), Arkansas River (2002) and White River bathymetry from Norrell Lock and Dam down to the White River (2015) was obtained from Little Rock District. Mississippi River Bathymetry from the mouth of the White River down to Arkansas City was obtained from Vicksburg district (2015)

The Arkansas River channel has changed significantly between 2002 and 2016. The 2002 survey was adjusted horizontally to match the 2016 Arkansas River channel alignment. The vertical elevations were adjusted 15 feet lower for cross-sections closer to the confluence with Mississippi River and adjusted less the further upstream the cross-sections were located, until Yancopin. HEC-RAS was used to convert the adjusted cross-sections into a bathymetry that was incorporated into the 2D HEC-RAS model terrain. This was an iterative process using the elevation hydrograph gage data at Yancopin and model results to determine the final Arkansas River bathymetry used in the geometry.

The overbank, floodplain, and bathymetric data were merged into a single raster of one meter grid cell size. The raster was then resampled to a 10 foot cell size when importing into HEC-RAS 5.0.1 due to the large computation run times required for the 1 meter cell size. See Figure 2-2: Elevation Sources.

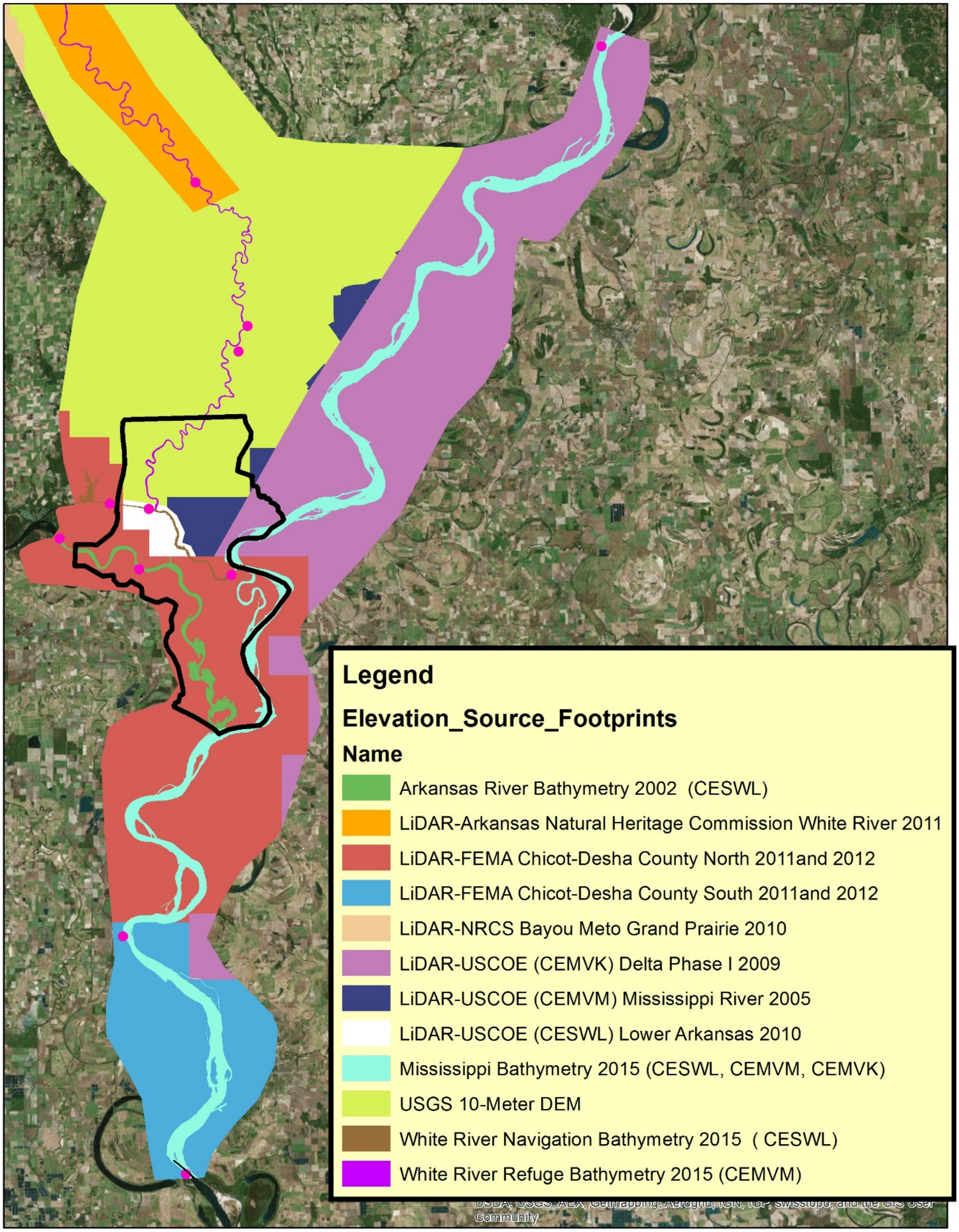

Figure 2-2: Elevation Sources

2.4 Geometry

2.4.1 Manning's n-values

Spatially varying Land Use classification, NLCD2011, obtained from the USGS website, was used to create a spatially varying Manning's roughness layer. The suggested n-values (Gary W. Brunner, CEIWR-HEC, 2016) and the NLCD2011 land use cover were used for the initial model runs, except for the section of White River downstream of St. Charles, AR Gage and north of Lock and Dam 1. This section of the river had meandered and the river channel was now spatially different then the land cover. In this case, the n-values were overwritten by user specified polygons that covered the footprint of the existing river channel. See Table 2-1: Initial and calibrated n-values. The final n-values were determined through calibration.

Table 2-1: Initial and calibrated n-values

NLCD Land Cover Classification Code	NLCD Land Cover Descriptions	Associated n-value	Calibrated n-value
0	NoData	0.06	0.06
31	Barren Land Rock/Sand/Clay	0.04	0.04
82	Cultivated Crops	0.06	0.05
41	Deciduous Forest	0.1	0.1
24	Developed, High Intensity	0.15	0.15
22	Developed, Low Intensity	0.08	0.08
23	Developed, Medium Intensity	0.1	0.1
21	Developed, Open Space	0.035	0.035
95	Emergent Herbaceous Wetlands	0.08	0.085
42	Evergreen Forest	0.12	0.12
71	Grassland/Herbaceous	0.04	0.04
43	Mixed Forest	0.08	0.08
11	Open Water	0.03	0.03
81	Pasture/Hay	0.06	0.06
52	Shrub/Scrub	0.08	0.08
90	Woody Wetlands	0.08	0.085

2.4.2 Existing Conditions

The entire area was modeled as a 2D area using HEC-RAS 5.0.1. The 2D model mesh limits were contained within levees and bounded upstream and downstream by stage or flow gages. A 500 by 500 foot cell size was used to build the computational mesh and then refined by breaklines and manually subdivided where necessary. Breaklines were used along oxbow and river banks, levees, railroad embankments, high ground, and at locations requiring finer delineation. River sections at gages, and other cross sections of interest, were modeled as 2D area connections and were reinforced by using breaklines with cell spacing ranging from 100 feet to 300 feet. See

Figure 2-3: Computational HEC-RAS 2D Mesh, for an example of the computational mesh. Stage and flow data at the 2D area connections were written to Hydrologic Engineering Center Data Storage System (HEC-DSS) 2.0.1 files for frequency and duration analysis.

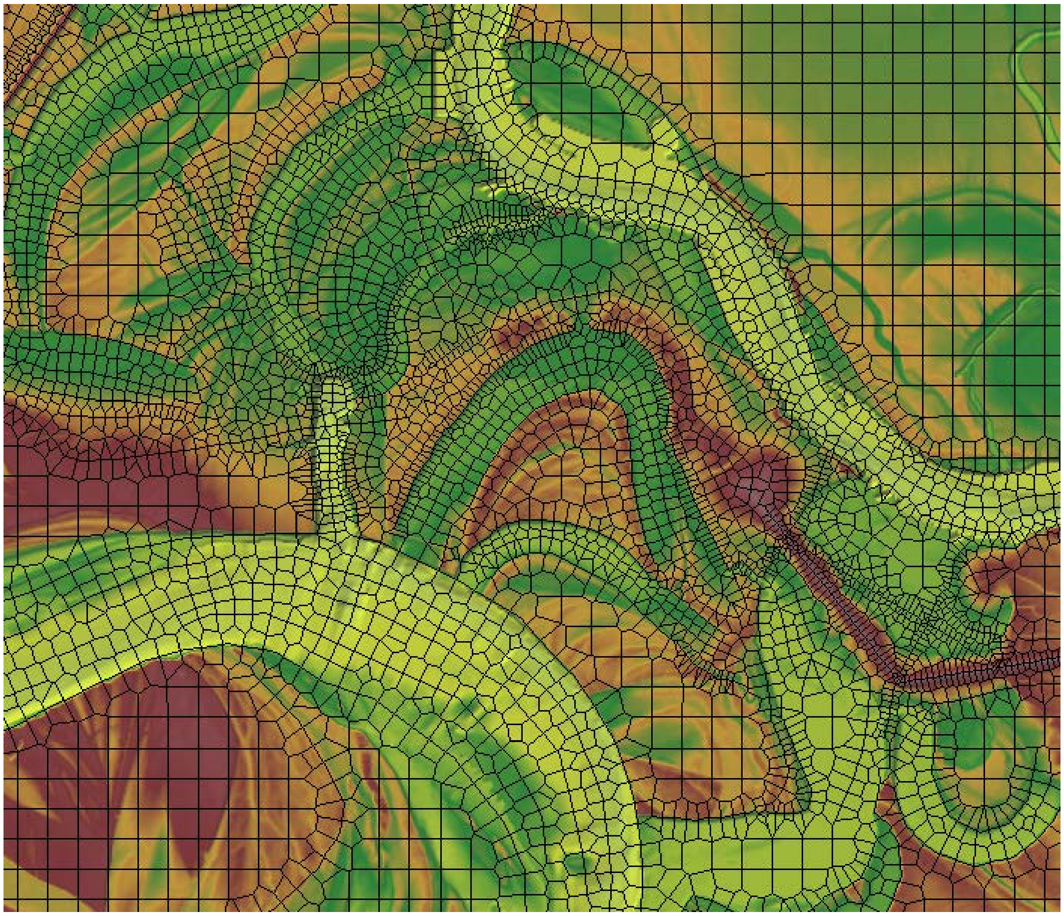

Figure 2-3: Computational HEC-RAS 2D Mesh

Lock and dams, locations of interest, and cross sections at gage locations were modeled as 2D area connections to automate the process of retrieving and writing hydrograph into output files for further analysis and calibration.

Montgomery Point Lock and Dam (MPLD) was modeled fully open for the entire simulation period. MPLD was not put into service until 2004 and, it is only utilized when the Mississippi River at the mouth of the White River falls below elevation 115 feet which is well below the elevations of the top banks of the White River in that location. Operation of MPDL has no effect on overland frequency and duration of flooding, overland flow velocity, and scour potential across the floodplain during high flow events.

The study area is a very dynamic biological, seasonal and hydrological system that is continually being altered by nature over time. To isolate the effects each alternative has on the hydrology, it is assumed that the system is static. The only difference will be the addition of structures in the HEC-RAS geometry and terrain for each alternative.

Below is a partial list of variables not accounted for through time in the HEC-RAS geometry.

- Seasonally changing n-values
- Migrating channel and active head cutting up the White River, Mississippi River, and Arkansas River
- Active dredging (This changes both the river cross-section and the dredge pile volume on the land)
- Bank caving and channel widening along the White and the Arkansas Rivers
- Beaver dams
- Shift in land cover (ex. logging industry)
- Active head cutting and widening of the Melinda Corridor
- Levee overtopping or failure.
- Rating curve shifts at gage locations

2.4.3 Alternatives: Modifications to Existing Geometry

Containment Structure at Elevation 157 feet (C157)

The Containment Structure, with a crest elevation of 157 feet, was added to the terrain and to the geometry as a 2D area connection. The existing Melinda Weir was removed to eliminate the risk of toe erosion of the new containment structure in the Melinda Headcut. See Figure 1-5: Alternative C157HC145 for general plan view.

Containment Structure at Elevation 157 feet with Relief Channel (C157HC145)

The Containment Structure at elevation 157 decreased the duration and frequency of overtopping events, but it also increased the head differential and therefore increased the scour potential across the isthmus. To decrease the head differential, an opening through the historic cutoff was included in the Containment Structure at elevation 157 Alternative. The Historic Cutoff was removed from the terrain down to elevation 130 ft. A 2D area connection was added into the 2D Mesh with a top weir elevation of 145 feet and 8% grades on the sides from elevation 145 up to existing ground. Two different weir widths were modeled: 500 feet and 1,000 feet. See Figure 1-5: Alternative C157HC145.

Distributed Flow or Multiple openings at elevation: 115,125,135 (M115, M125, M135)

Owens Lake, also referred to as the Melinda Corridor, and the Historic Cutoff were used to model the multiple opening alternatives. See Figure 1-6: Alternative M135 for a general plan view. Owens Weir and the Melinda Weir were removed from the Melinda Corridor and the new channel thalweg lowered to elevation 105 feet to allow water to freely pass between the two rivers. The Historic Cutoff Containment Structure was removed and the Historic Cutoff thalweg was lowered to elevation 90 feet. The Historic Cutoff was widened to almost 0.5 miles wide on the White River side to about 0.25 miles wide closer to the Arkansas River following the existing footprint. Manning’s n values were changed in the multiple open channels to reflect open water instead of heavily wooded trees.

Three different weir elevations were modeled for this alternative: 115, 125 and 135 feet. Results for each weir elevation were evaluated for its effectiveness at shifting the Refuge toward a drier hydrology and for reducing the duration of damaging head differentials across the isthmus. The final design will have a minimum of three step-down structure in each corridor to minimize head differentials across the structures to less than four feet.

2.5 HEC RAS Plans

The same flow file was used for each plan. Due to study time constraints, only a 15 year period of record (POR) analysis starting on 01 January 2000 ending on 31 December 2014 was completed for each alternative. Instead of running the entire POR in one plan, the plans were broken down into 15 one-year plans for each alternative. Each one-year plan took four to six days of continuous computation to complete. Breaking the 15 year POR into smaller manageable segments allowed the runs to complete by minimizing the probability of simulation interruptions due to network connection problems, power failures, equipment failures, and software updates that require restarts.

3 HEC RAS Calibration

3.1 Observed and Calibrated Elevation Hydrographs

See Appendix A for Calibration Hydrographs for elevation gages. See Table 2-1: Initial and calibrated n-values.

4 Hydrologic Model Outputs

At the onset of this study, five alternatives were modeled: Existing, C157, M115, M125, and M135. As model outputs were obtained and studied, the team determined that M115, M125, and M135 would decrease head cut probability across the isthmus, but the alternatives offered no environmental benefits to the Refuge, they negatively impacted bottomland hardwoods and oxbow lakes in the isthmus, and they would most likely introduce dangerous cross currents into the shipping lane and so were subsequently dropped from further hydraulic analysis. Refined alternatives of C157 were developed, C157HC145_500ft and C157HC145_1000ft, and became the focus of the hydraulic modeling effort.

4.1 Head differentials Plots

Maximum head differentials and duration is a convenient way to determine the effectiveness of each alternative's ability to reduce scour and head cutting potential across the isthmus. See Figure 1-4: Measured Head Differentials for locations where head differentials were calculated. Head differentials between the two rivers can be in excess of 10 feet for long durations, but scour only occurs when there is overland flow across the Isthmus. Isthmus scour occurs when either the White River or the Arkansas River rises above elevation 145 feet at Owen's weir or the Historic Cutoff. See Figure 4-1: Historic Cutoff: Annual Overtopping Absolute Head Differential Exceedance Duration and Figure 4-2: Melinda Corridor: Annual Overtopping Absolute Head Differential Exceedance Duration for results. Severe damage has not been observed for events with head differentials less than four feet so reducing the head differential to less than four feet or minimizing the duration of those damaging head differentials would reduce head cutting erosion across the isthmus. See Table 4-1 and Table 4-2 for absolute head differentials and corresponding exceedance durations in days for each alternative.

Table 4-1: Absolute Head Differential Annual Exceedance Duration: Melinda Corridor

Absolute Head Difference Annual Exceedance Duration: Melinda Corridor above Elevation 145 feet				
Head Differential	Alternative Annual Exceedance Duration in Days			
	EXISTING	C157_HC145 500FT	C157_HC145 1000FT	C157
Feet	Days	Days	Days	Days
4	20.4	21.9	20.8	24.8
5	14.9	17.9	15.3	20.5
6	9.3	11.6	8.9	16.2
7	4.7	6.2	3.9	10.9
8	1.5	1.8	1.5	5.5

Table 4-2: Absolute Head Differential Annual Exceedance Duration: Historic Cutoff

Absolute Overtopping Head Difference Annual Exceedance Duration: Historic Cutoff above Elevation 145 feet				
Head Differential	Alternative Annual Exceedance Duration in Days			
	EXISTING	C157_HC145 500FT	C157_HC145 1000FT	C157
Feet	Days	Days	Days	Days
4	22.9	23.8	22.3	27.2
5	19.8	20.8	19.1	23.6
6	14.1	15.8	11.7	19.7
7	6.9	7.5	5.2	14.3
8	2.2	2.0	1.4	6.2

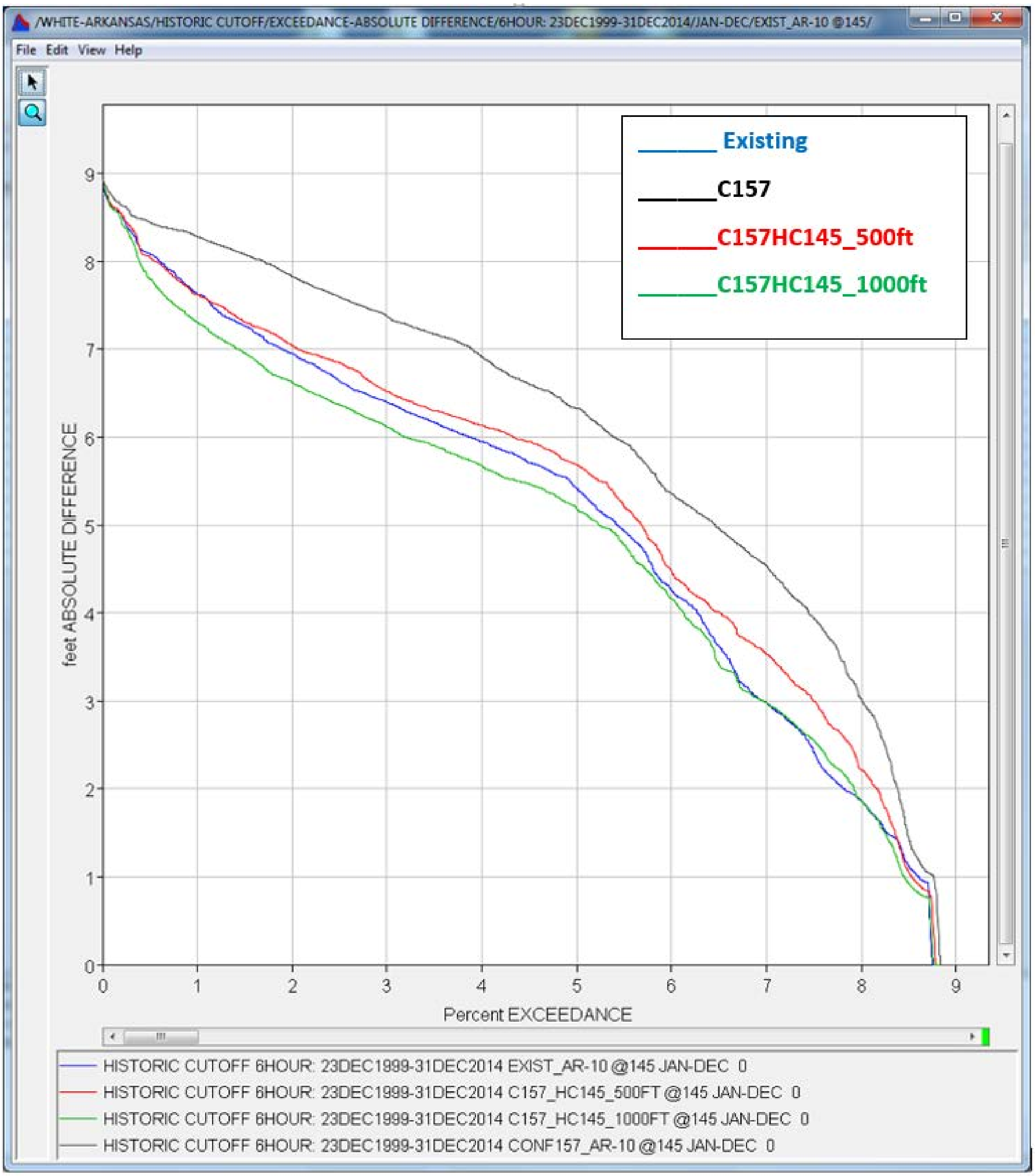

Figure 4-1: Historic Cutoff: Annual Overtopping Absolute Head Differential Exceedance Duration

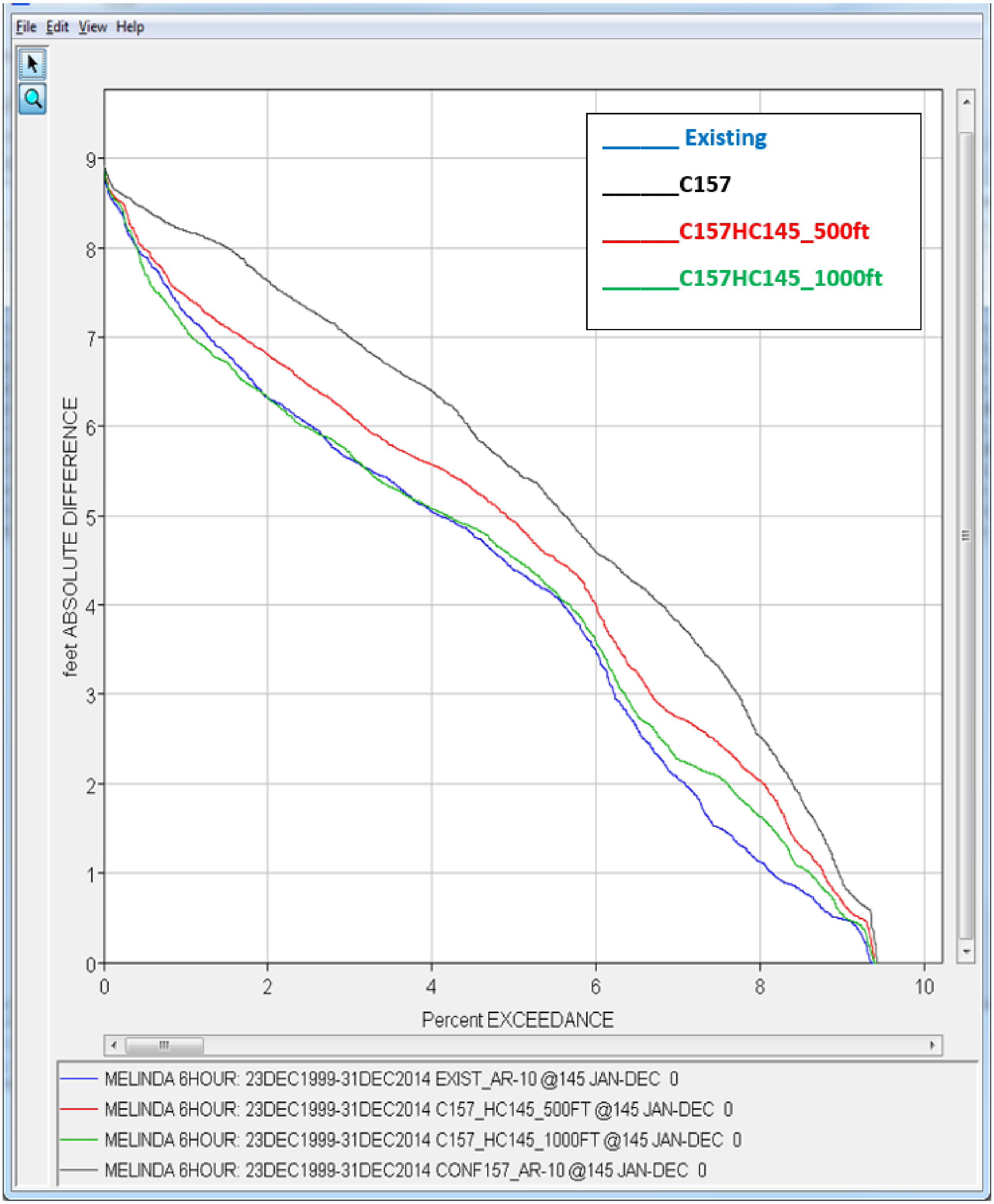

Figure 4-2: Melinda Corridor: Annual Overtopping Absolute Head Differential Exceedance Duration

4.2 Velocity Map

NRCS Soil Survey Maps and published permissible mean velocity data were combined to determine a threshold scour velocity across the isthmus. Locations that are prone to scour and head cutting were easily identified due to the increase of velocities in these areas.

The permissible or allowable velocity is the greatest mean velocity that will not cause the channel boundary to erode and scour. Fortier and Scobey (1926) presented a table of maximum permissible velocities for earthen irrigation canals with no vegetation or structural protection (Natural Resources Conservation Service , 2007). See Table 4-3: Permissible Mean Velocities.

Table 4-3: Permissible Mean Velocities

Permissible Mean velocity, for straight canals of small slope, after aging with flow depths less than 3 feet. Presented by Fortier and Scobey (1926)			
Original Material excavated for canals	Clear water, no detritus (ft/s)	Water transporting colloidal silts (ft/s)	Water transporting noncolloidal silts, sands, gravels, or rock fragments (ft/s)
Fine sand (noncolloidal)	1.5	2.5	1.5
Sandy loam (noncolloidal)	1.75	2.5	2
Silt loam (noncolloidal)	2	3	2
Alluvial silt (noncolloidal)	2	3.5	2
Ordinary firm loam	2.5	3.5	2.25
Stiff clay (very colloidal)	3.75	5	3
Alluvial silt (colloidal)	3.75	5	3
Shales and hardpans	6	6	5
Volcanic ash	2.5	3.5	2
Fine gravel	2.5	5	3.75
Graded, loam to cobbles (when noncolloidal)	3.75	5	5
Graded silt to cobbles (when colloidal)	4	5.5	5
Coarse gravel (noncolloidal)	4	6	6.5
Cobbles and shingles	5	5.5	6.5

Table 4-3: Permissible Mean Velocities values were combined with the NRCS Soil Surveys of Desha and Arkansas Counties to determine a threshold scour velocity across the isthmus based on soil type. See Table 4-4: Estimated Permissible Velocity based on NRCS Soil Survey. See also Figure 4-3: Estimated Permissible Mean Velocity.

Table 4-4: Estimated Permissible Velocity based on NRCS Soil Survey

Isthmus Soil Types: Natural Resource Conservation Service Soil Survey of Desha and Arkansas County	Estimated Permissible Velocity (fps)
Commerce silt loam	2
Crevasse loamy fine sand	1.5
Desha clay	3
Desha silty clay	2.5
Keo loam	2
Perry clay	3
Portland clay	3
Rilla silt loam	2
Riverwash, sandy	1.5
Sharkey-Commerce-Coushatta association	2.5
Sharkey clay	3
Udipsamments	1.5
Yancopin silty clay loam	2.5
Yorktown silty clay	2.5

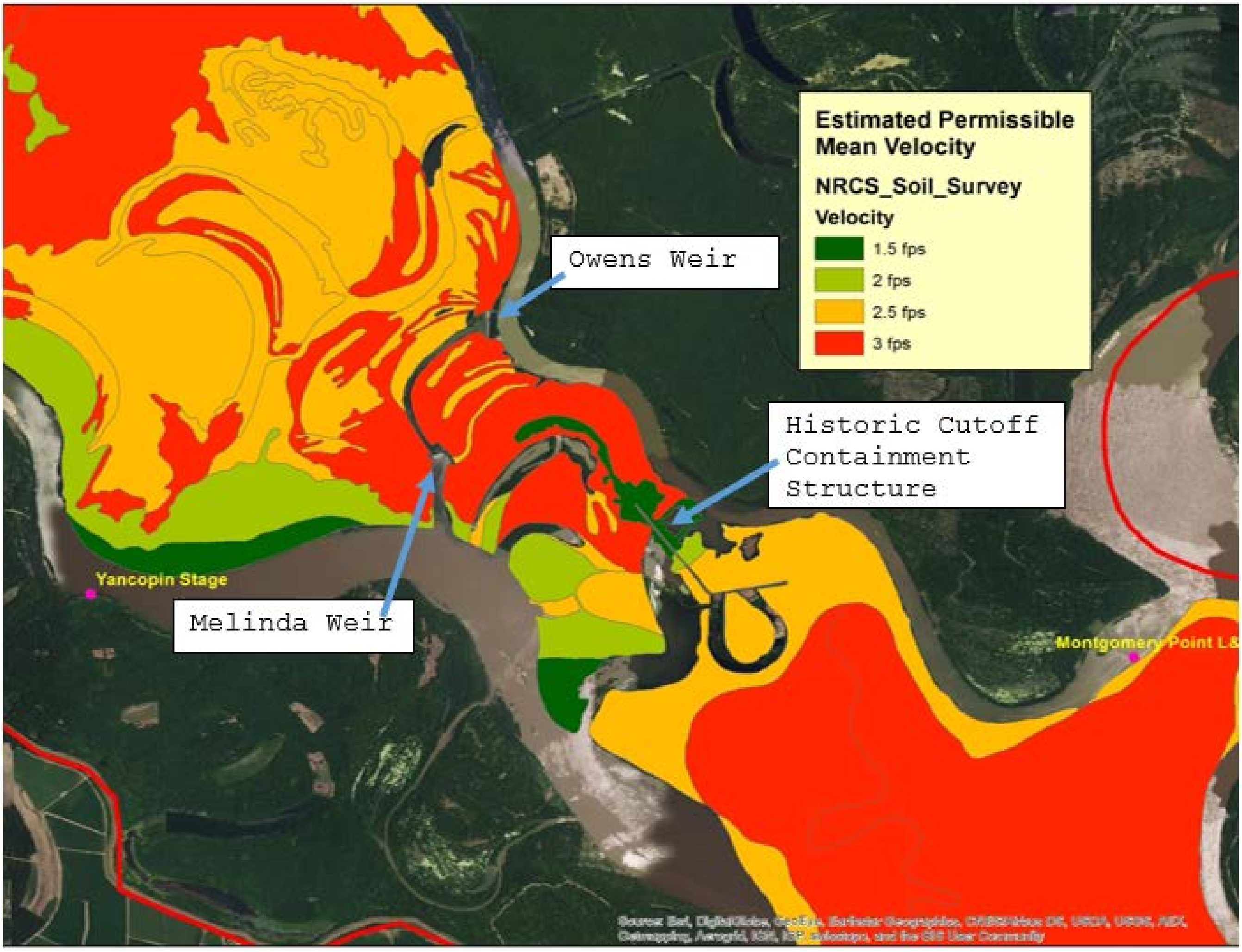

Figure 4-3: Estimated Permissible Mean Velocity

Based on the isthmus soil types and permissible mean velocity information, average velocities of 1.5 ft/s up to 3.0 ft/s can cause erosion in the isthmus. The HEC-RAS gridded velocity maps are calculated over an averaged 10 ft^2 area. Because of the nature of averaging, maximum velocities tend to be reduced. Therefore a minimum velocity of 2 ft/s was chosen as the threshold for identifying areas susceptible to erosion for each alternative. See Figure 4-5 through Figure 4-9 for minimum 2 ft/s velocity maps.

Of particular interest, Figure 4-4 and is a close up of one nick point in Webfoot Lake. Aerial photographs show signs of multiple nick points and scour even when the existing conditions results indicate velocities less than 2 ft/s. Based on soil type and corresponding permissible velocity, this area should withstand 2.5 ft/s. This supports using the general assumption of 2 ft/s as a velocity threshold in locating potential scour locations.

Figure 4-4: Nick Point on east bank of Webfoot Lake

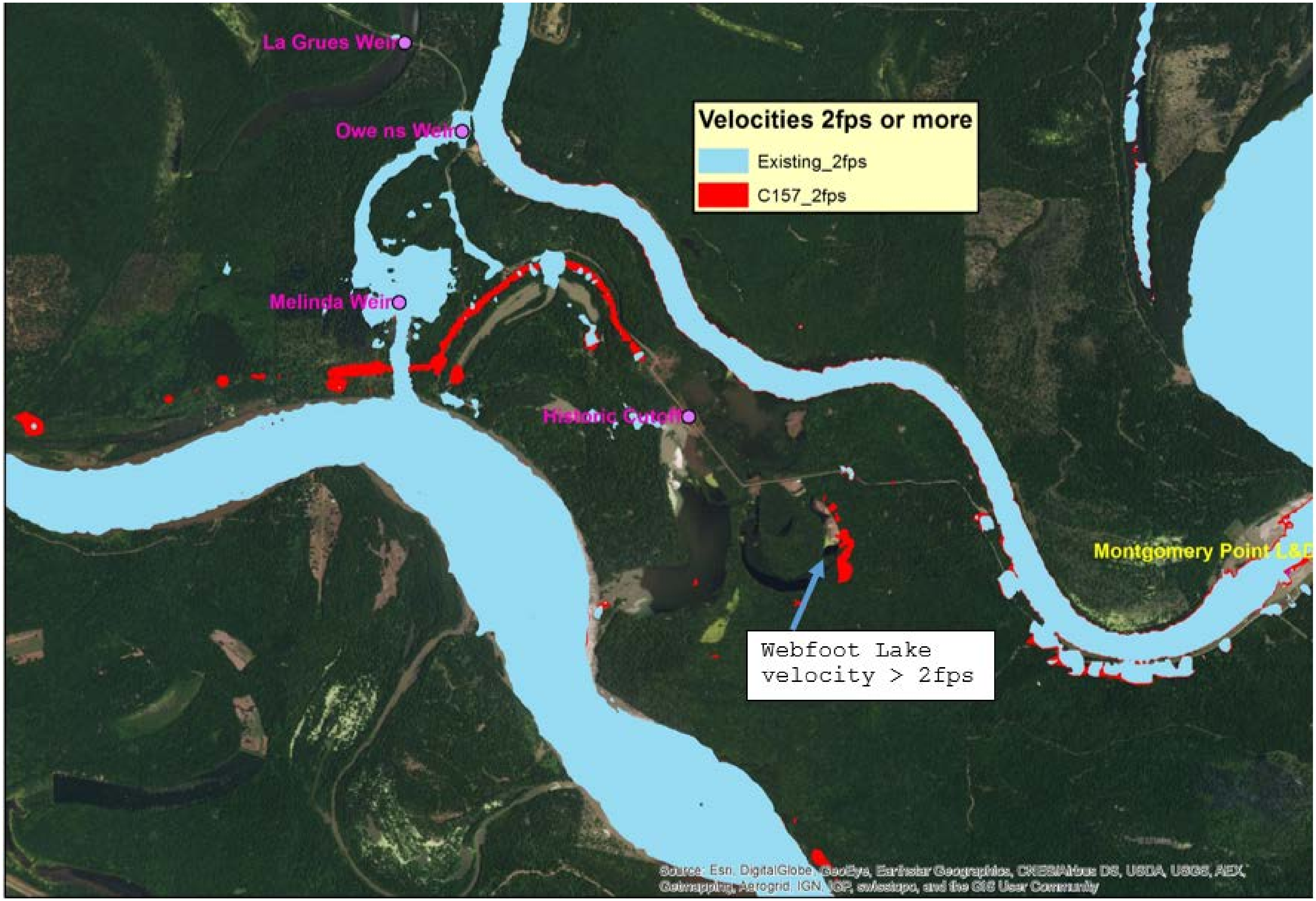

Figure 4-5: Velocities 2 ft/s or more: Exist and C157

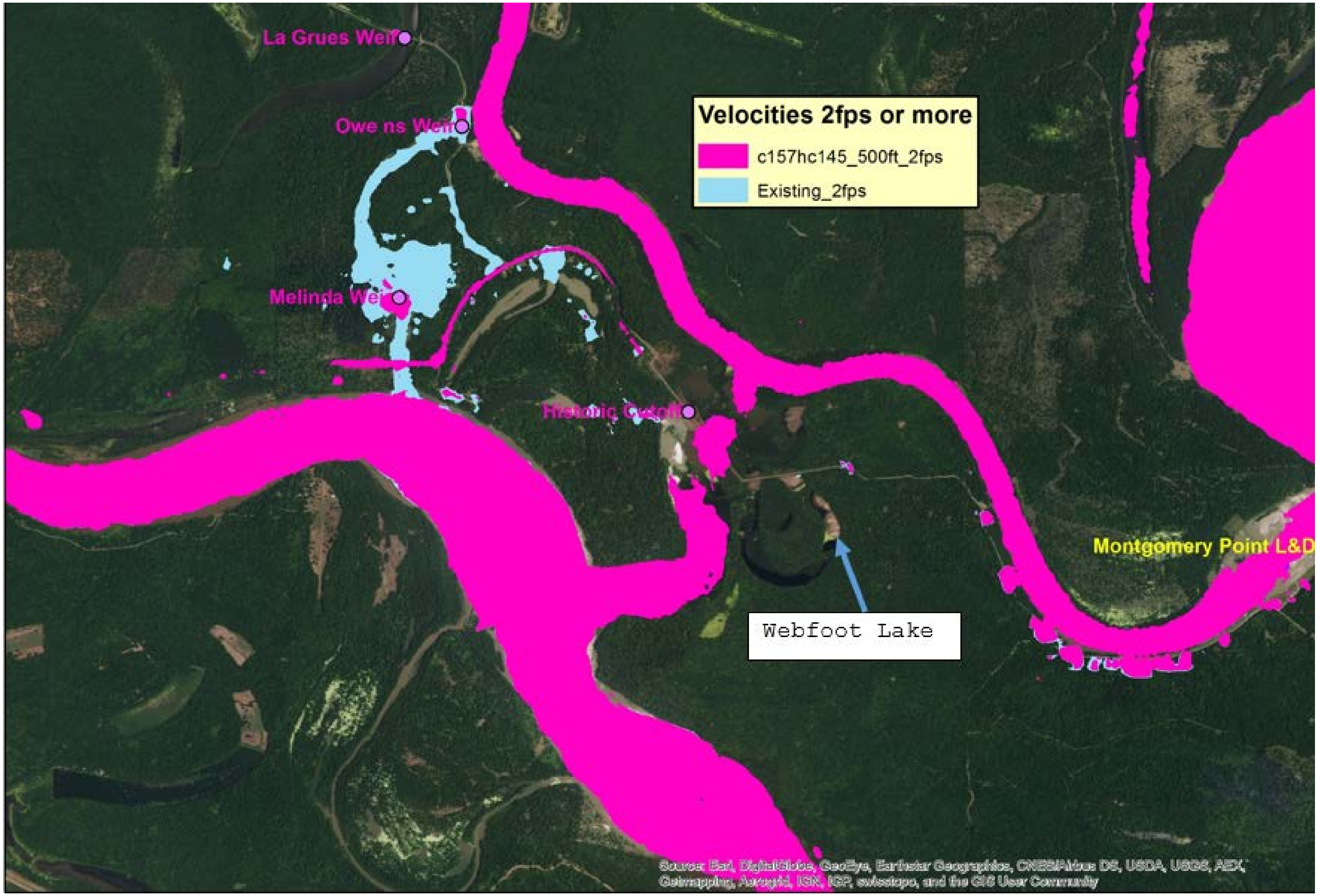

Figure 4-6: Velocities 2 ft/s or more: Exist and C157HC145_500ft

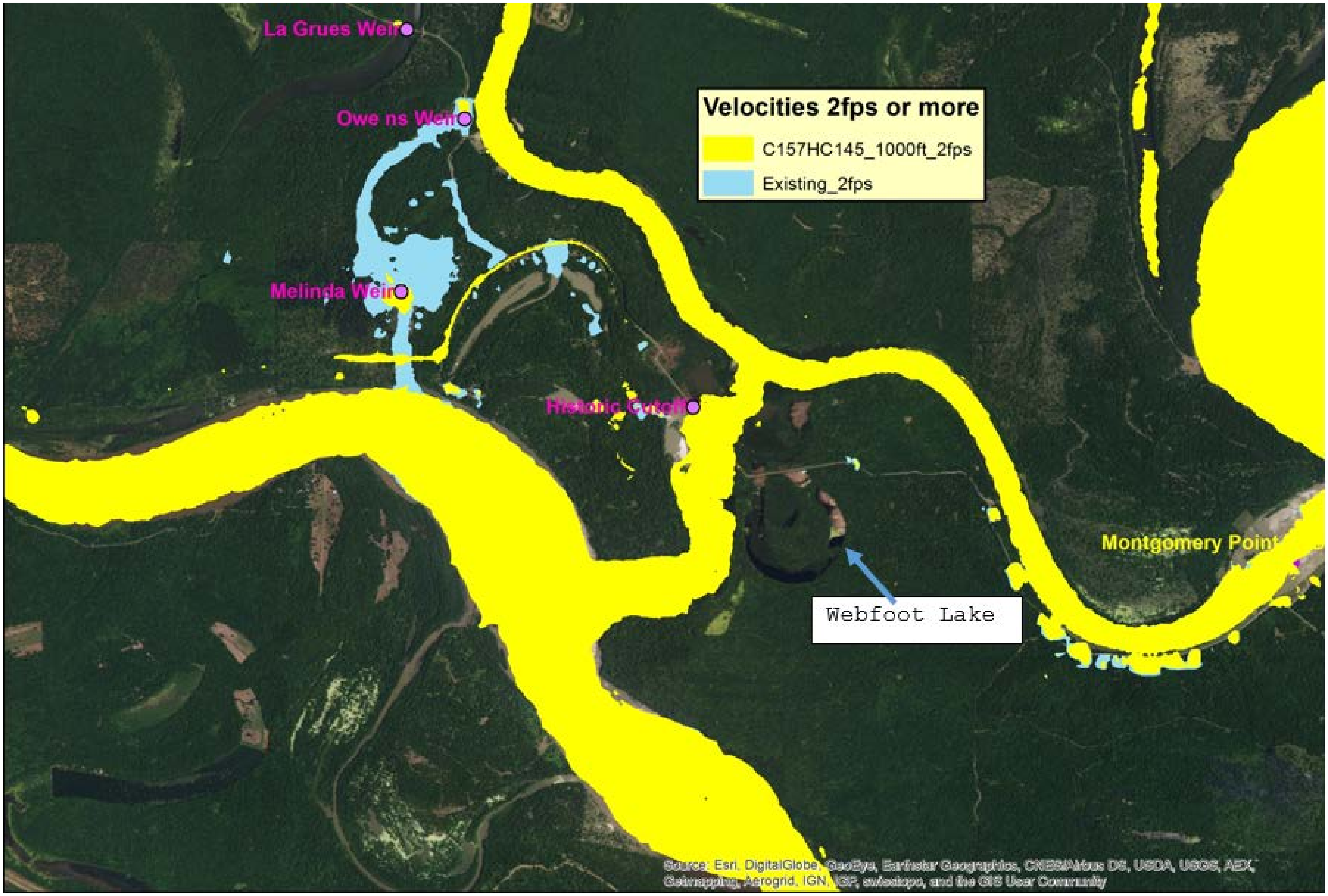

Figure 4-7: Velocities 2 ft/s or more: Exist and C157HC145_1000ft

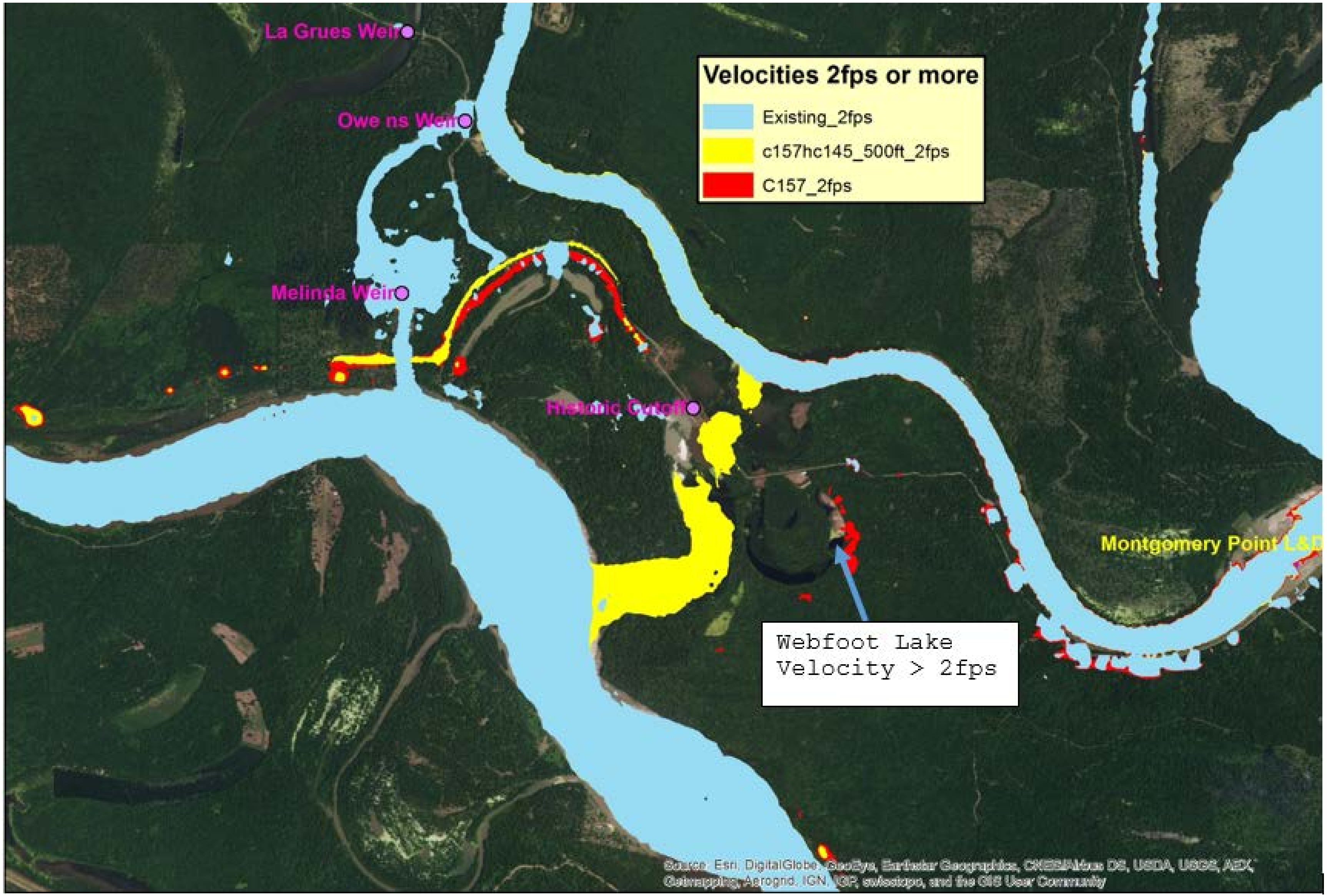

Figure 4-8: Velocities 2 ft/s or more: Exist, C157HC145_500ft, and C157

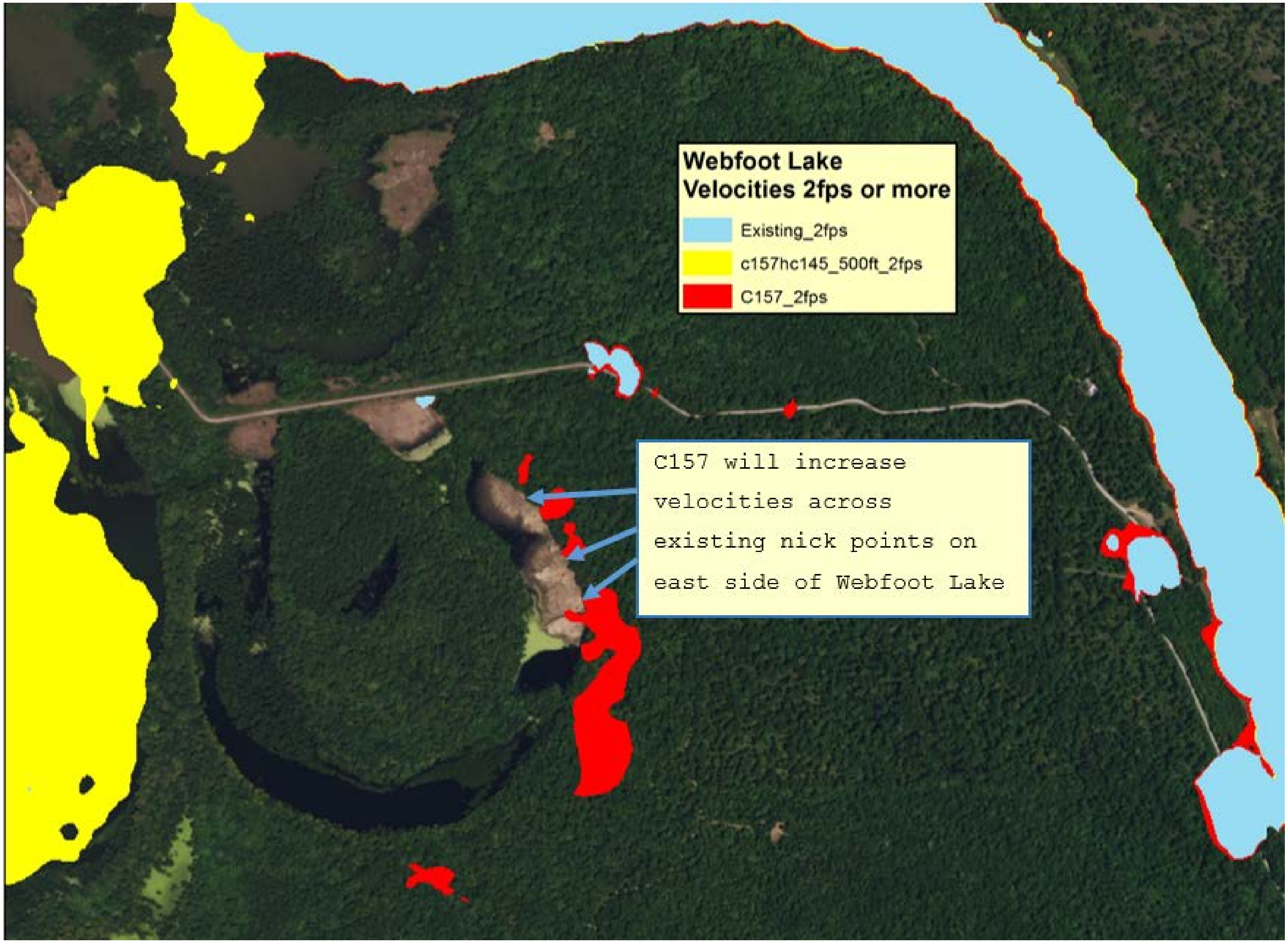

Figure 4-9: Velocities 2 ft/s or more: Webfoot Lake: Exist, C157HC145_500ft, and C157

4.3 Flooding Duration Maps

Percent time inundated grids for the growing season, defined as starting on 15 March and ending on 15 November, for the period of record (2000-2014) were produced for each alternative and compared to existing conditions.

To identify areas that will be affected the most by each alternative, U.S. Fish and Wildlife in cooperation with Arkansas Game and Fish, and Arkansas Natural Heritage Commission, requested the percent time inundated grids be changed into grids that identify areas that will experience an average of seven days or more inundation and seven days or less of inundation during the growing season. See Appendix B for seven days wetter and seven days drier inundation duration maps for the study area.

4.4 Refuge Landform, Microsite, Elevation: Seasonal Inundation Duration

A polygon shapefile of Landform, Microsite topography delimited by elevations was provided by U.S. Fish and Wildlife and used to categorize the days different in inundation for the Refuge. See Figure 4-10: Landform Microsite Elevation Zones. See Table 4-5: Change in Seasonal Inundation based on Refuge Landform, Microsite, and Elevation for results.

Table 4-5: Change in Seasonal Inundation based on Refuge Landform, Microsite, and Elevation

Growing Season (15 March - 15 November, 245 days) Average Annual Days Inundated (Period of Record 2000-2014)							
	ANNUAL AVERAGE DAYS INUNDATED	AVERAGE ANNUAL DAYS DIFFERENT FROM EXISTING (-) Drier (+) Wetter					
		Alternative 1			Alternative 2		
Landform, Microsite based on Elevation	EXISTING	C157	C157HC145 500ft	C157HC145 1000ft	M115	M125	M135
PVL2 Flats below 147.5 feet	50	0	0	0	-4	-4	-4
PVL2 Flats above 147.5 feet	13	1	0	0	-8	-8	-8
HPS Ridges below 145 feet	42	0	0	0	-2	-2	-2
HPS Ridges above 145 feet	20	1	0	0	-4	-4	-4
HPS Natural Levees below 145 feet	55	0	0	0	0	0	0

Growing Season (15 March - 15 November, 245 days) Average Annual Days Inundated (Period of Record 2000-2014)							
Landform, Microsite based on Elevation	ANNUAL AVERAGE DAYS INUNDATED	AVERAGE ANNUAL DAYS DIFFERENT FROM EXISTING (-) Drier (+) Wetter					
		Alternative 1			Alternative 2		
	EXISTING	C157	C157HC145 500ft	C157HC145 1000ft	M115	M125	M135
HPS Natural Levees above 145 feet	13	1	0	0	-7	-7	-7
HPS Flats below 142 feet	66	0	0	0	0	0	0
HPS Flats above 142 feet	43	0	0	0	-3	-3	-3
Three Rivers back swamp final	73	0	0	0	0	0	-1

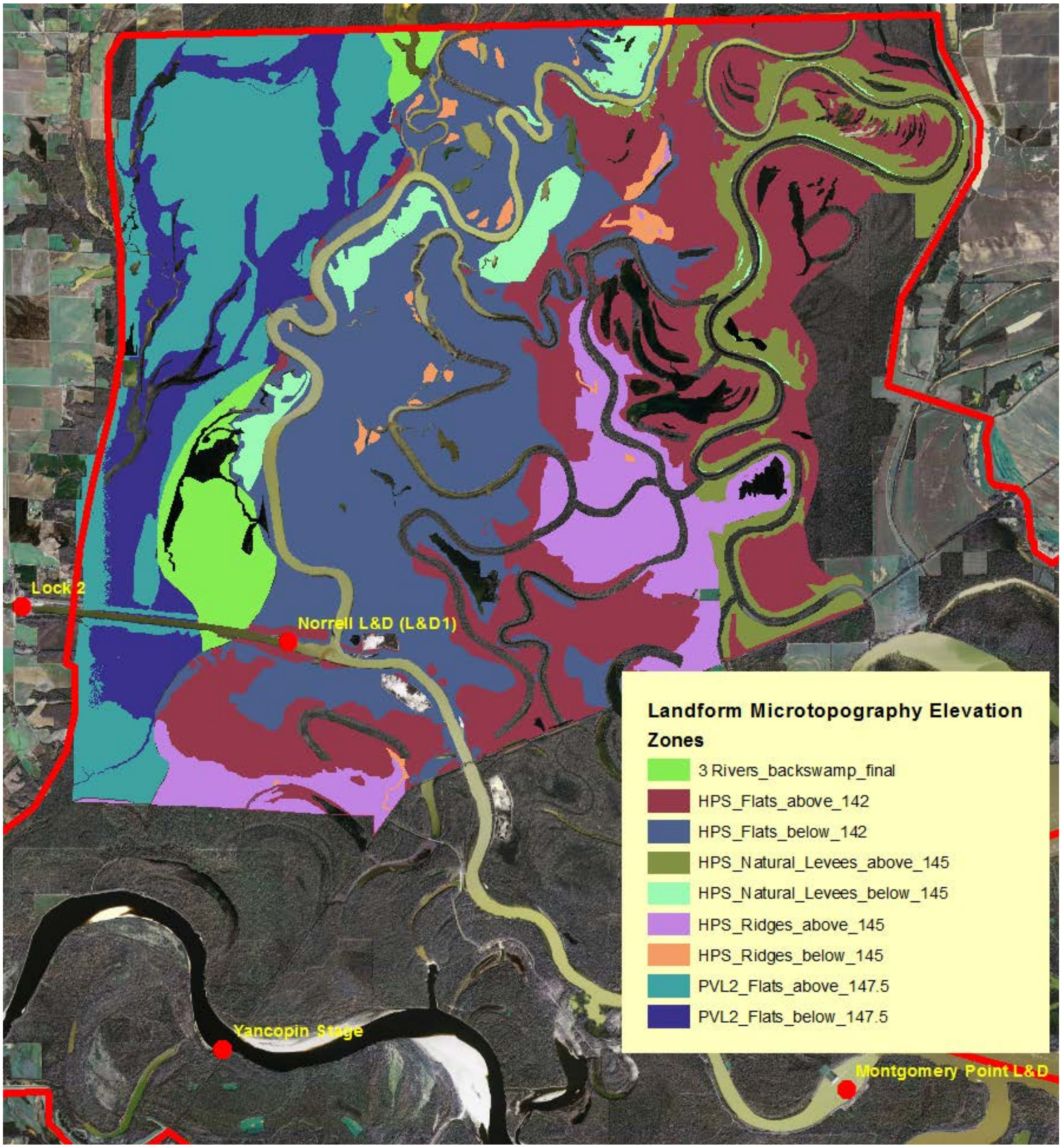

Figure 4-10: Landform Microsite Elevation Zones

4.5 Exceedance Duration: Oxbow Existing Outlets

Exceedance duration for existing conditions, C157HC145_500ft and C157HC145_1000ft were the same. Existing fish passage into LaGrues Lake is through three corrugated metal culverts around elevation 138 feet with an annual exceedance duration of 22.7% and through two corrugated metal culverts around elevation 129 feet with an annual exceedance duration of 47.4%. See Figure 4-11: Elevation Exceedance Duration: White River La Grues Lake Outlet.

Owens Lake Weir, at elevation 145 feet, with an annual exceedance duration of 9.7%, has to be overtopped before fish can migrate into or out of the lake from the White River. Final exceedance duration should be based on period of record observed gage data at Lock and Dam 1 and Montgomery Point Lock and Dam to determine optimal seasonal fish passage elevations. See Figure 4-12: Elevation Exceedance Duration: White River Owens Lake Weir and Table 4-6: Lake Recharge: Elevation Duration Exceedance

Table 4-6: Lake Recharge: Elevation Duration Exceedance

Lake Recharge: Percent Time Elevation Duration Exceedance Existing Conditions, C157HC145_500ft, and C157HC145_1000ft are statistically Identical		
Oxbow	Recharge Elevation (feet)	Annual Exceedance
LaGrues Lake (3 culverts)	138	22.7%
LaGrues Lake (2 Culverts	129	47.4%
Owens Lake (Weir)	145	9.7%

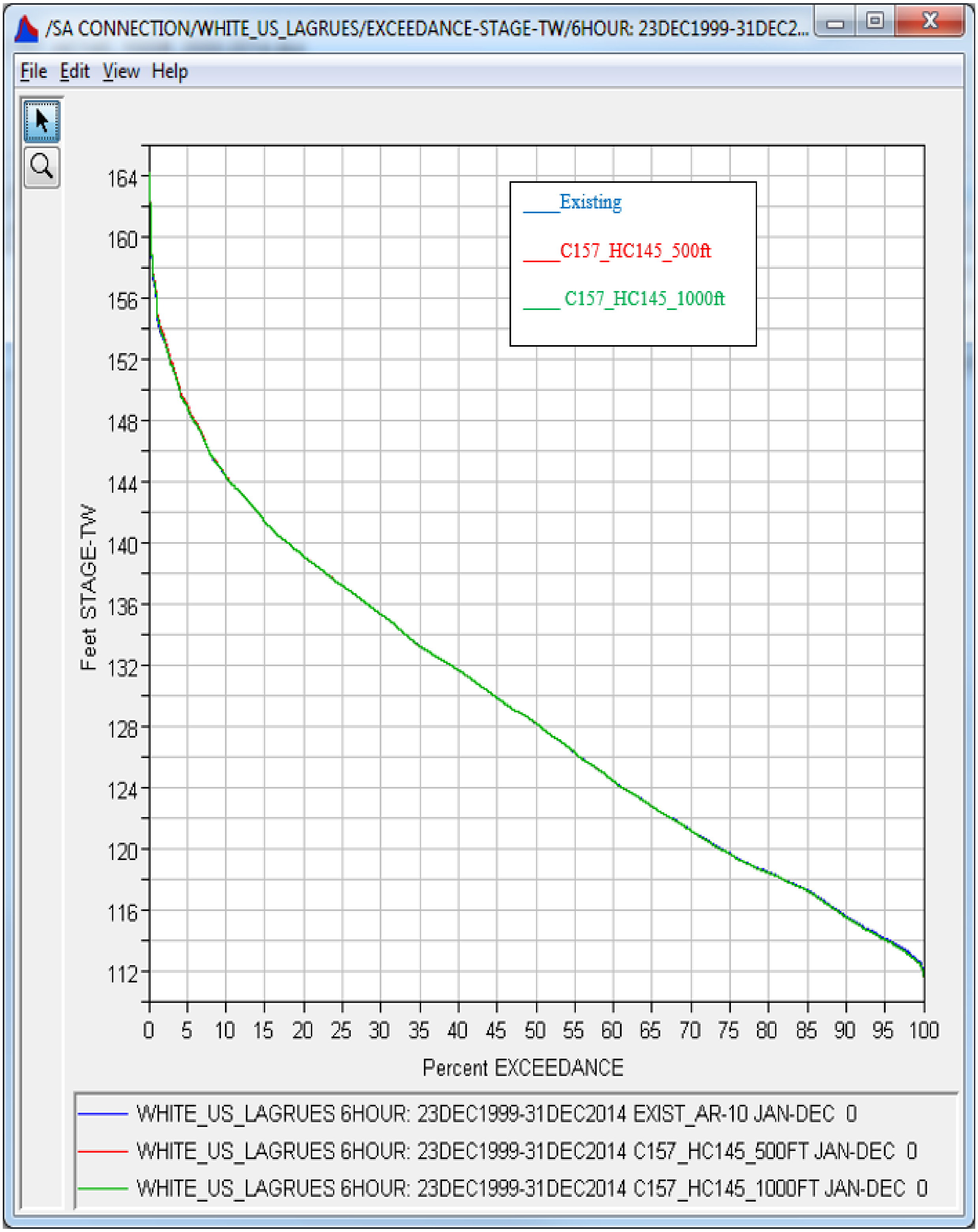

Figure 4-11: Elevation Exceedance Duration: White River La Grues Lake Outlet

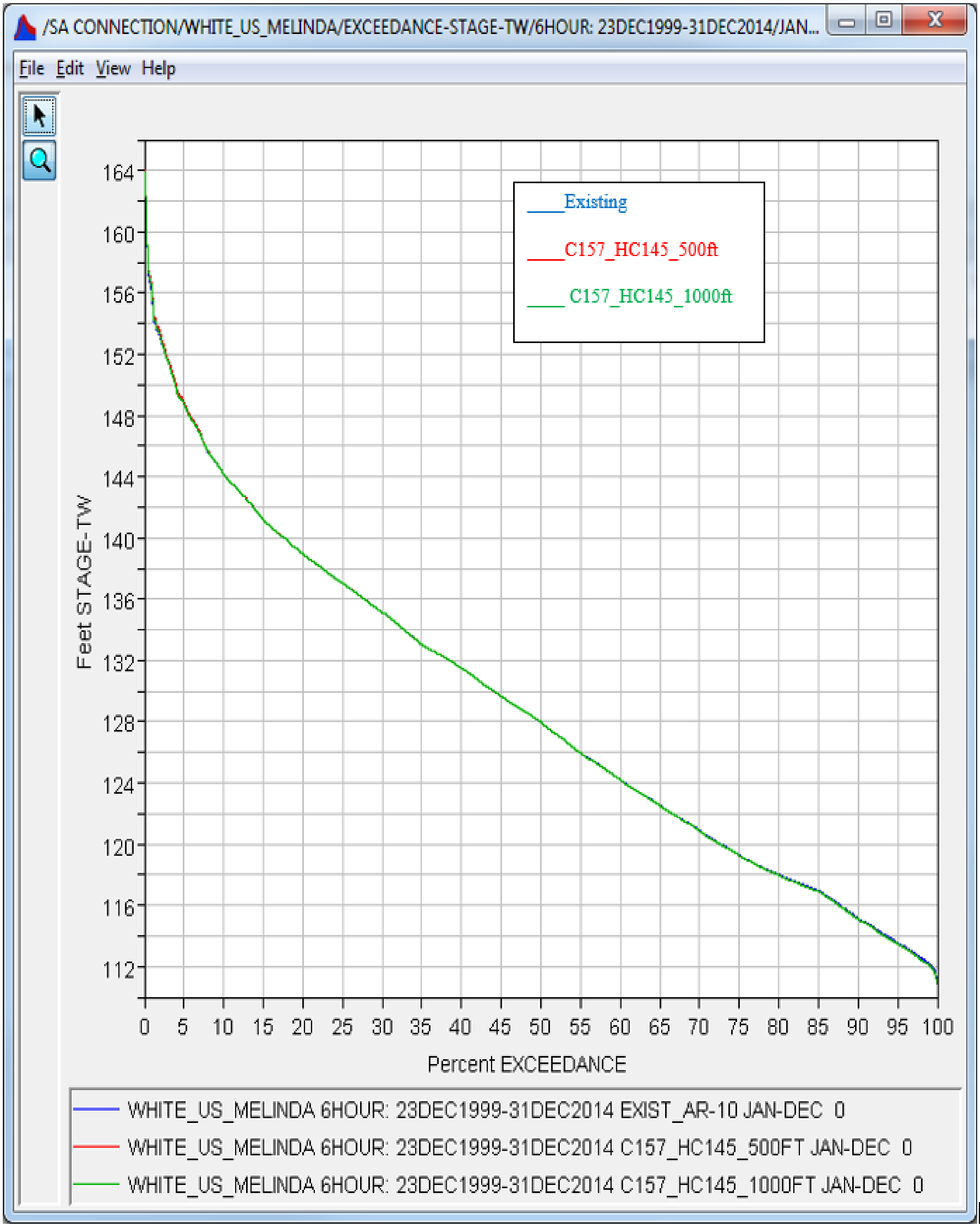

Figure 4-12: Elevation Exceedance Duration: White River Owens Lake Weir

4.6 Exceedance Duration: Areas of Interest

See Appendix C for the exceedance duration analysis at locations identified in Figure 4-13: Elevation Exceedance Duration: Areas of Interest.

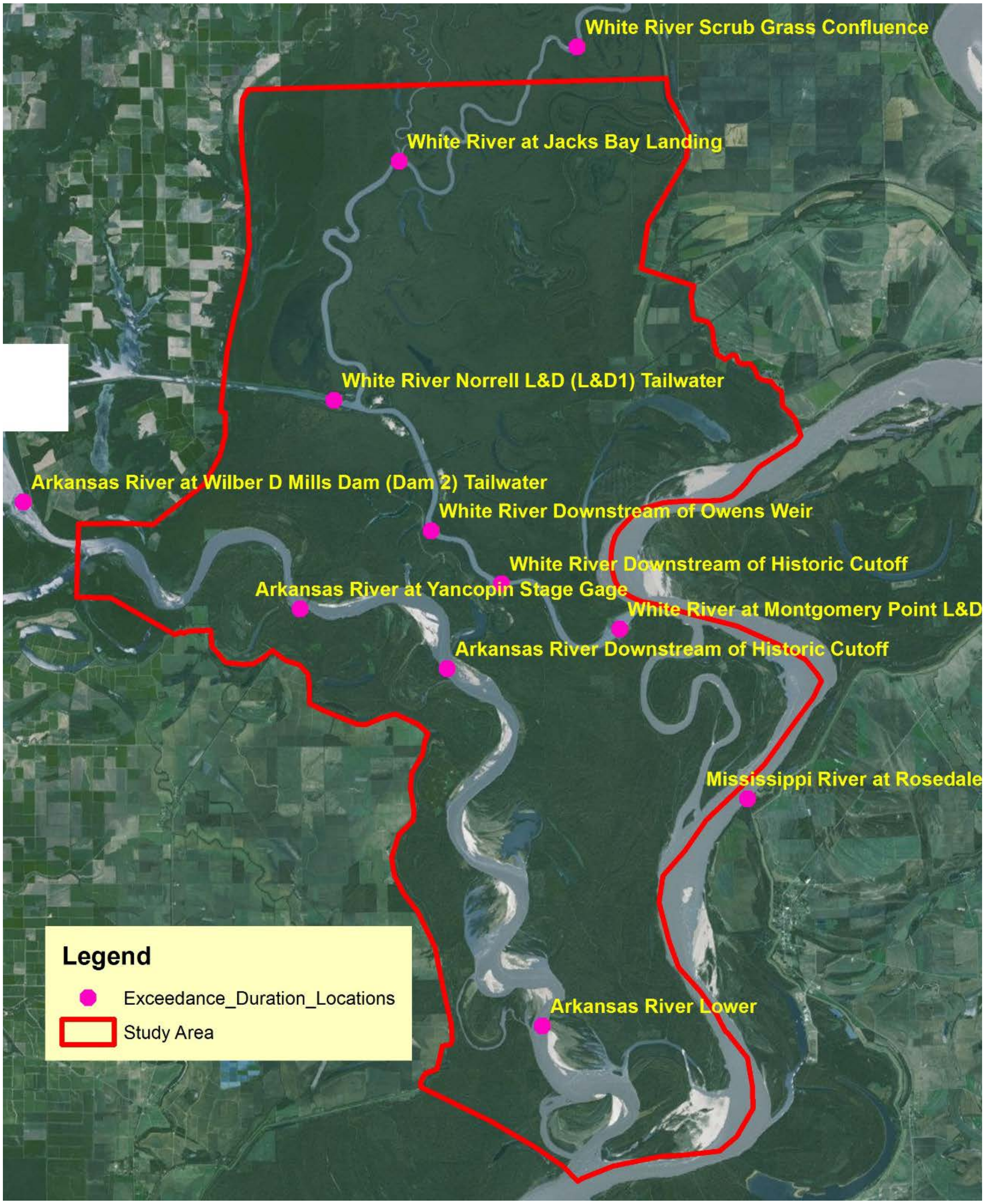

Figure 4-13: Elevation Exceedance Duration: Areas of Interest

4.7 Floodplains

4.7.1 2 year and 5 year Floodplains: Environmental Effects

See Figure 4-14: 2 Year Floodplain and Figure 4-15: 5 Year Floodplain for floodplain inundations for existing conditions, C157, and M135. C157HC145_500ft and C157HC145_1000ft will map almost identically to existing conditions. Flood plain remained essentially the same across the alternatives and so therefore was not a significant factor in determination of the Tentatively Selected Plan, TSP. Although it was used to confirm small to no change in hydrology in the Refuge across the alternatives.

4.7.2 100 year Floodplain: FEMA

The project area is FEMA Zone A. This means an alternative may not have a cumulative rise in the Base Flood Elevation (BFE, 1% exceedance frequency) of more than 1.00 feet. Floodplains for C157HC145_500ft and C157HC145_1000ft do not exceed the allowable 1.00 foot cumulative rise. See Table 4-7: Change in 100 year Elevations and Figure 2-1: HEC RAS Model Limits for locations of gages. The 100 year floodplain inundation map for C157HC145_500ft and C157HC145_1000ft and Existing Conditions were the same with less than a tenth of a food difference in water surface elevations.

Table 4-7: Change in 100 year Elevations

Location	Maximum 100 Year Water Surface Elevation Difference from Existing in feet	
	C157HC145_500ft	C157HC145_1000ft
Arkansas: Wilber D Mills (Dam2) Gage	-0.01	-0.03
Arkansas: Yancopin Gage	-0.04	-0.01
Arkansas River: ~11 miles downstream of confluence with Historic Cutoff	0	0
Mississippi: Rosedale Gage	-0.01	-0.02
White: Hudson Landing Gage	0.01	-0.01
White: Norrell Lock and Dam (LD01) Gage	0.02	0
White: Montgomery Point Lock and Dam Gage	-0.01	-0.04

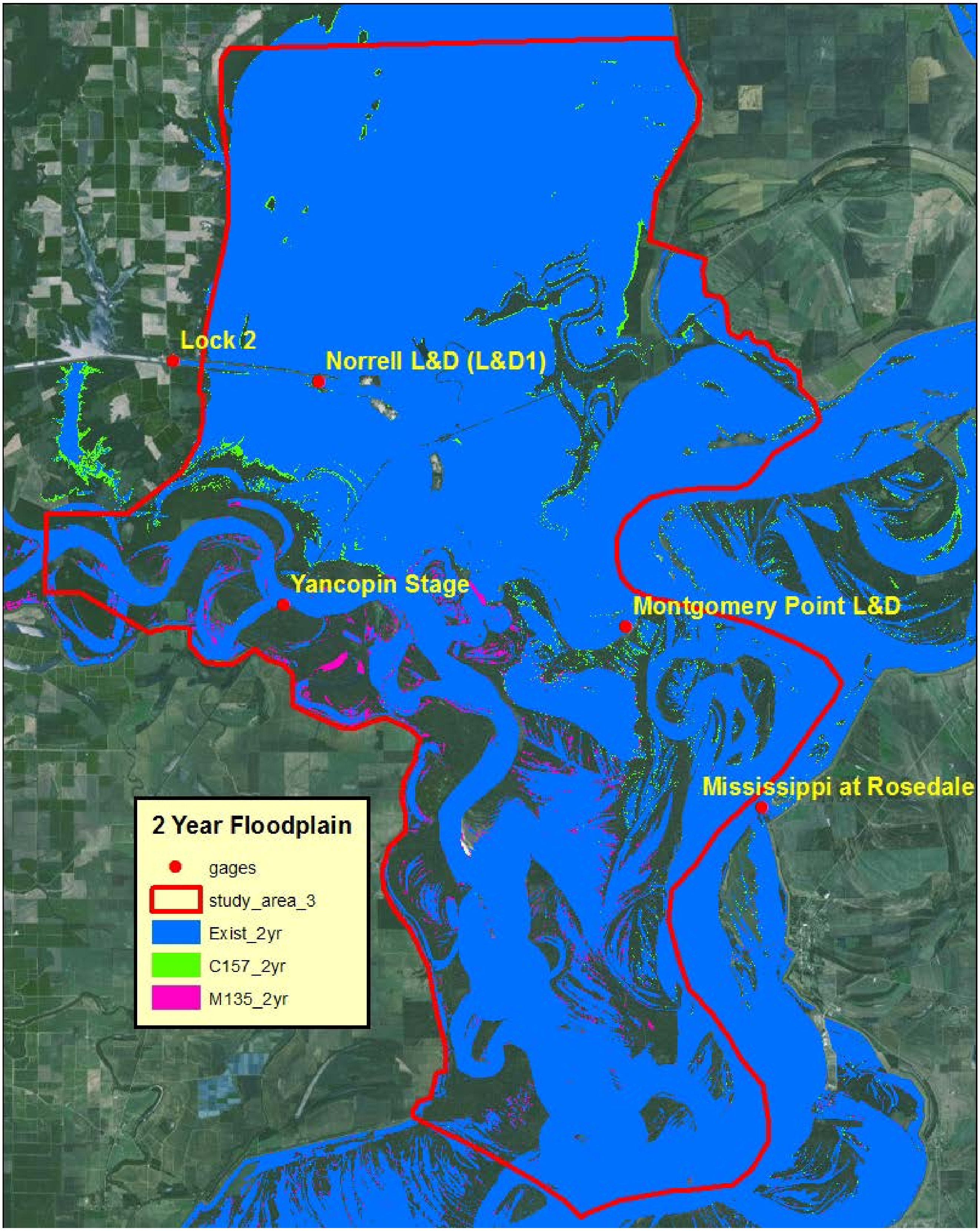

Figure 4-14: 2 Year Floodplain

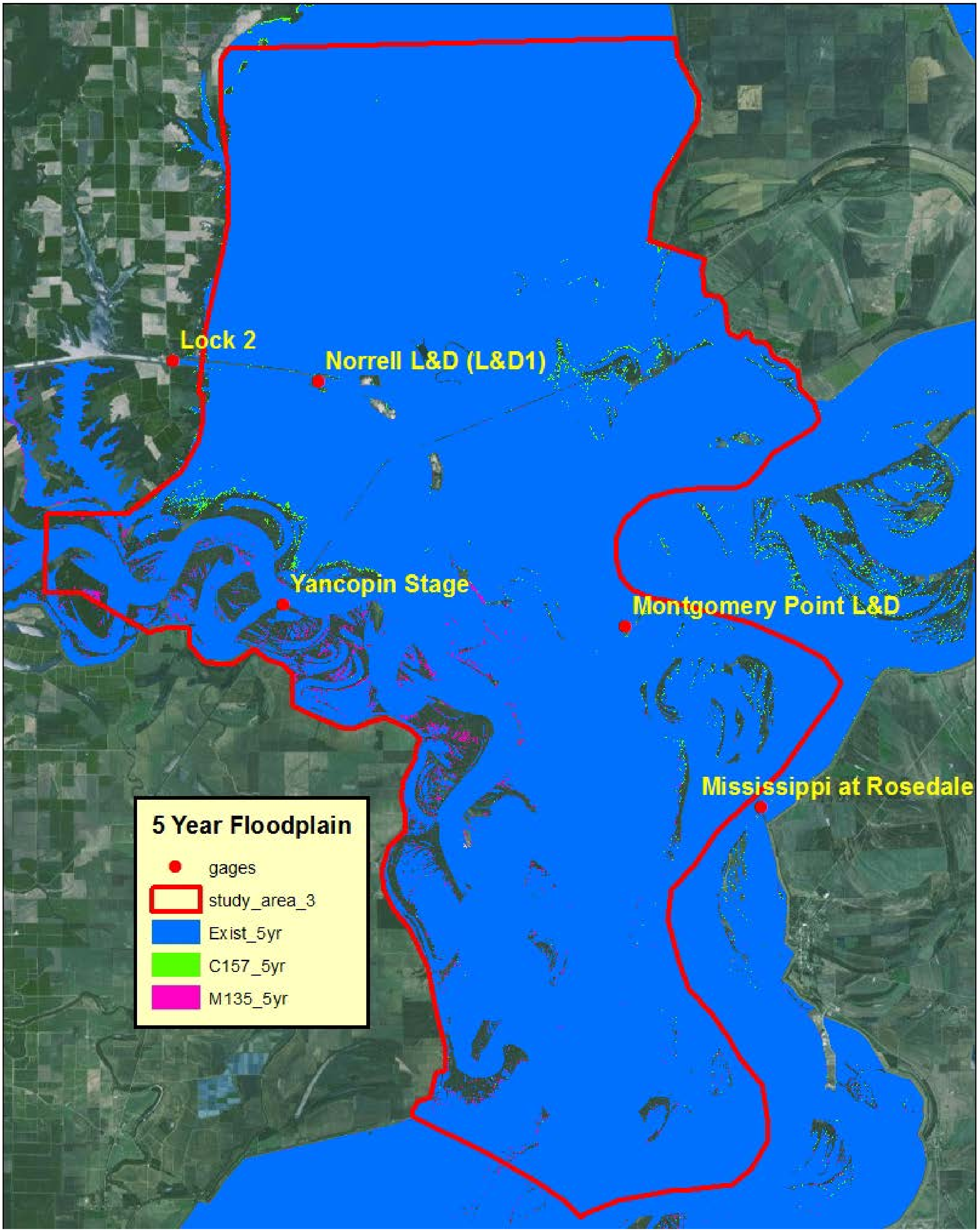

Figure 4-15: 5 Year Floodplain

5 Future Modeling

5.1 Model Oxbow Recharge

Culvert inverts and sizes were surveyed and will be incorporated into the hydraulic model for the next series of modeling effort to investigate increasing fish passage efficiency. This effort will be focused on LaGrues and Owens Lakes.

5.2 Ship Tow simulator for cross current

Alternatives C157HC145_500ft and C157HC145_1000ft included opening up the Historic Containment Structure with a relief structure down to elevation 145 feet. The final width of this opening will rely on the maximum width of the opening which will provide the isthmus the greatest stability against scour and erosion without introducing dangerous cross currents into the shipping lane. A Ship Tow simulator would provide the upper limits on the width of the relief structure.

5.3 Increased velocity and shear stress in White River

If the Ship Tow Simulator results in a relatively large opening that results in excessive increase in velocity and scour potential in the White River, then scour protection in the shipping lane and across Montgomery Point Lock and Dam will need to be included in the final design.

6 Glossary

Camp Bend: The Arkansas River bend just downstream of the Yancopin Bridge and immediately upstream of House Bend, in 2003 the bend was approximately RM 18.
Closure Structure: The structure built to close the Historic Cutoff. The structure's top elevation is approximately 172 feet – a non-overtopping elevation.
Containment Structure: A soil-cement structure between the White and Arkansas River to ensure that the entire isthmus overtops at the same elevation (150 NGVD). The structure runs from the Owens Lake Weir to the Closure Structure.
Geotube: Is a sand/dredged material filled geotextile tube made of permeable but soil-tight geotextile. It comes in different diameter sizes. These tubes were filled with dredge material and used as dikes.
headcut: An abrupt deepening and widening of a channel that moves upstream during high flow events.
House Bend: The Arkansas River bend to which the Melinda Corridor connects, in 2003 the bend was approximately RM 17.
Hydraulic slope: The change in elevation of a water surface over a known distance.
J. Smith Lake: An ox-bow lake between White and Arkansas Rivers just east of the Melinda Corridor. Some maps list the lake as John Smith Lake and others mark it as Jim Smith Lake.
LaGrues Lake Weir: A rock structure maintaining the 150 elevation between the rail road and the naturally higher ground at the west end of the Owens Lake Weir. This structure has a small V-notch to allow some low flow interchange linking the lake and the White River.
Lower Arkansas River: For this study the lower Arkansas River was defined as the reach downstream of Dam 02 (Wilbur D. Mills Dam).

Lower White River: For this study the lower White River was defined as the reach downstream of Lock 01 (Norrell Lock and Dam).
McClellan-Kerr Arkansas River Navigation System (MKARNS): A 445-mile-long waterway with 17 locks and dams navigable to the Tulsa Port of Catoosa. The system was authorized in 1946.
Melinda Corridor: A channel between the White and Arkansas Rivers. The corridor consists of Owens Lake and the Melinda Headcut, which began developing in the 1970s. The headcut intersected the lake to form the corridor. The corridor continues to grow, but the widening and deepening is hampered by two weirs: Melinda and Owens.
Melinda Headcut Structure (Melinda): The structure sits between Owens Lake and the Melinda Headcut, in an attempt to prevent the headcut from progressing up the lake into the White River. The crest is approximately 142 NGVD.
Nick point: Part of the thalweg of a river or channel where there is a sharp change in thalweg elevation or abrupt change in slope that is caused by erosion.
Owens Lake Weir: The hydraulic control structure at the head of the Owens Lake, the crest elevation is 145 feet.
Yancopin Bridge: The rail road bridge across the Arkansas River at approximately RM 20 in 2003.

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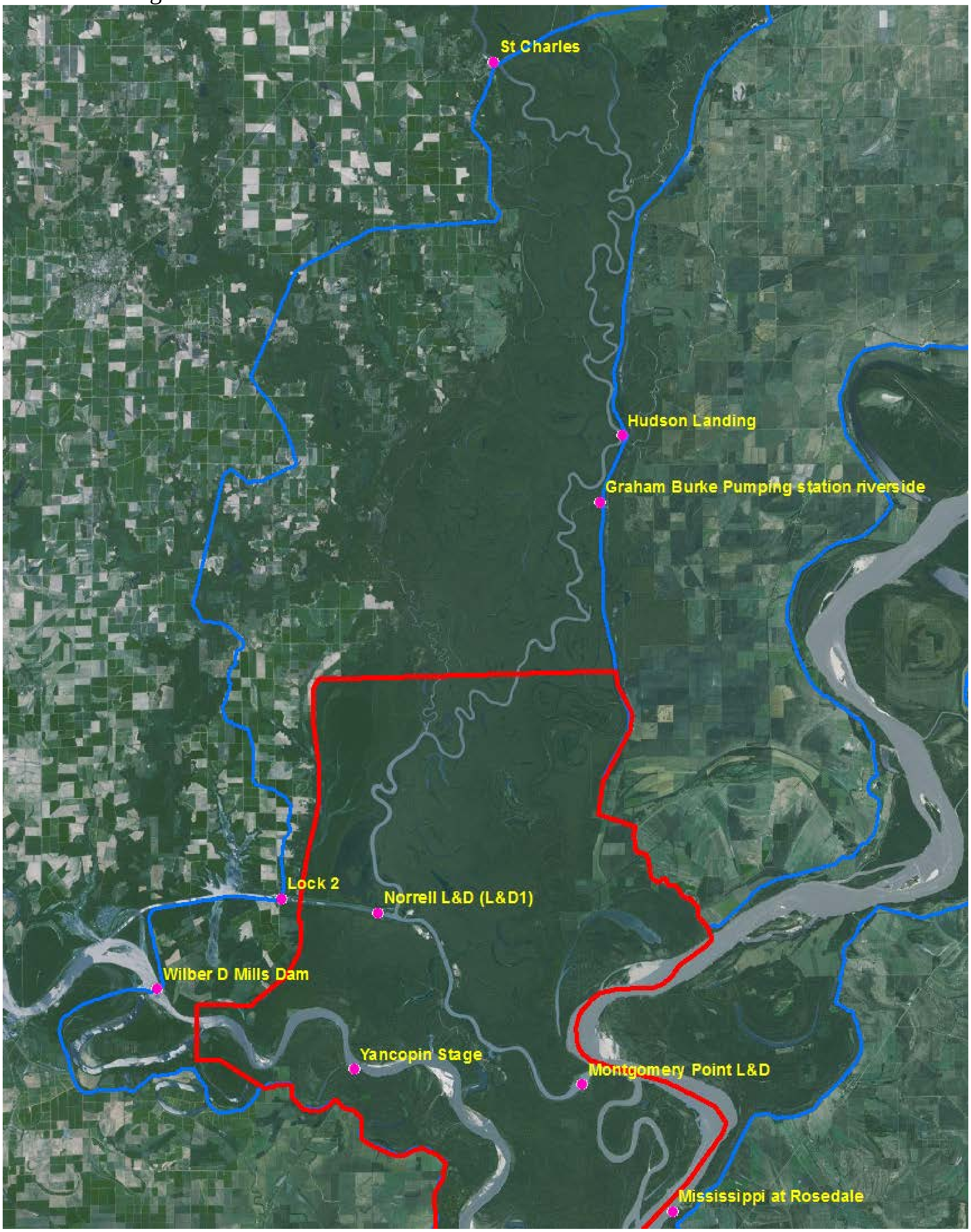
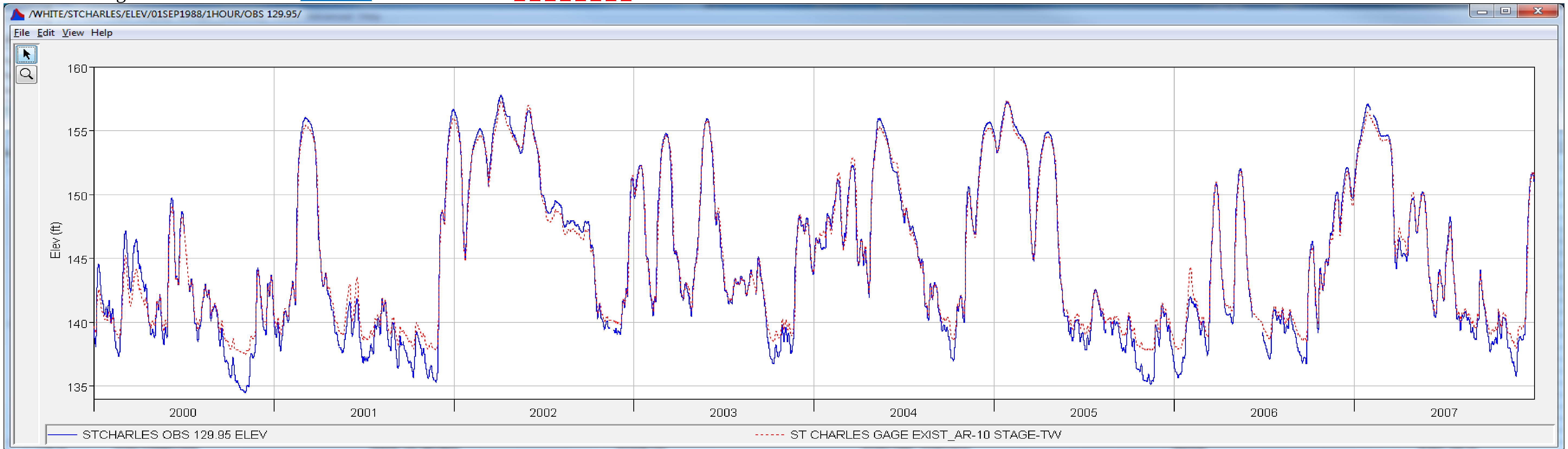
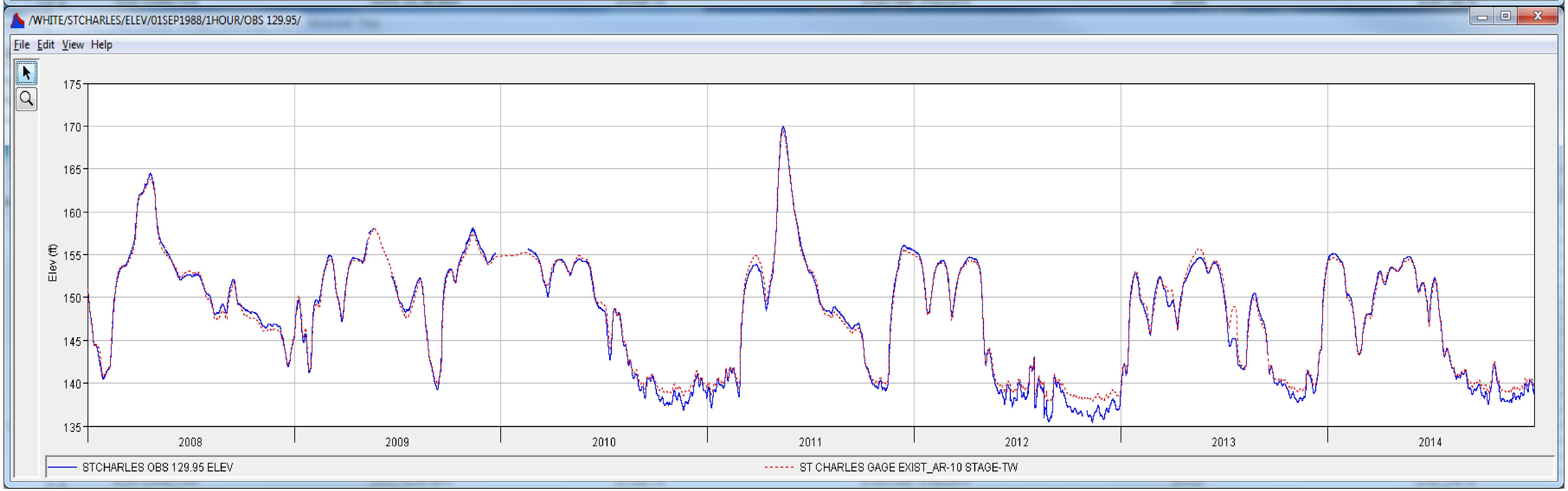
Appendix A Calibration Hydrographs

Calibration Gage Locations

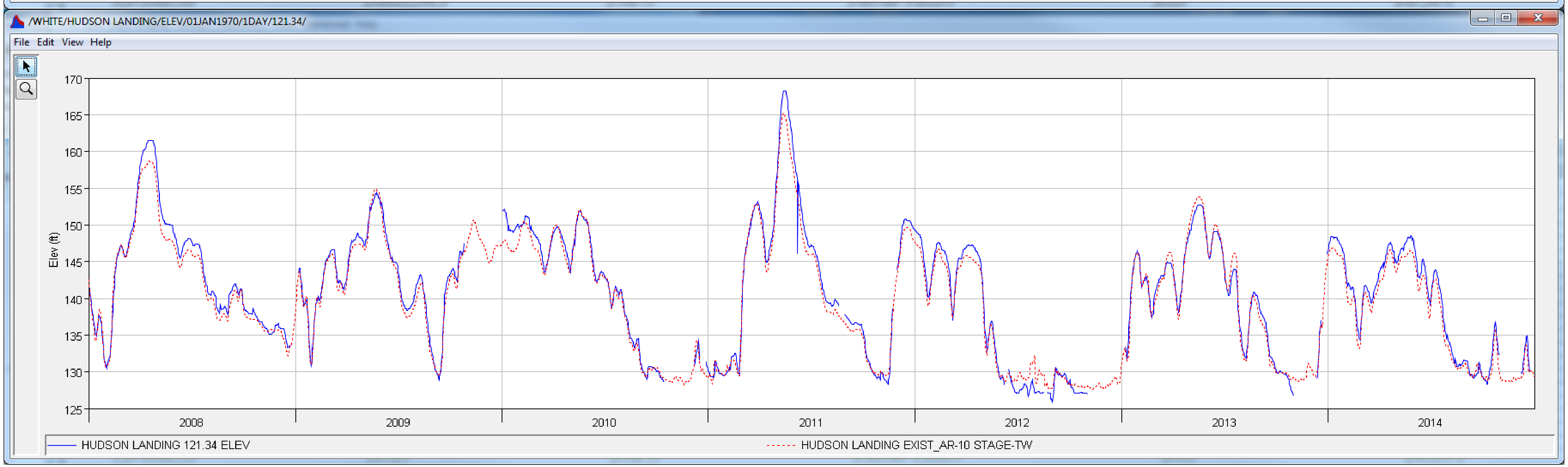


St Charles Gage: White River _______ Observed _ _ _ _ _ _ _ _Modeled

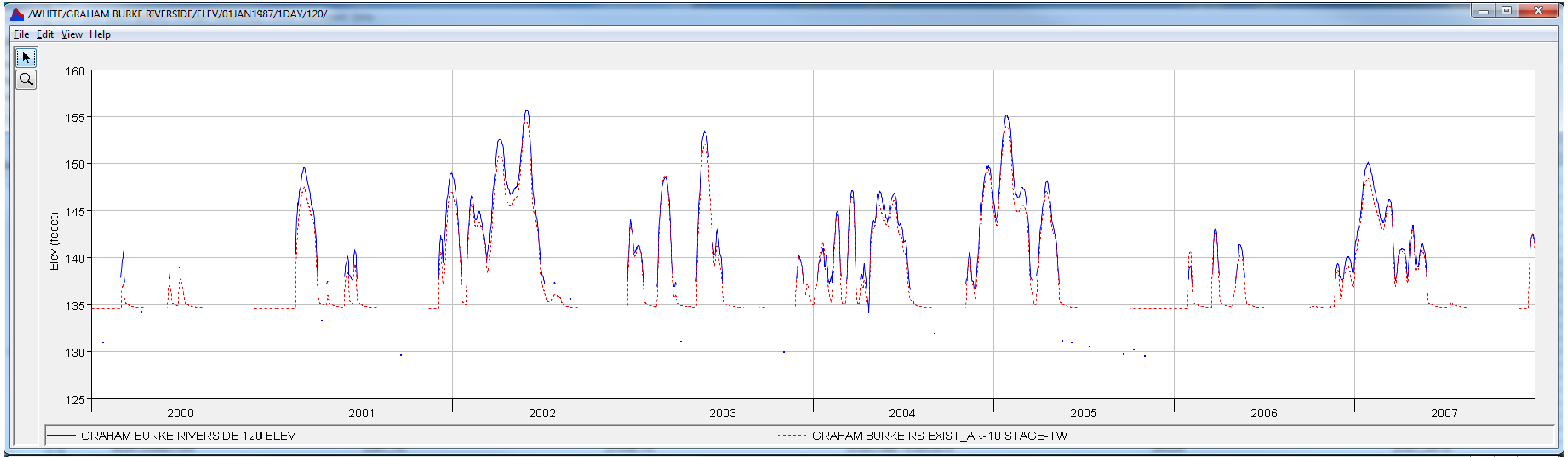


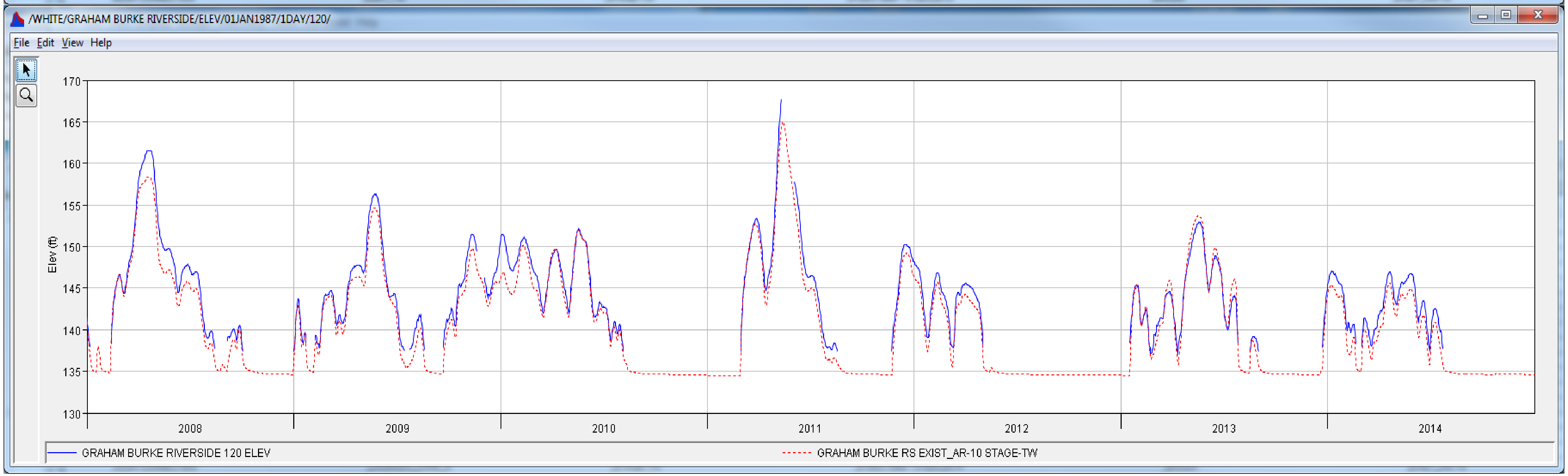


Hudson Landing: White River ________ Observed _ _ _ _ _ _ _ _ _Modeled

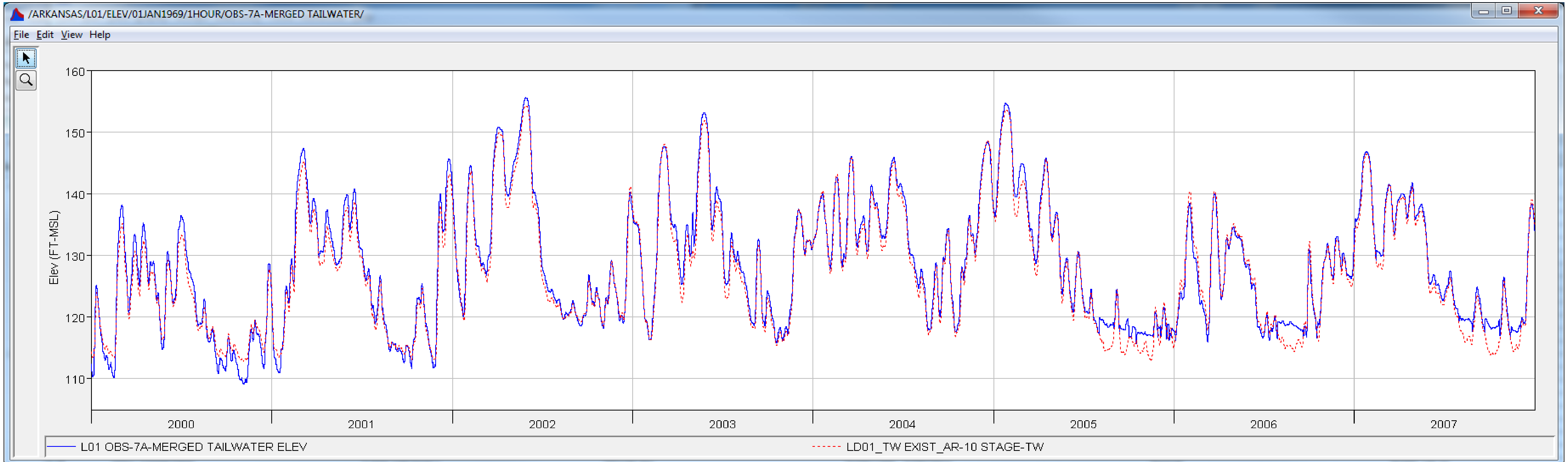


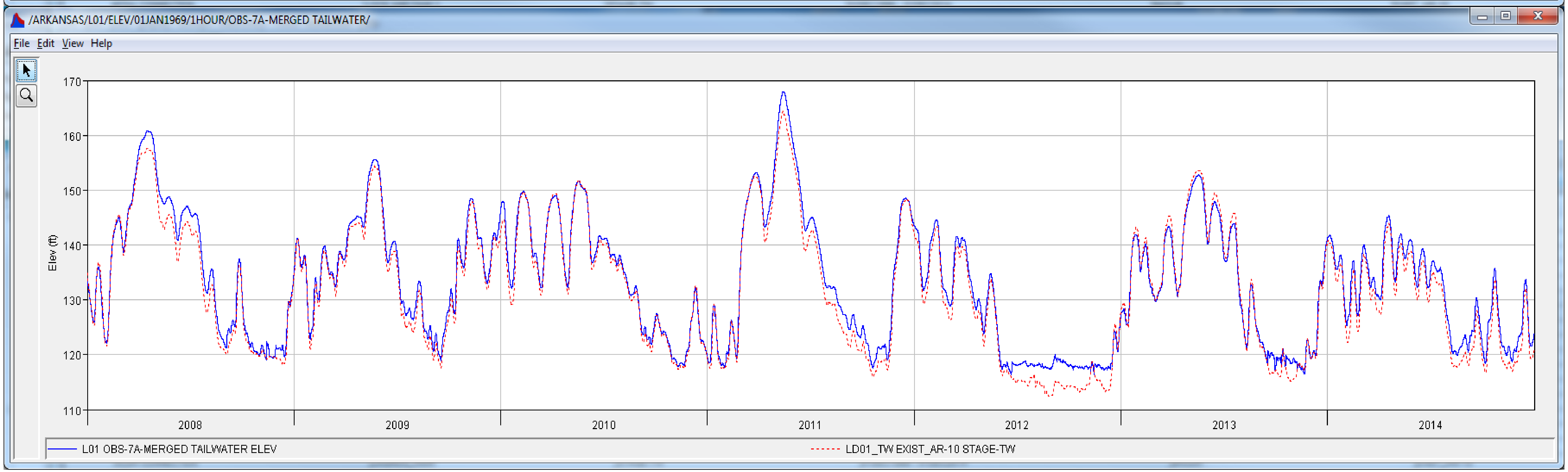
Graham Burke Riverside: White River ________ Observed _ _ _ _ _ _ _ _Modeled



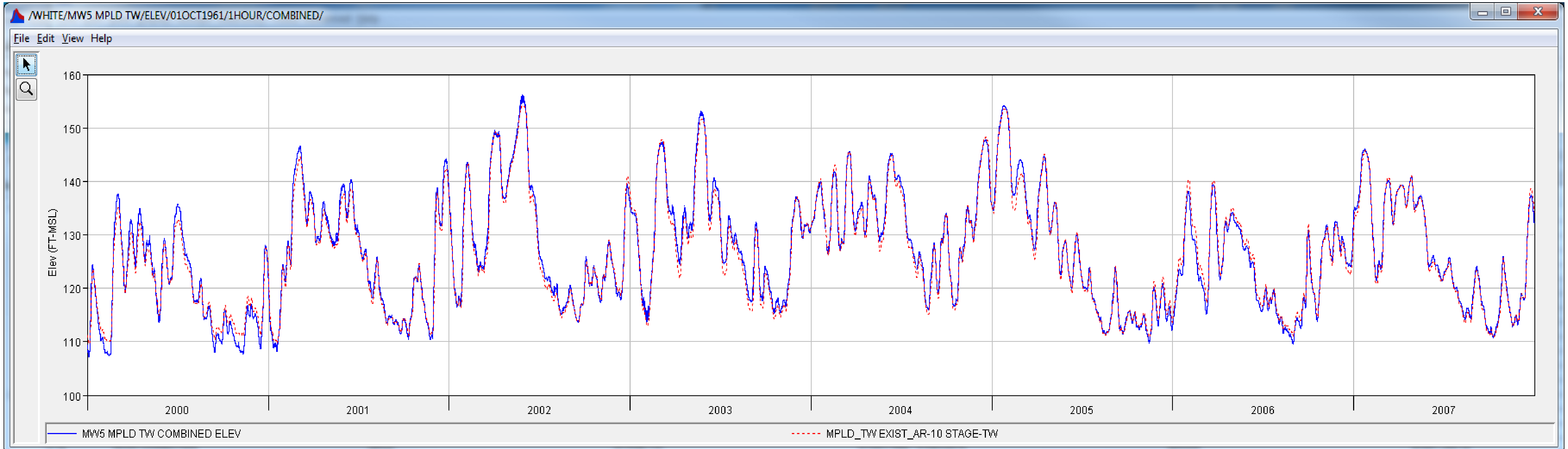


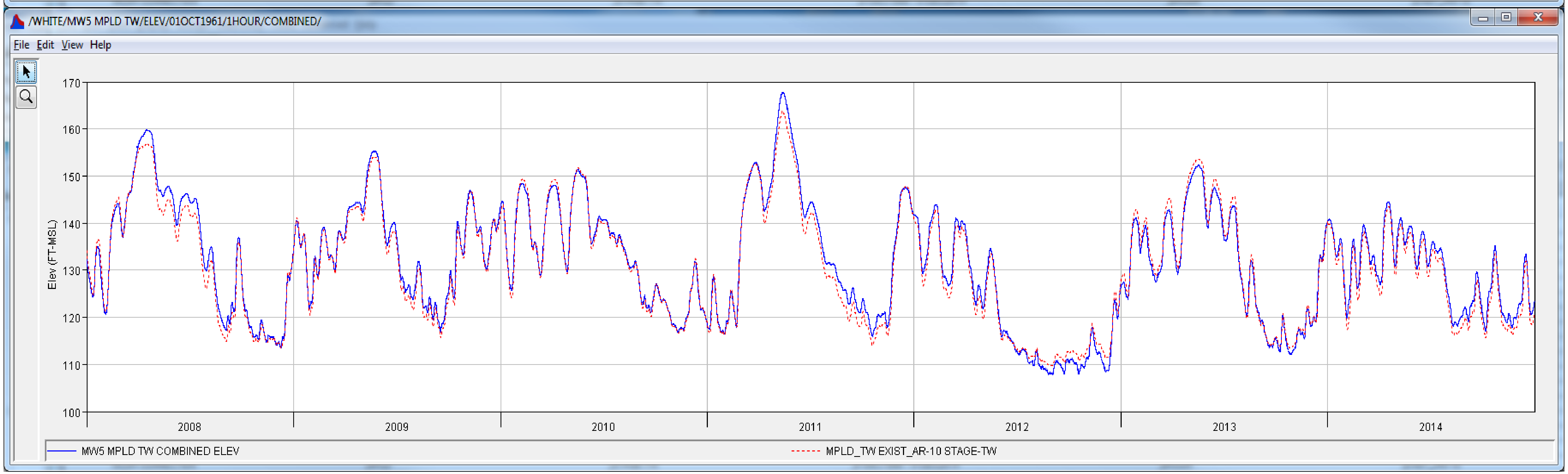
Lock and Dam 1 Tailwater: White River _______ Observed _ _ _ _ _ _ _ _Modeled



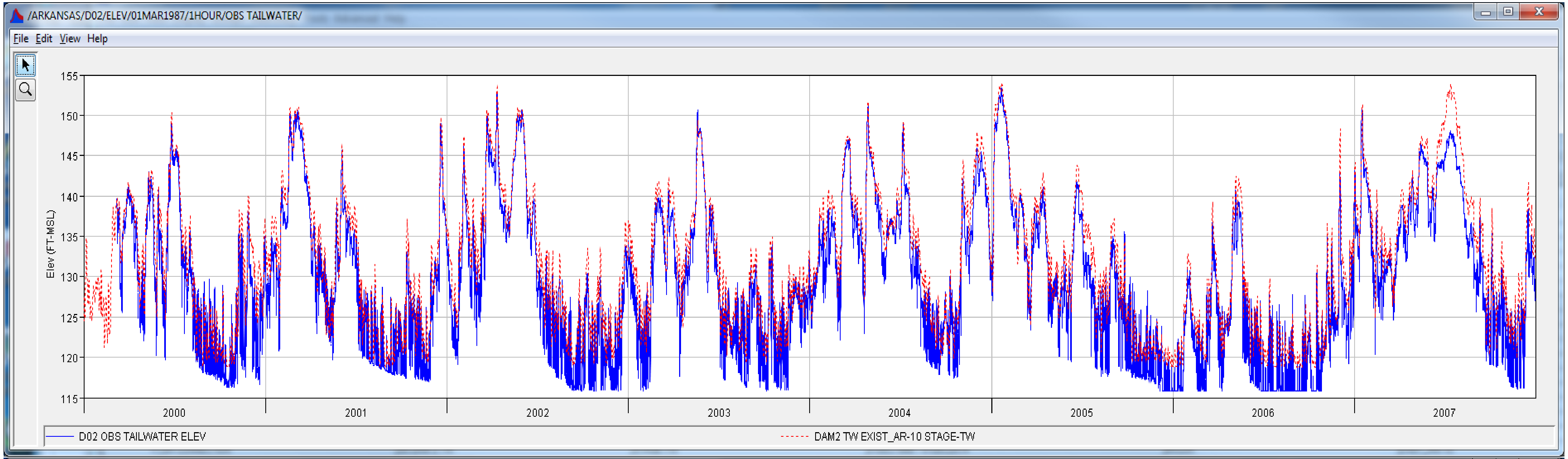


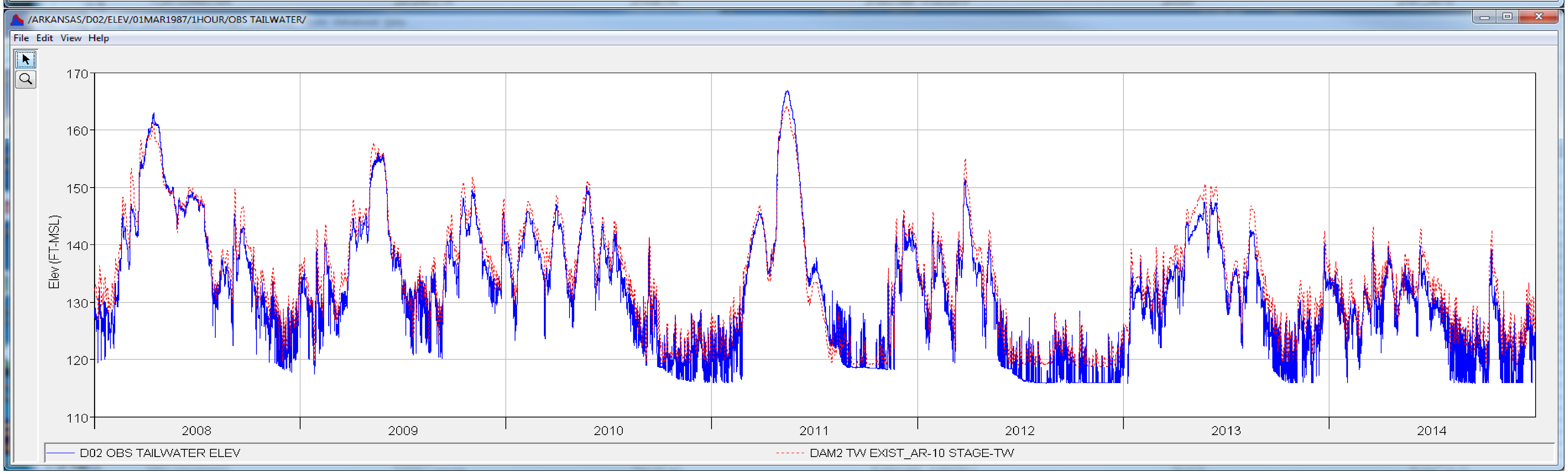
Montgomery Point Lock and Dam Tailwater: White River ______ Observed _ _ _ _ _ _ _ _Modeled



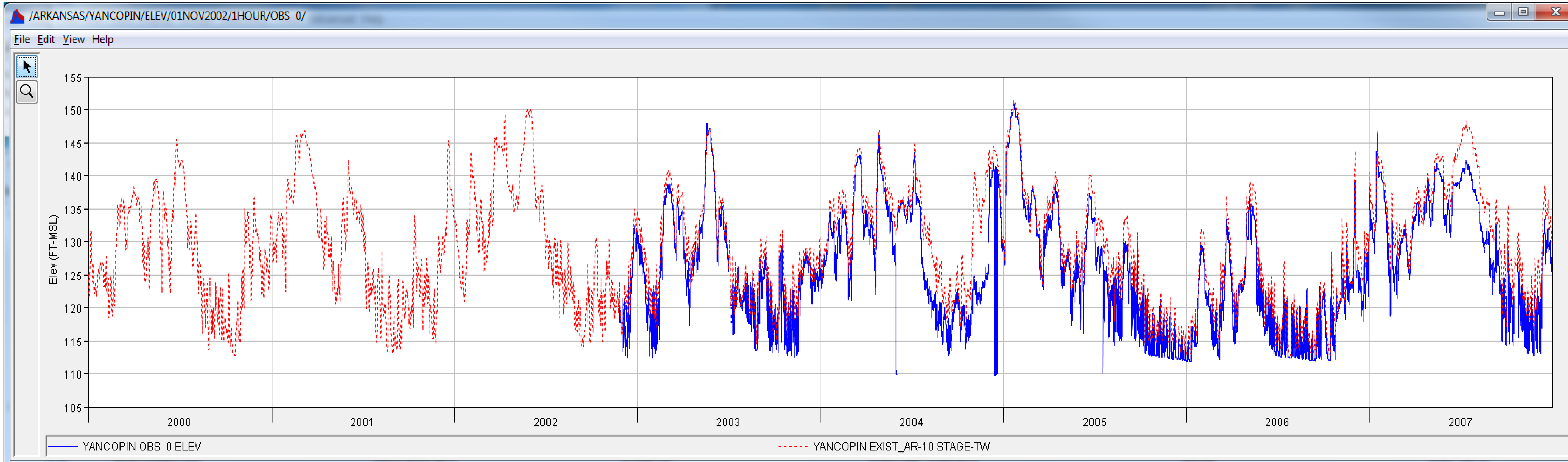


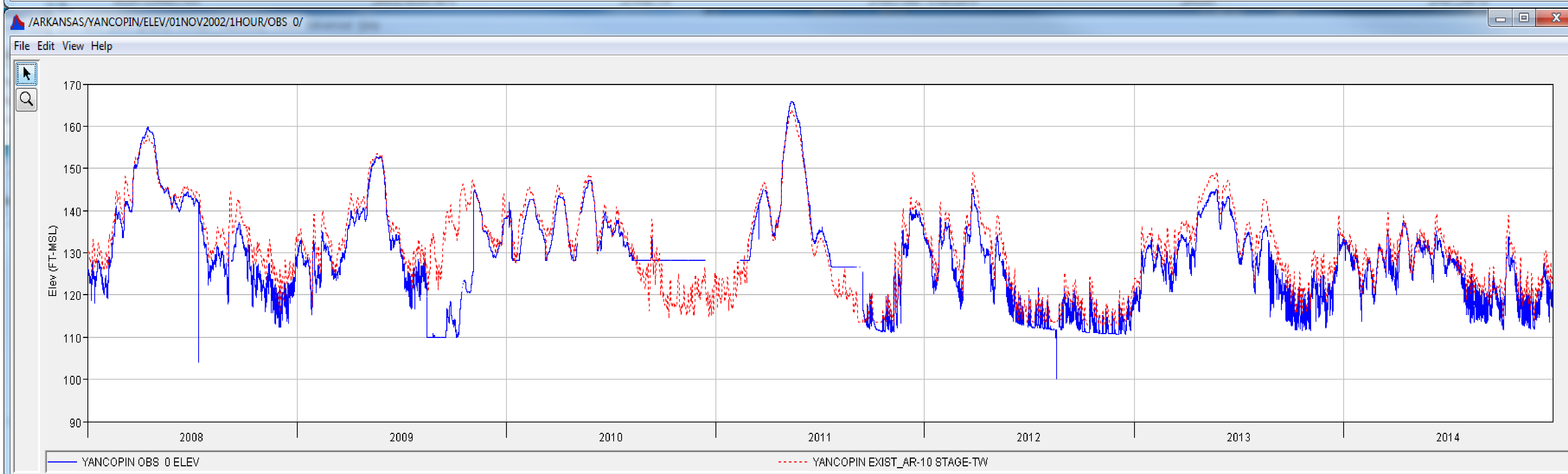
Lock and Dam 2 Tailwater: Arkansas River _______ Observed _ _ _ _ _ _ _ _Modeled


/ARKANSAS/D02/ELEV/01MAR1987/1HOUR/OBS TAILWATER/
File Edit View Help
Elev (FT-MSL)
155
150
145
140
135
130
125
120
115
2000
2001
2002
2003
2004
2005
2006
2007
D02 OBS TAILWATER ELEV
DAM2 TW EXIST_AR-10 STAGE-TW

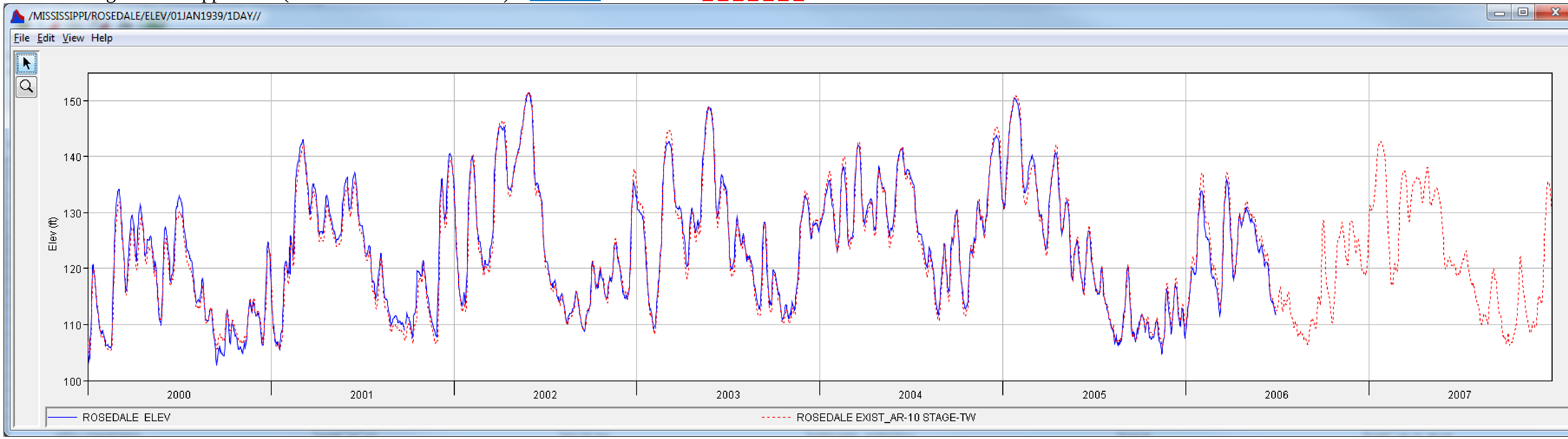

/ARKANSAS/D02/ELEV/01MAR1987/1HOUR/OBS TAILWATER/
File Edit View Help
Elev (FT-MSL)
170
160
150
140
130
120
110
2008
2009
2010
2011
2012
2013
2014
D02 OBS TAILWATER ELEV
DAM2 TW EXIST_AR-10 STAGE-TW

Yancopin Gage: Arkansas River ________ Observed _ _ _ _ _ _ _ _Modeled



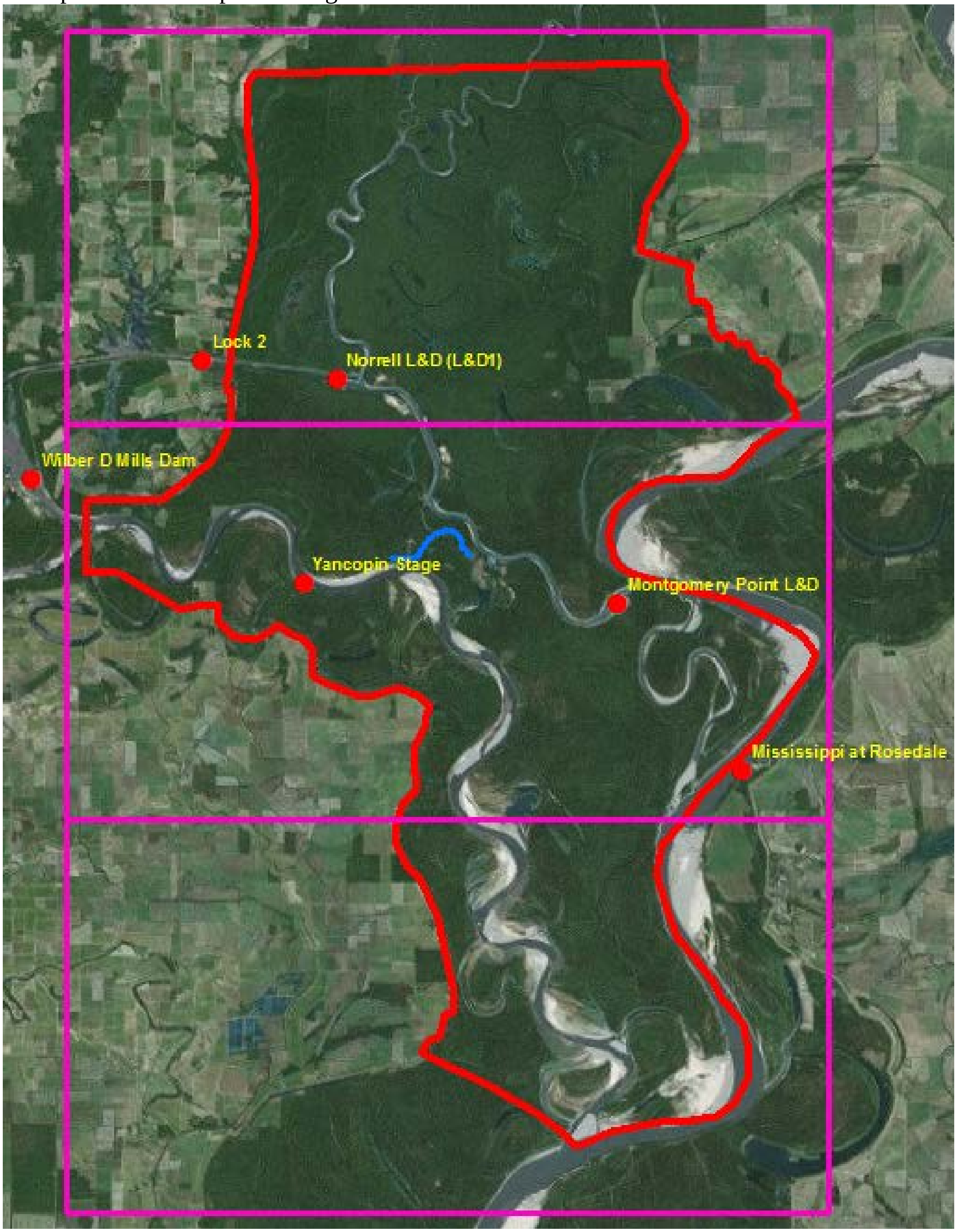


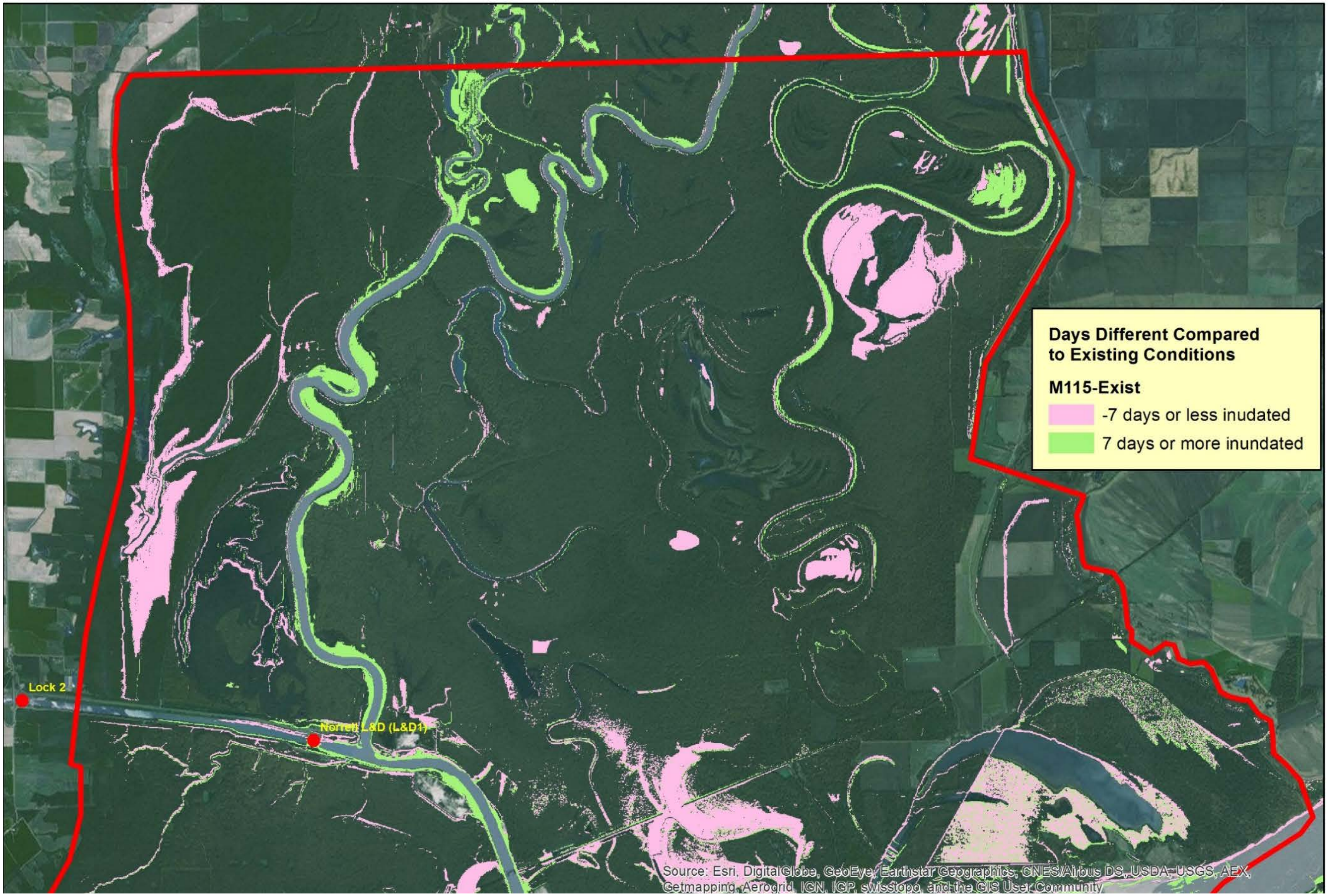
Rosedale Gage: Mississippi River (take out of service in 2006) ________ Observed _ _ _ _ _ _ _ _Modeled



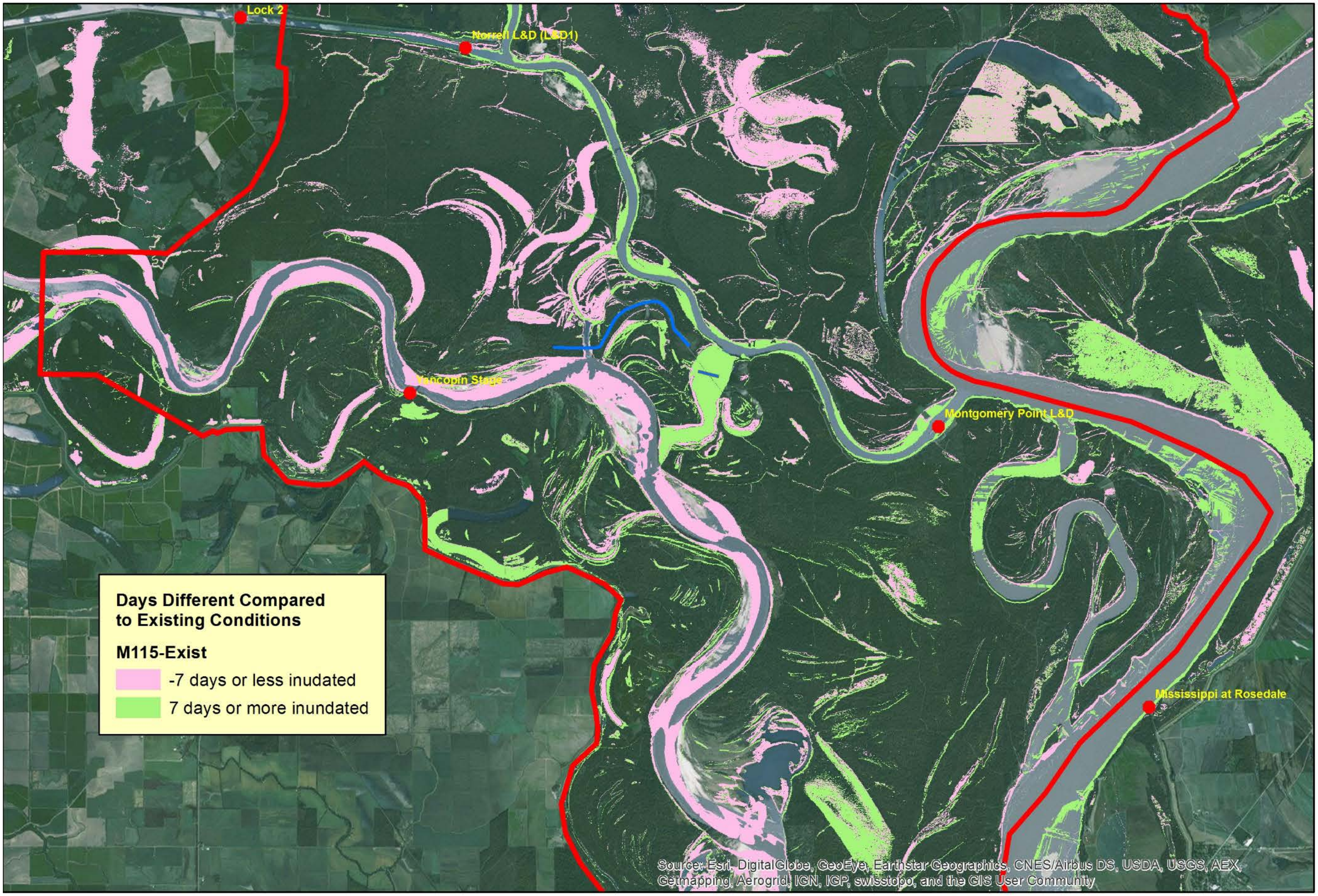
Appendix B Seven Days Wetter And Drier Inundation Maps

Each plot is broken up into 3 segments as indicated in below.



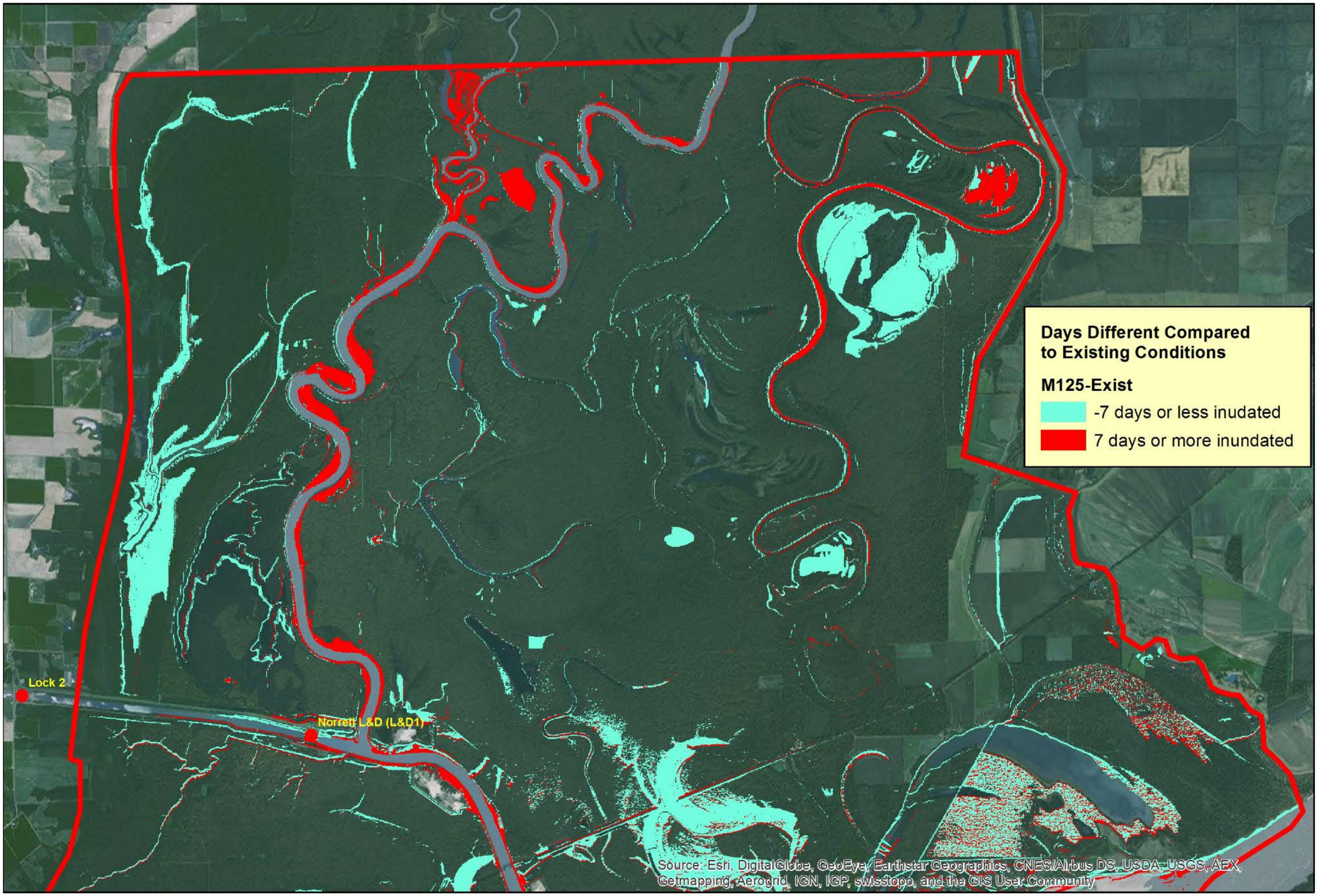


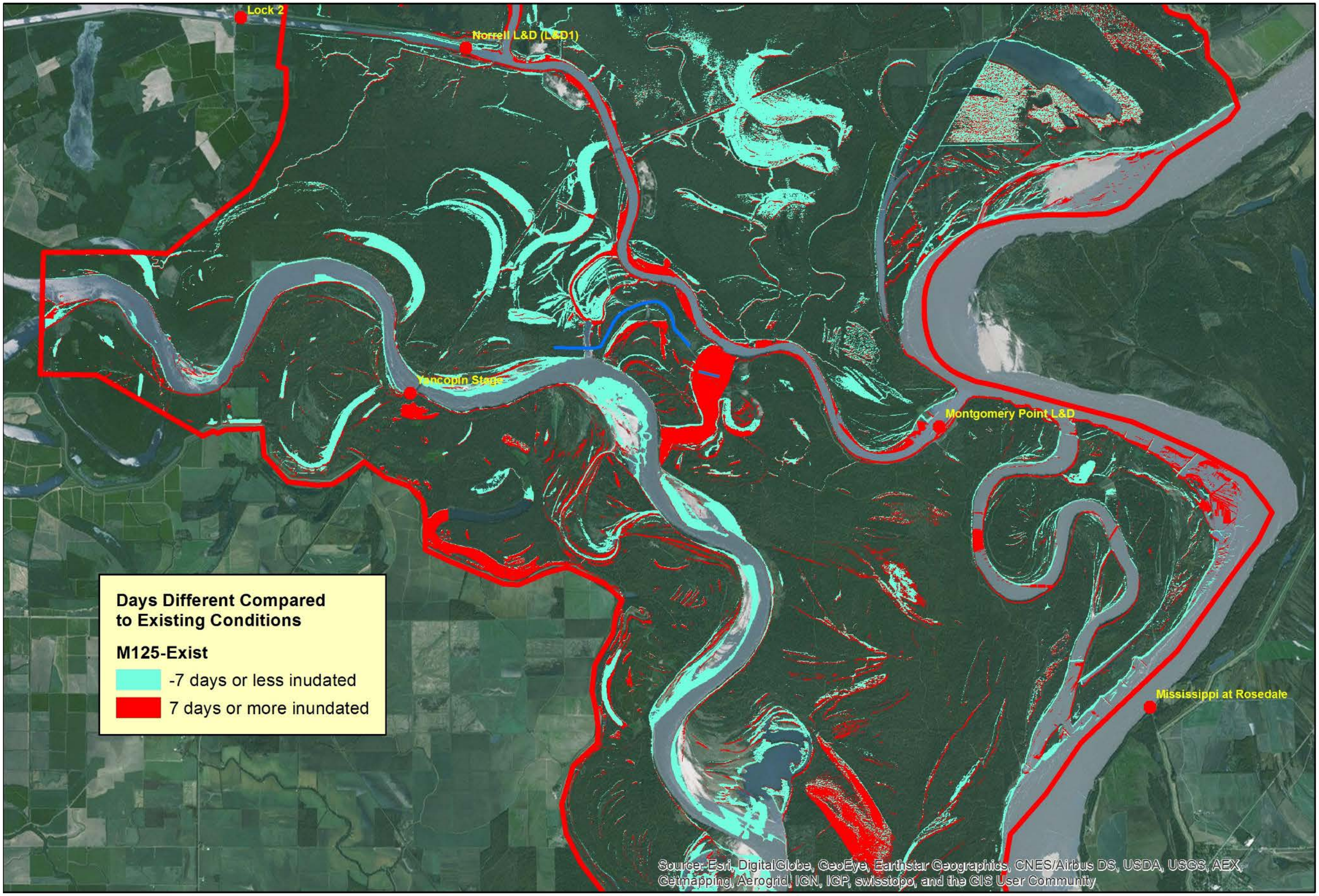
Days Different Compared to Existing Conditions
M115-Exist
-7 days or less inudated
7 days or more inundated
Lock 2
Norrell L&D (L&D1)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

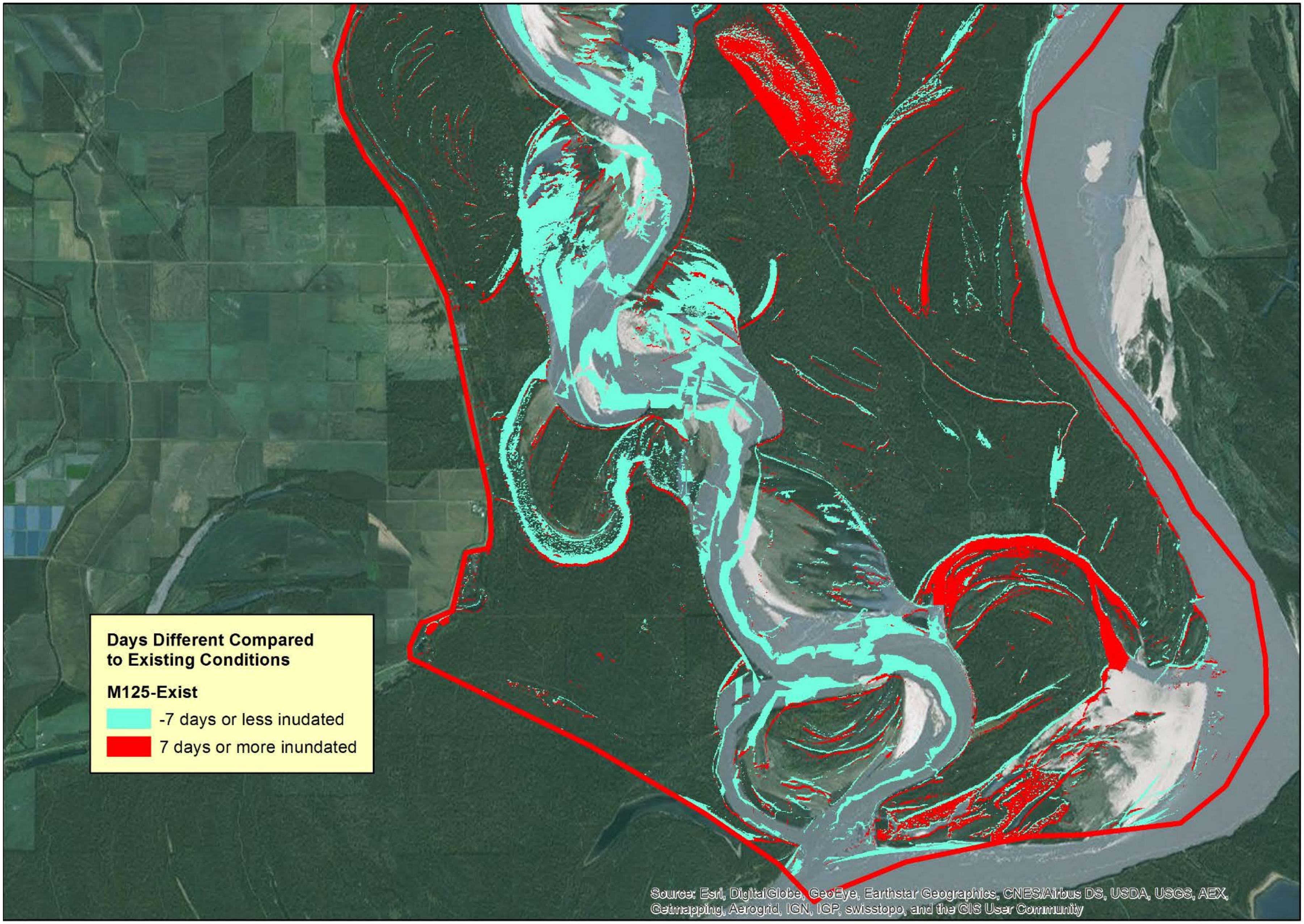


Lock 2
Norrell L&D (L&D1)
Vancopin Stage
Montgomery Point L&D
Mississippi at Rosedale
Days Different Compared
to Existing Conditions
M115-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

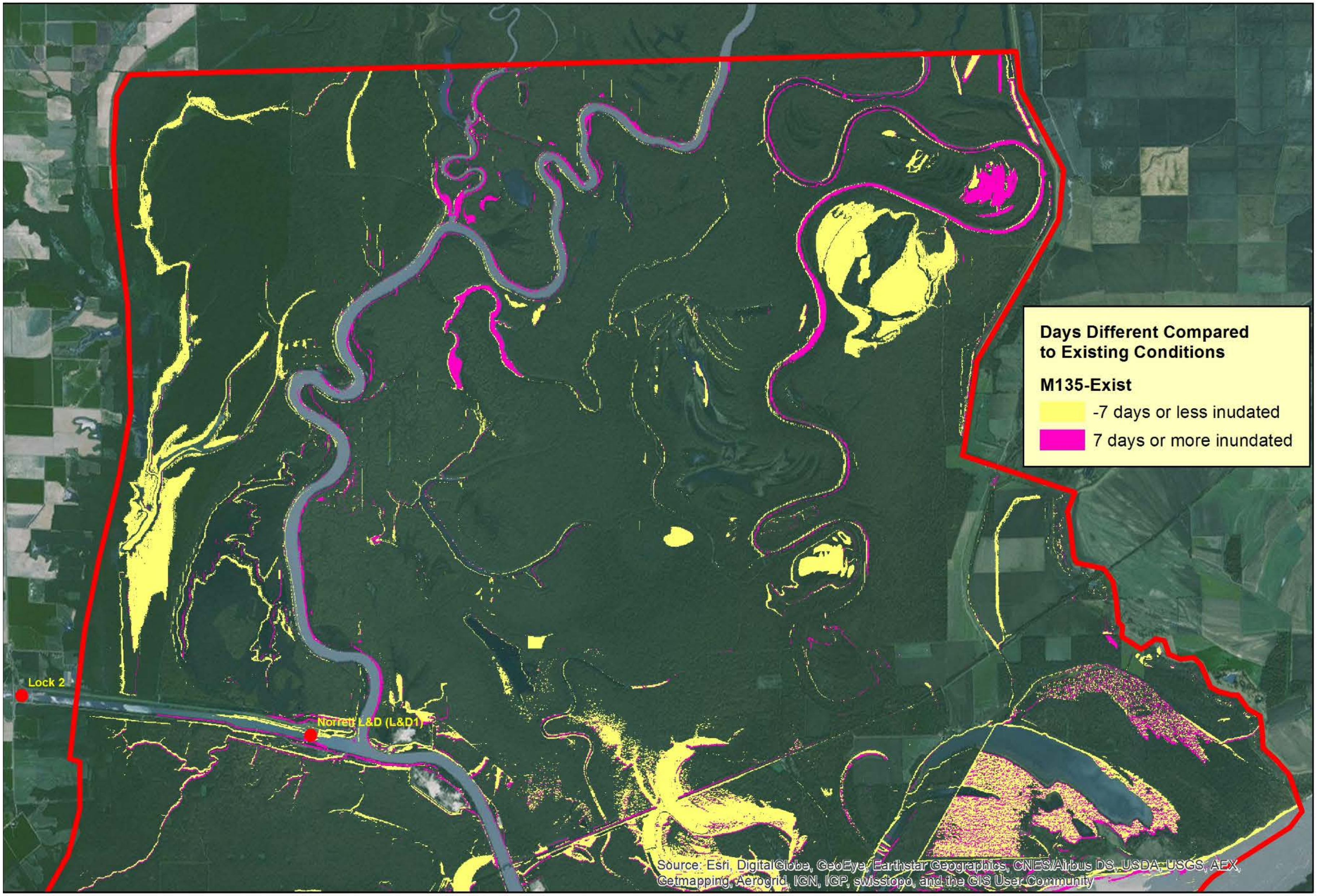

Days Different Compared
to Existing Conditions
M115-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Days Different Compared
to Existing Conditions
M125-Exist
-7 days or less inundated
7 days or more inundated
Lock 2
Norrell L&D (L&D1)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

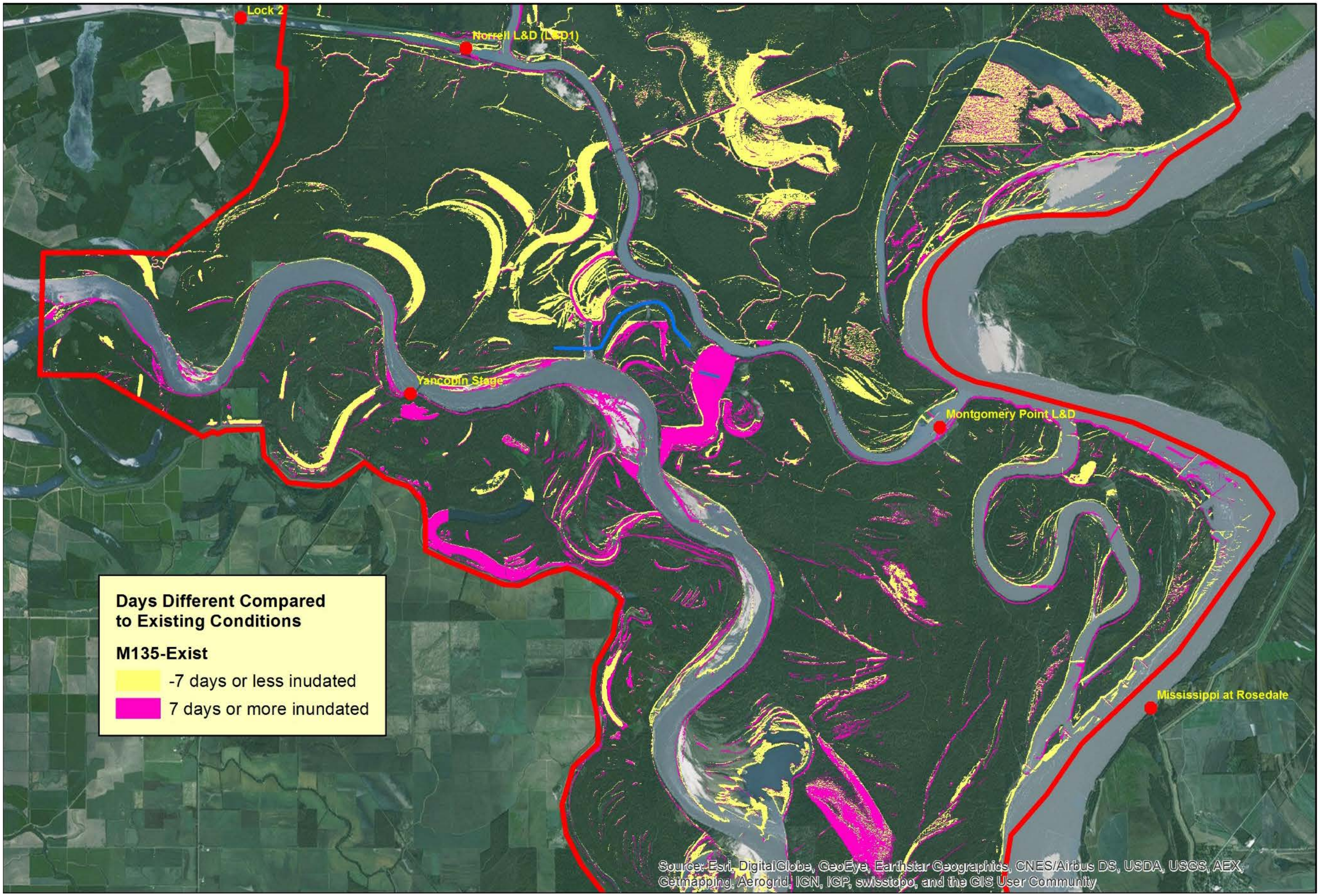

Lock 2
Norrell L&D (L&D1)
Yancopin Stage
Montgomery Point L&D
Mississippi at Rosedale
Days Different Compared
to Existing Conditions
M125-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



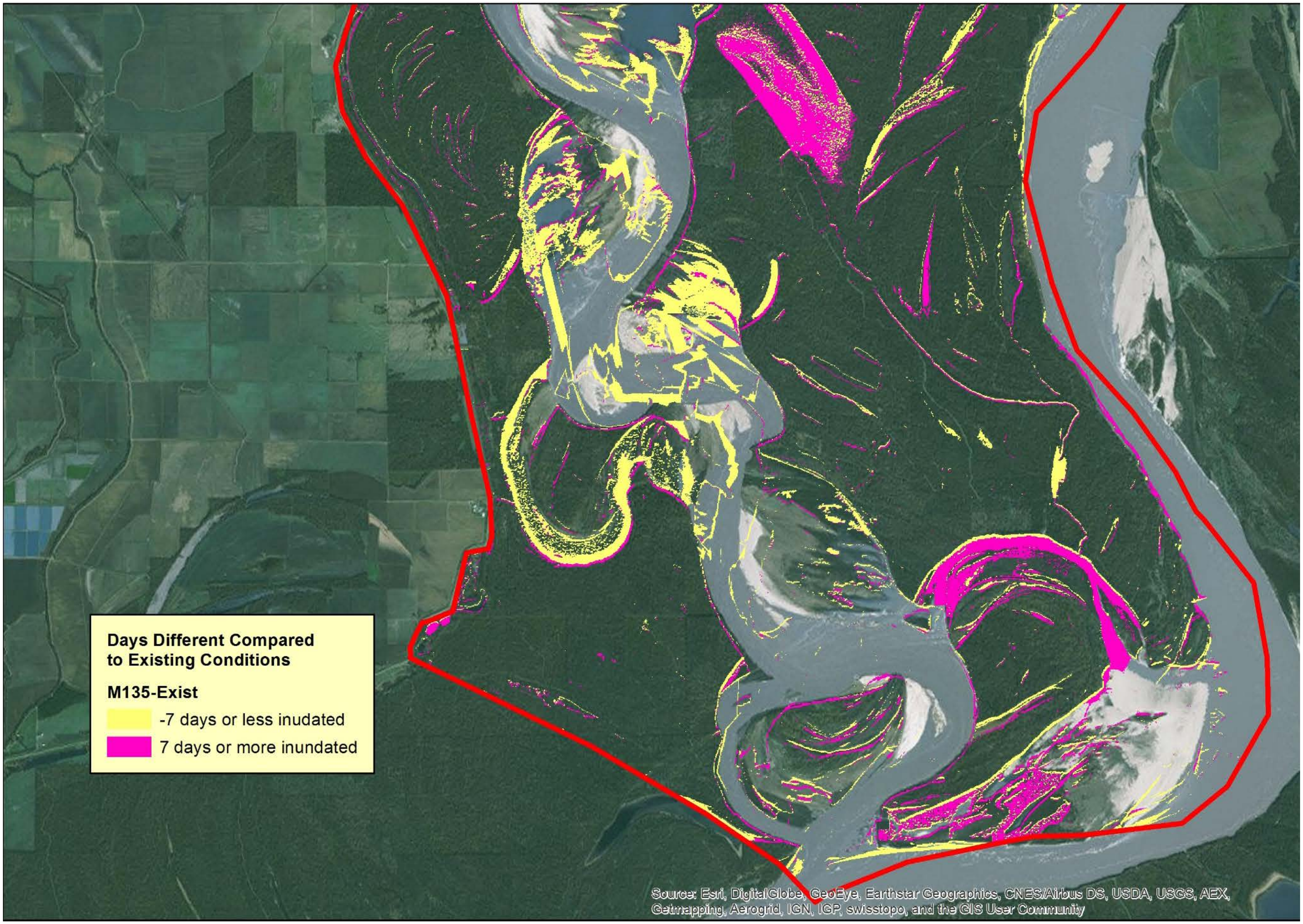
Days Different Compared
to Existing Conditions
M125-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



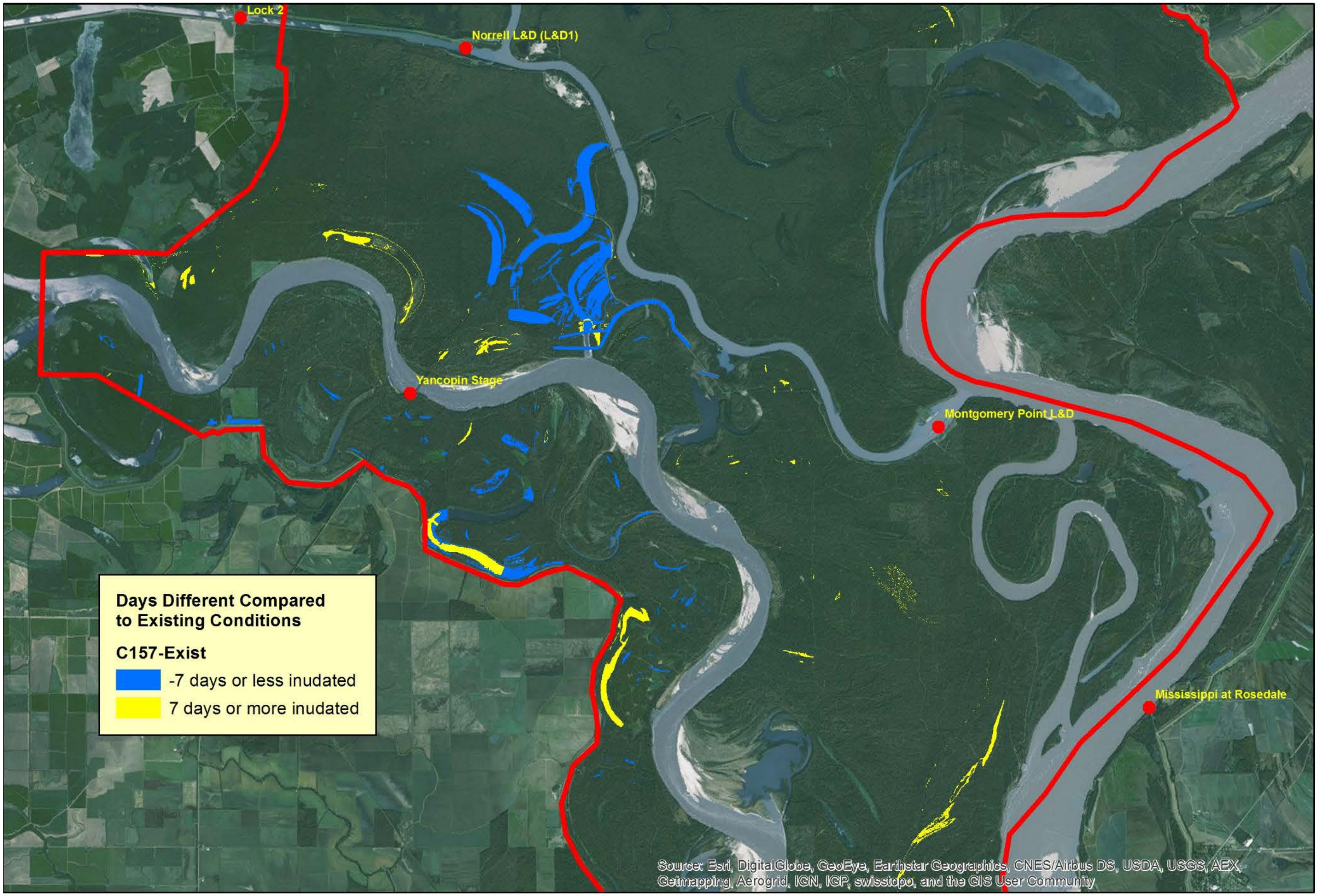
Days Different Compared to Existing Conditions
M135-Exist
-7 days or less inudated
7 days or more inundated
Lock 2
Norrell L&D (L&D1)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Lock 2
Norrell L&D (L&D1)
Yancopin Stage
Montgomery Point L&D
Mississippi at Rosedale
Days Different Compared
to Existing Conditions
M135-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

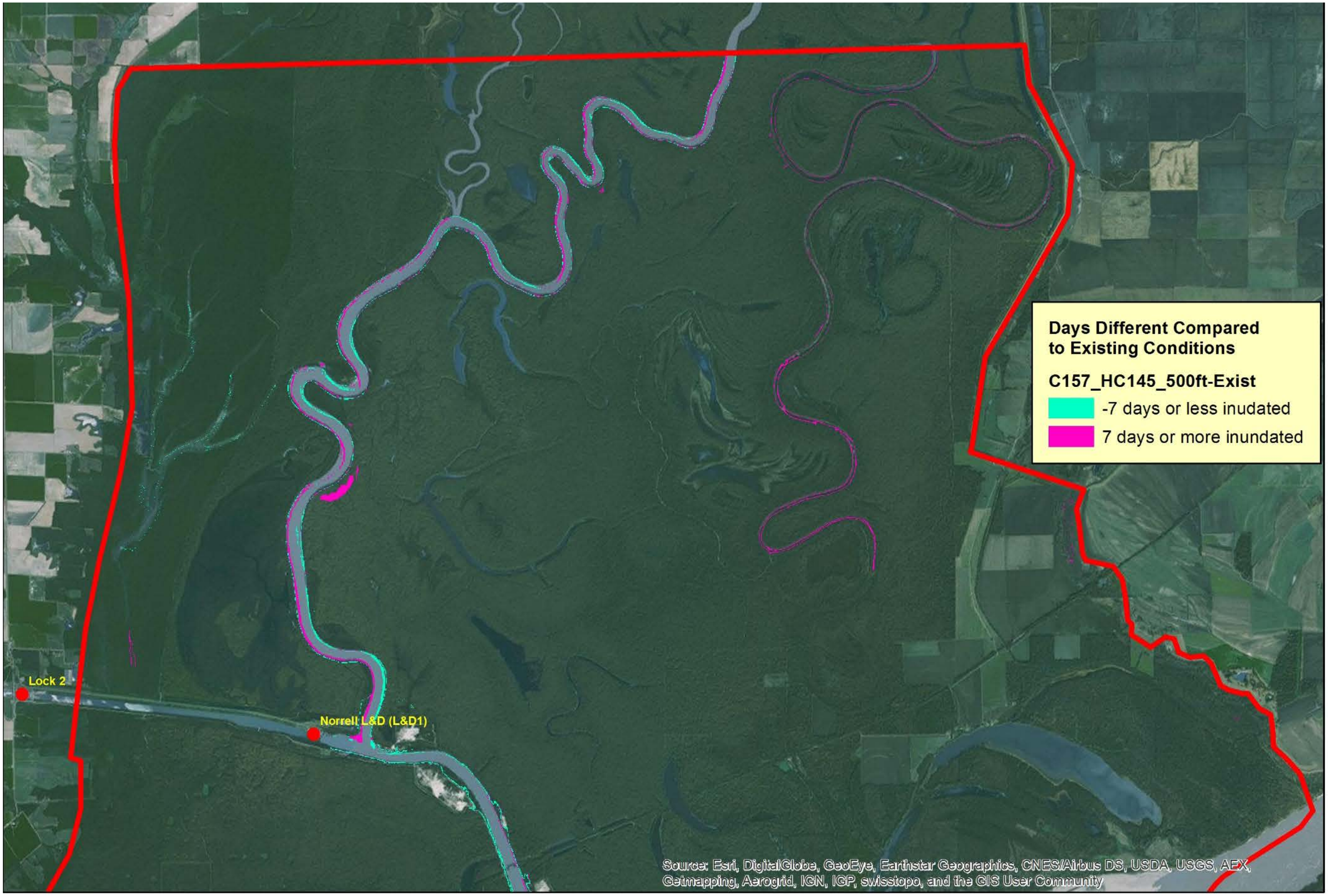

Days Different Compared to Existing Conditions
M135-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

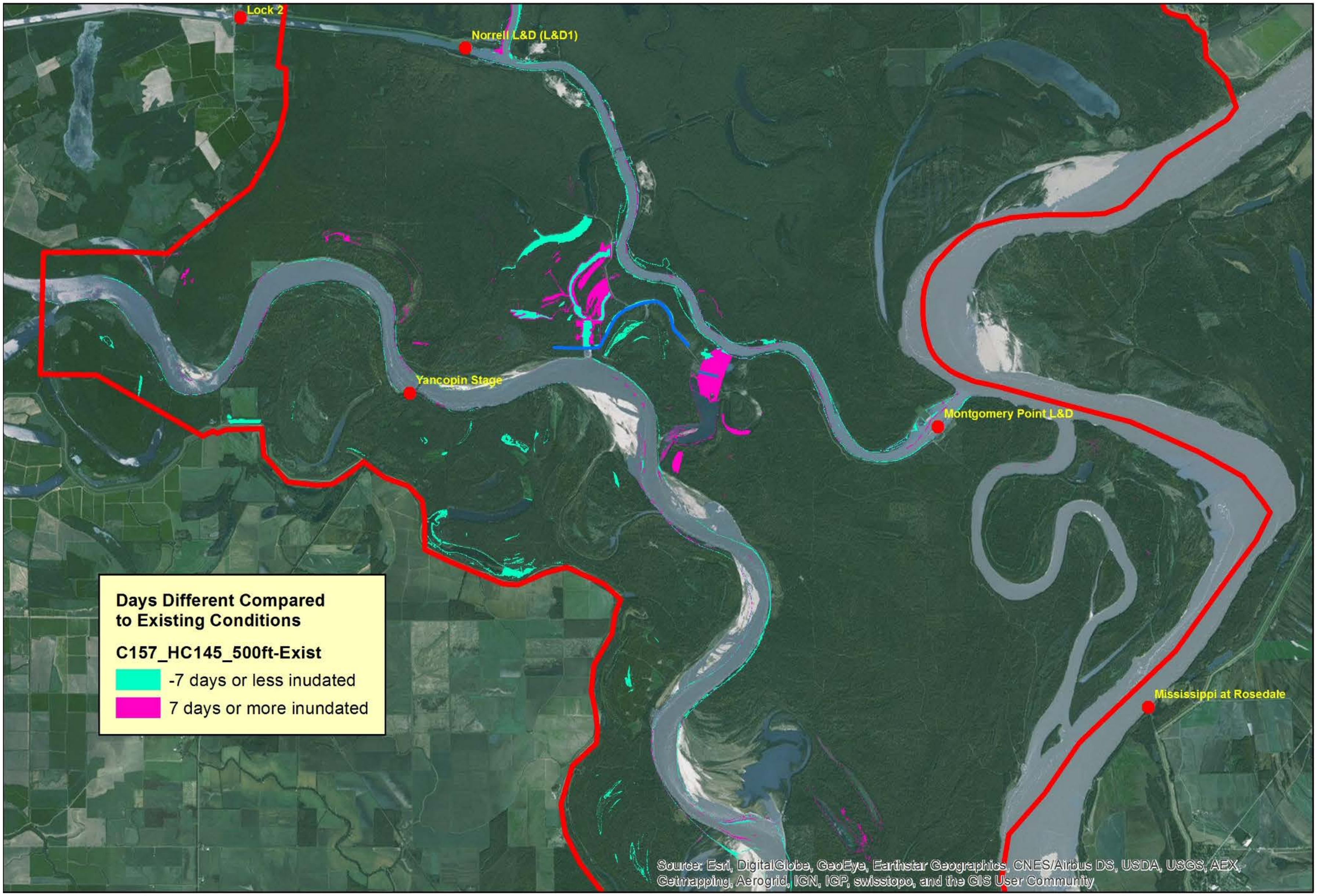

Days Different Compared to Existing Conditions
C157-Exist
-7 days or less inudated
7 days or more inudated
Lock 2
Norrell L&D (L&D1)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



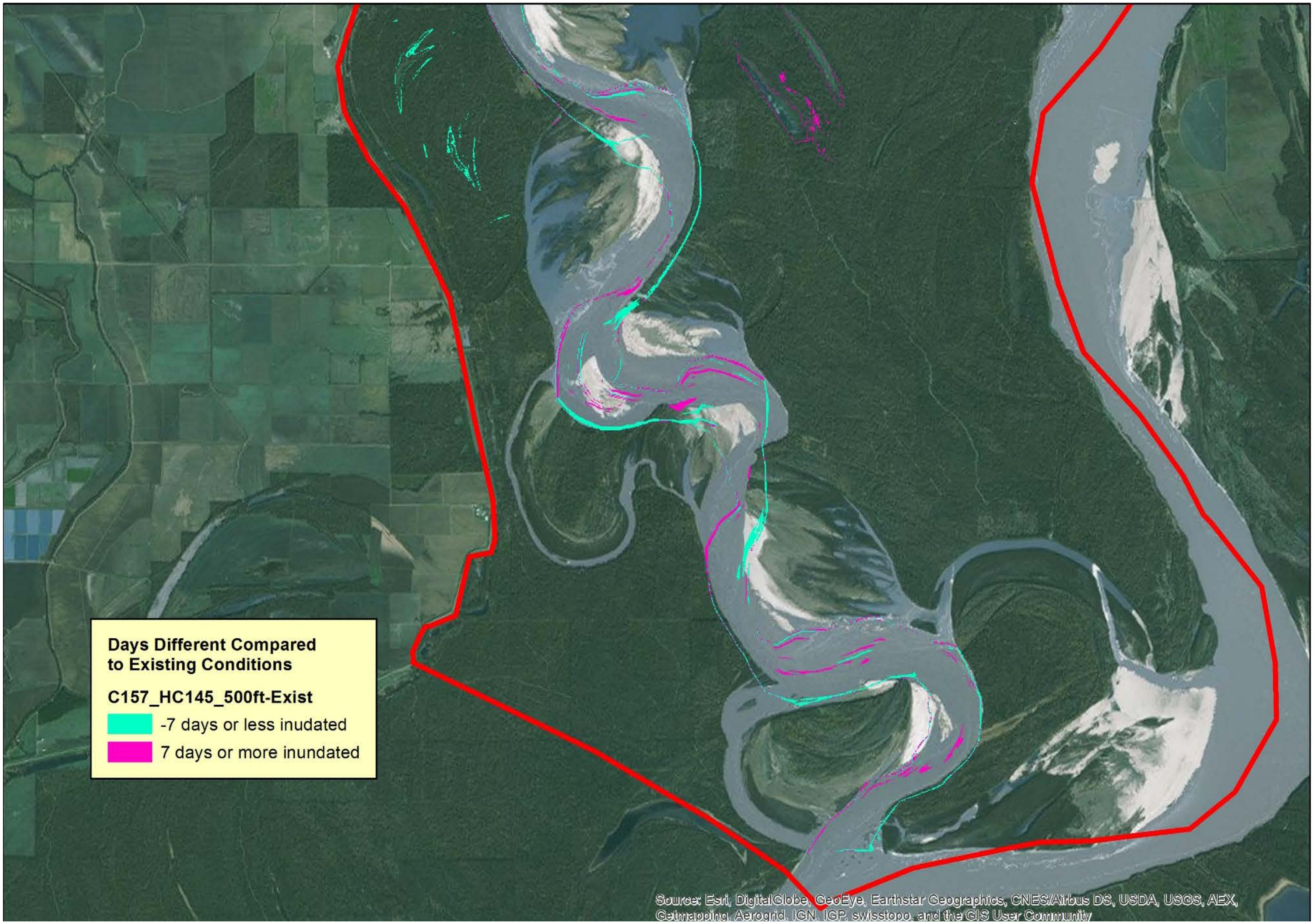
Lock 2
Norrell L&D (L&D1)
Yancopin Stage
Montgomery Point L&D
Mississippi at Rosedale
Days Different Compared
to Existing Conditions
C157-Exist
-7 days or less inudated
7 days or more inudated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

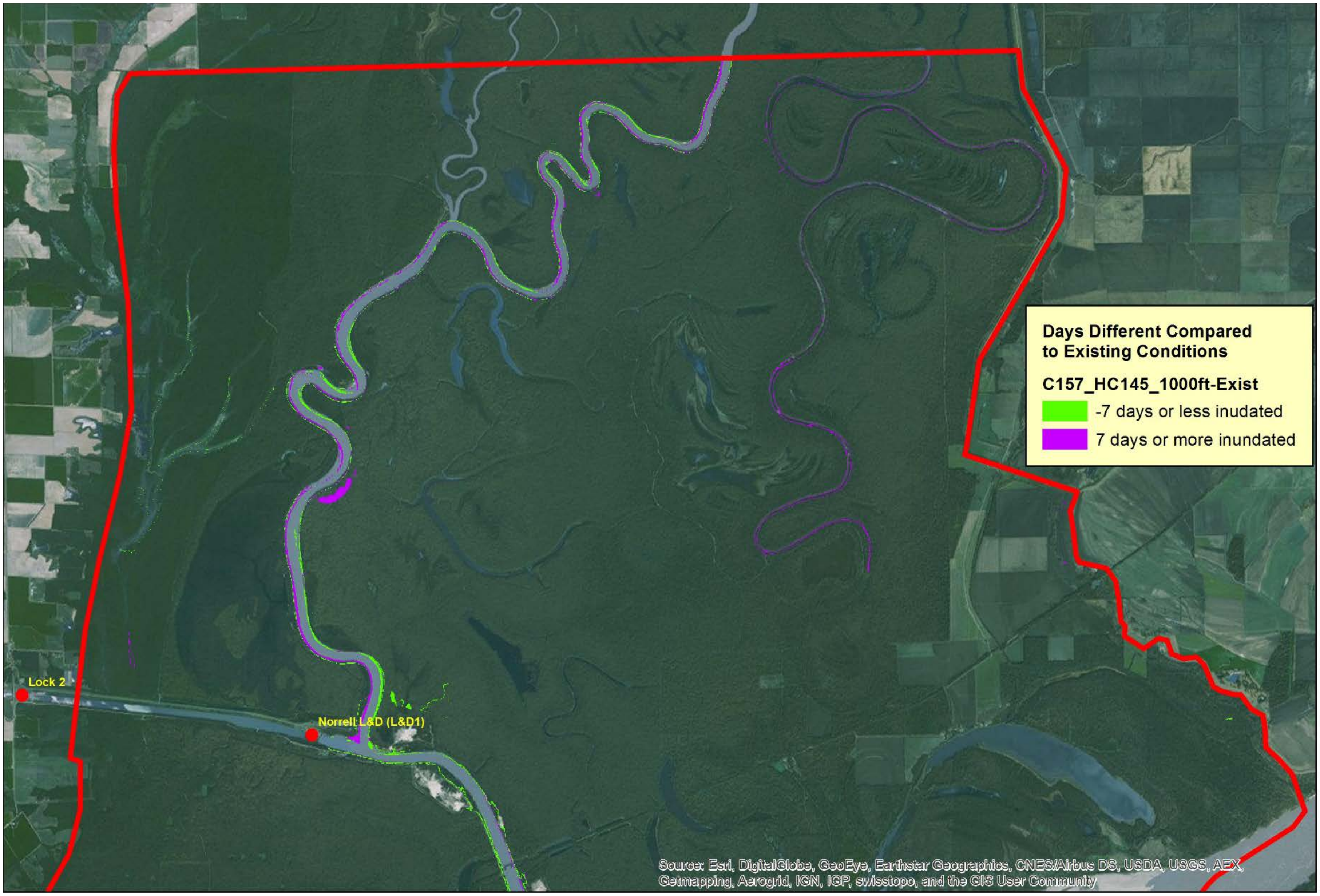
Days Different Compared to Existing Conditions
C157-Exist
-7 days or less inudated
7 days or more inudated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

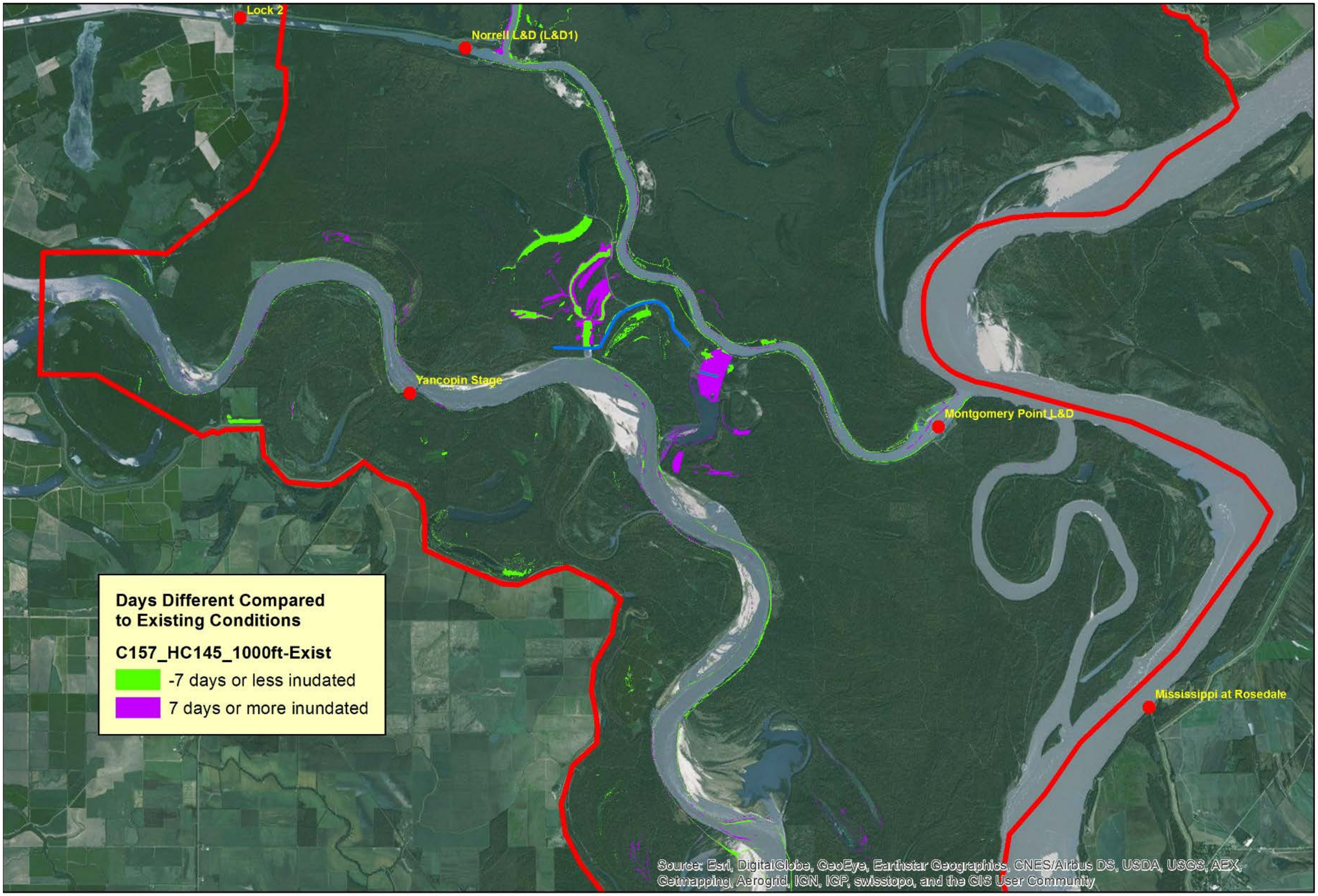

Days Different Compared
to Existing Conditions
C157_HC145_500ft-Exist
-7 days or less inudated
7 days or more inundated
Lock 2
Norrell L&D (L&D1)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Lock 2
Norrell L&D (L&D1)
Yancopin Stage
Montgomery Point L&D
Mississippi at Rosedale
Days Different Compared
to Existing Conditions
C157_HC145_500ft-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community


Days Different Compared
to Existing Conditions
C157_HC145_500ft-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

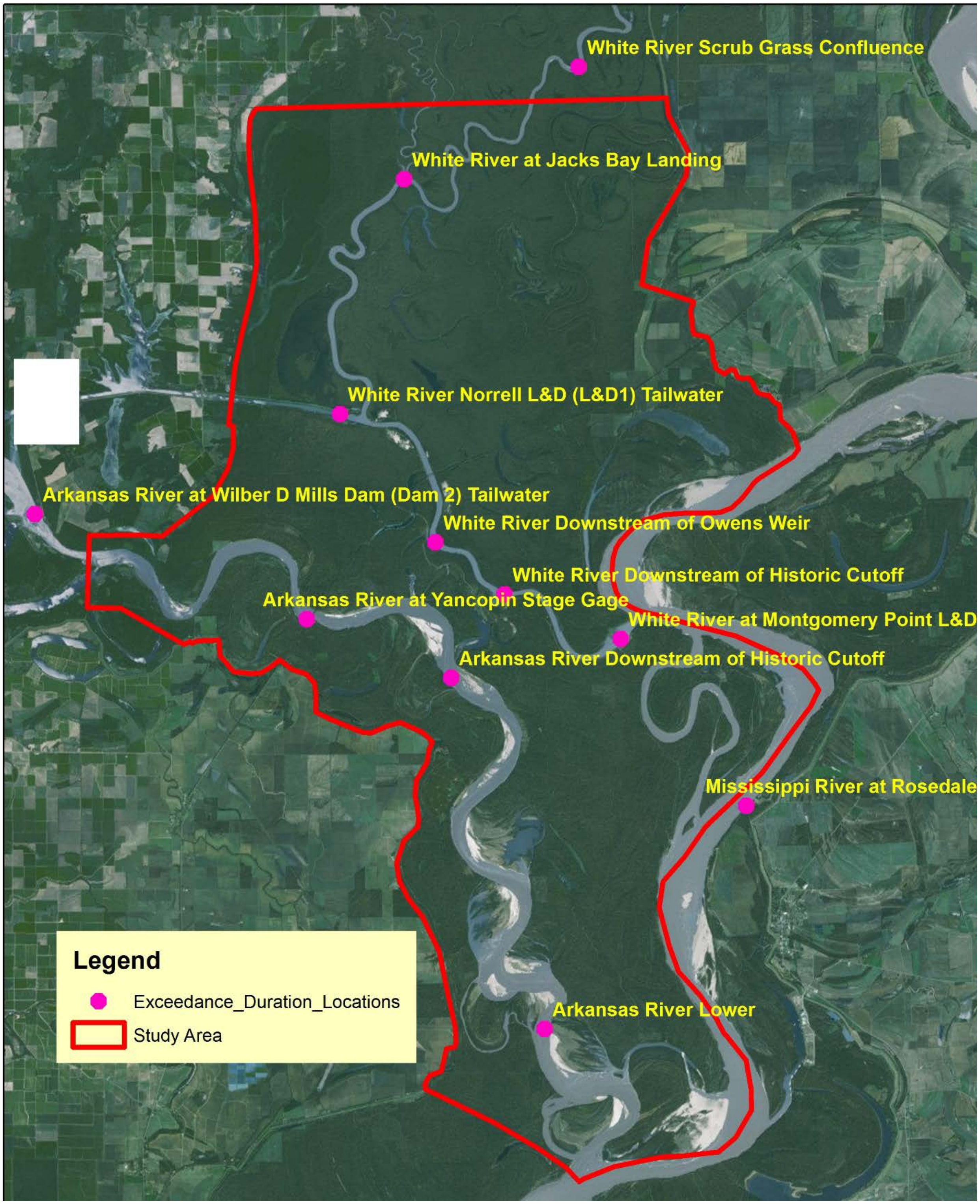

Days Different Compared to Existing Conditions
C157_HC145_1000ft-Exist
-7 days or less inudated
7 days or more inundated
Lock 2
Norrell L&D (L&D1)
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community



Lock 2
Norrell L&D (L&D1)
Yancopin Stage
Montgomery Point L&D
Mississippi at Rosedale
Days Different Compared to Existing Conditions
C157_HC145_1000ft-Exist
-7 days or less inudated
7 days or more inundated
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

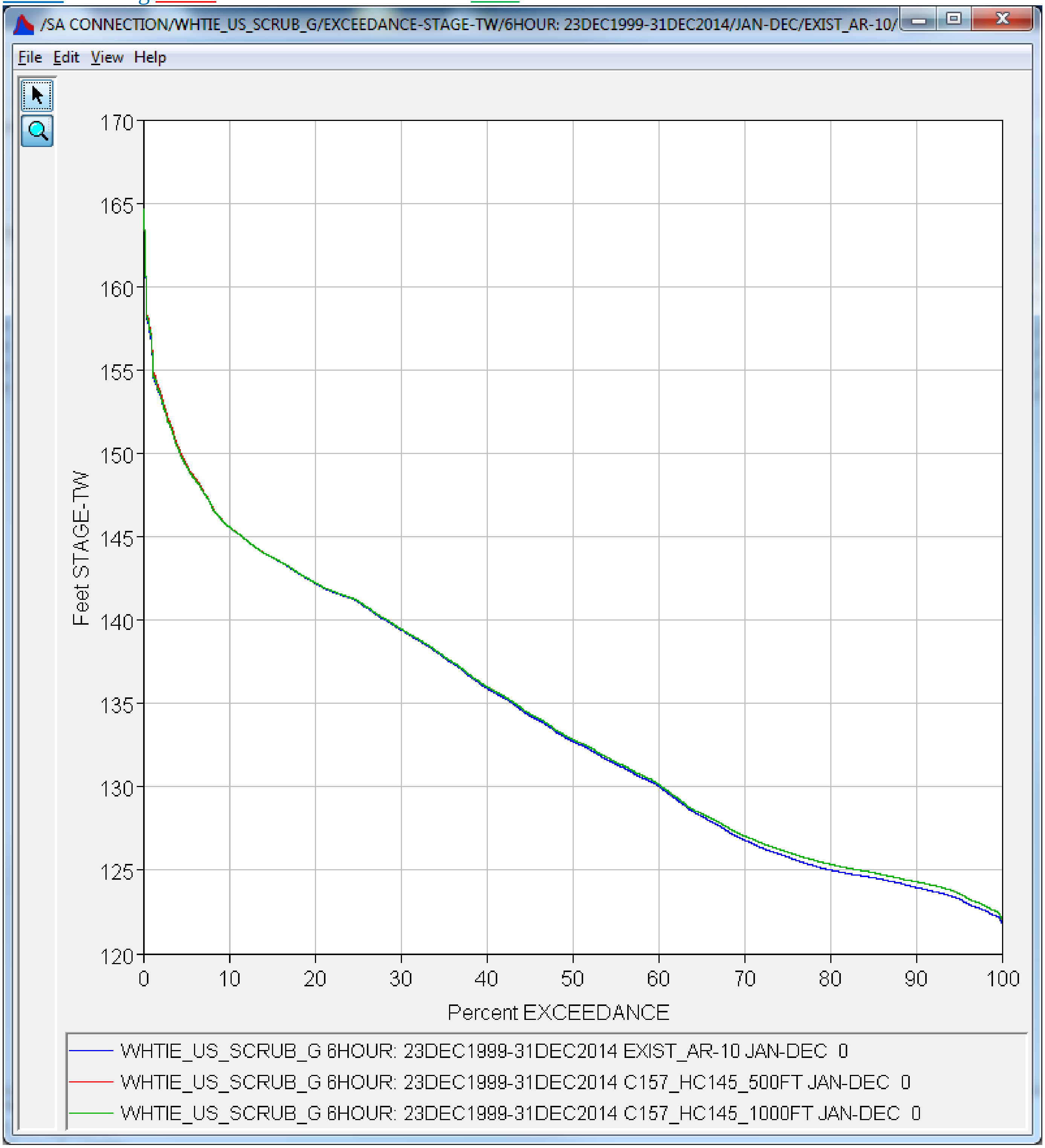
Appendix C Exceedance Duration Analysis

Exceedance Duration Locations



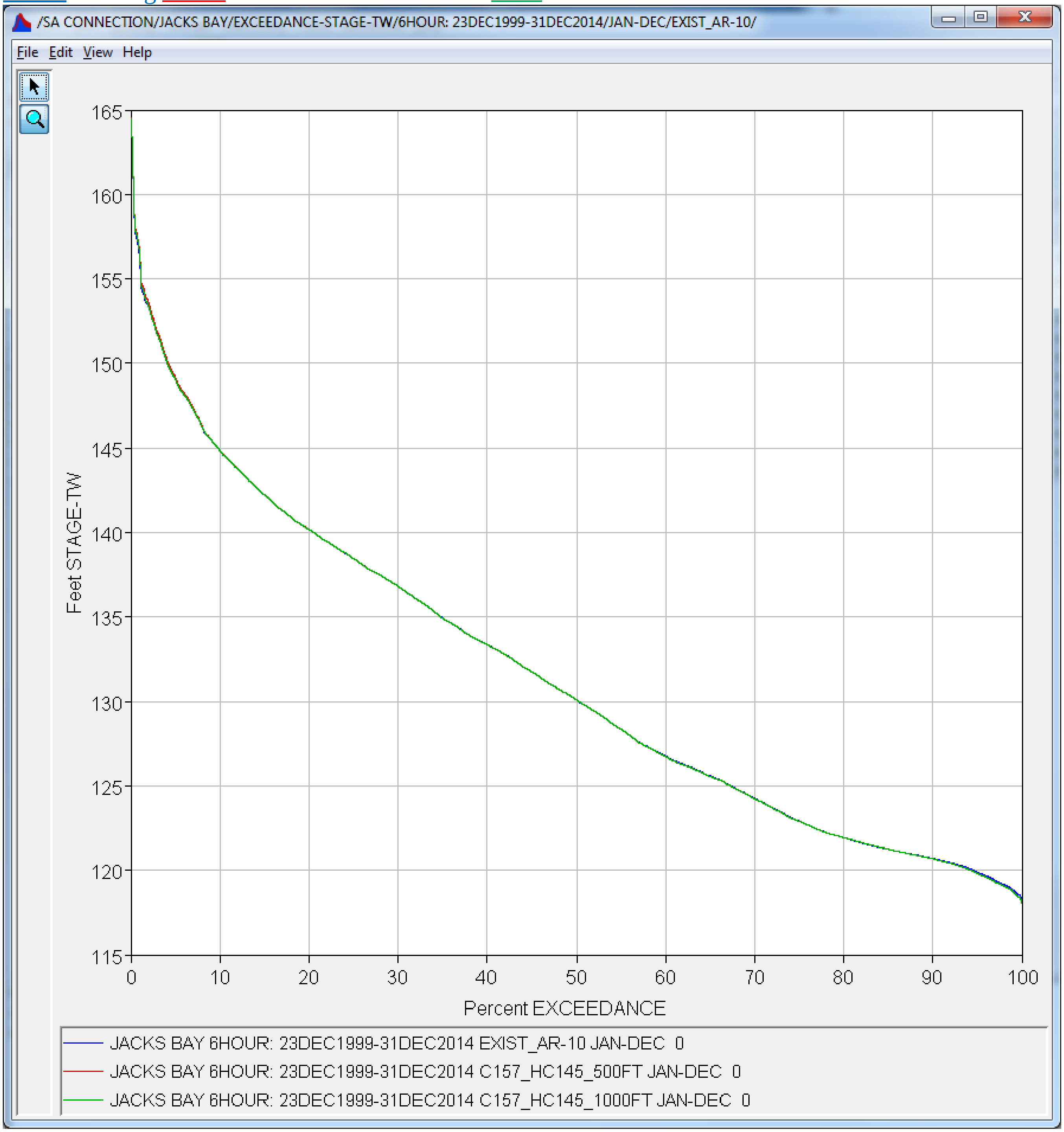
White River Confluence with Scrub Grass

______ Existing ______C157 HC145 500ft Wide ____C157 HC145 1000ft wide



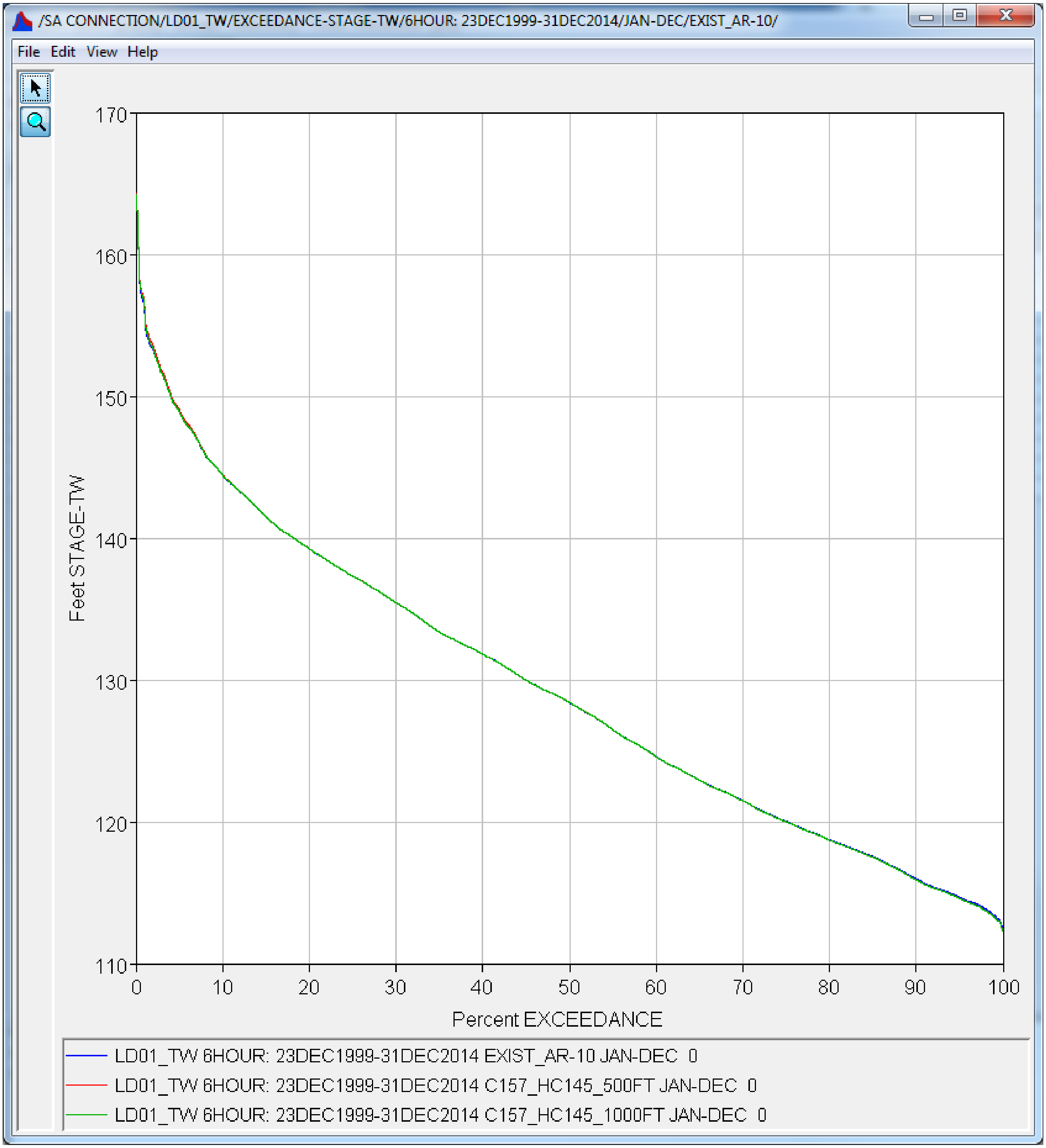
White River at Jacks Bay Landing

______ Existing ______C157 HC145 500ft Wide ____C157 HC145 1000ft wide

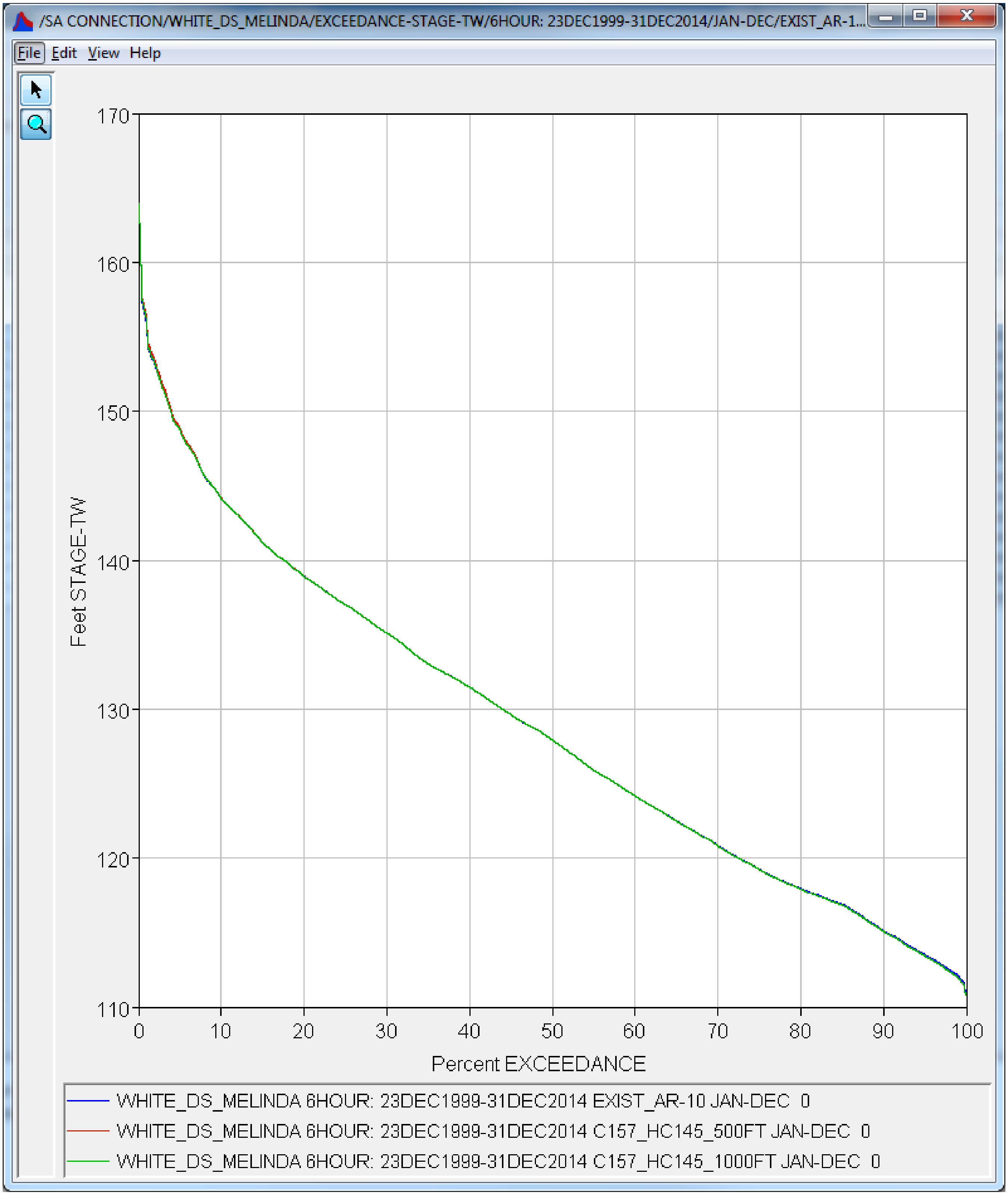


White River Norrell L&D (Lock and Dam 1) Tailwater

______ Existing ______C157 HC145 500ft Wide ____C157 HC145 1000ft wide

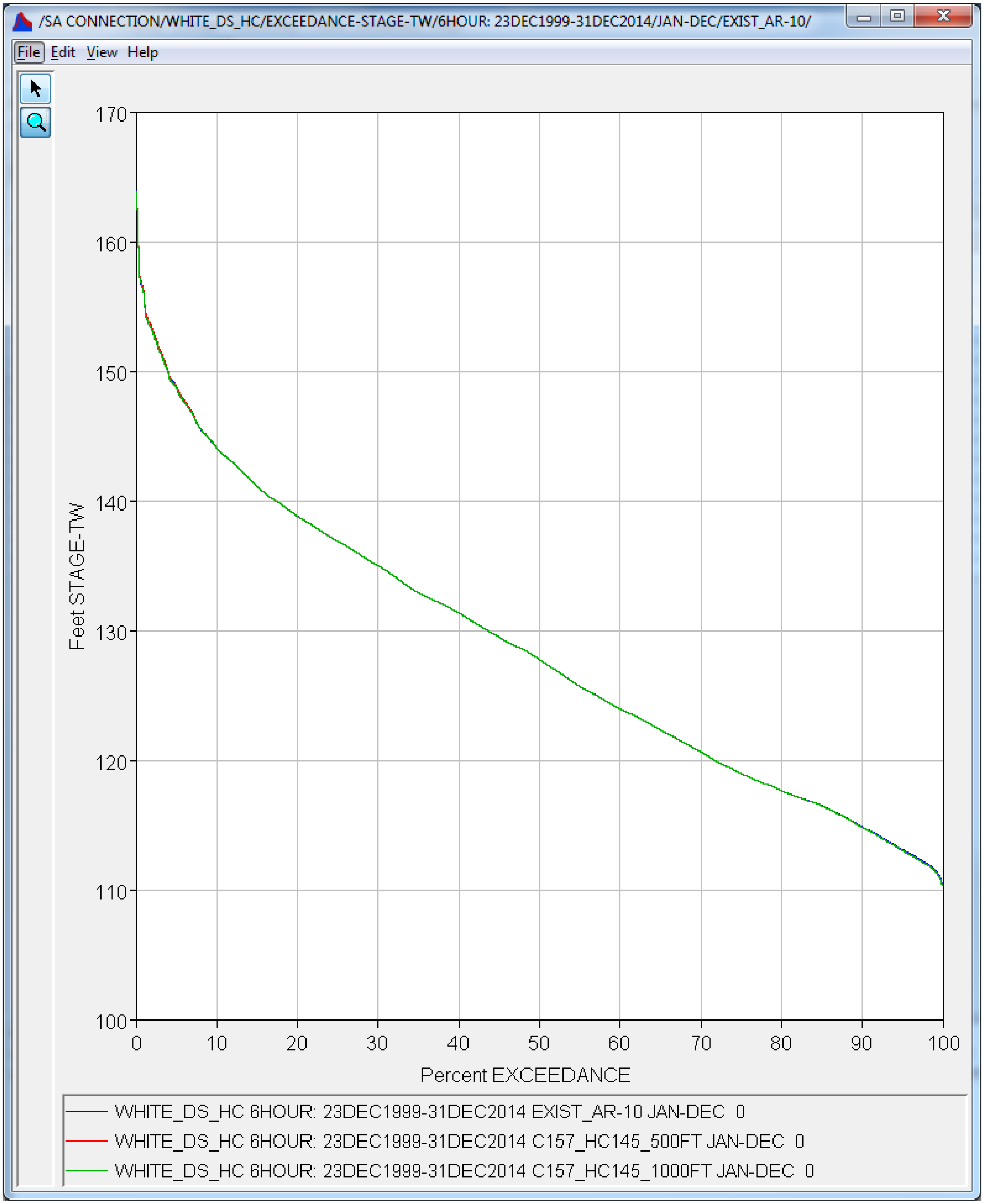


White River Downstream of Owens Weir
_____ Existing _____C157 HC145 500ft Wide ____C157 HC145 1000ft wide



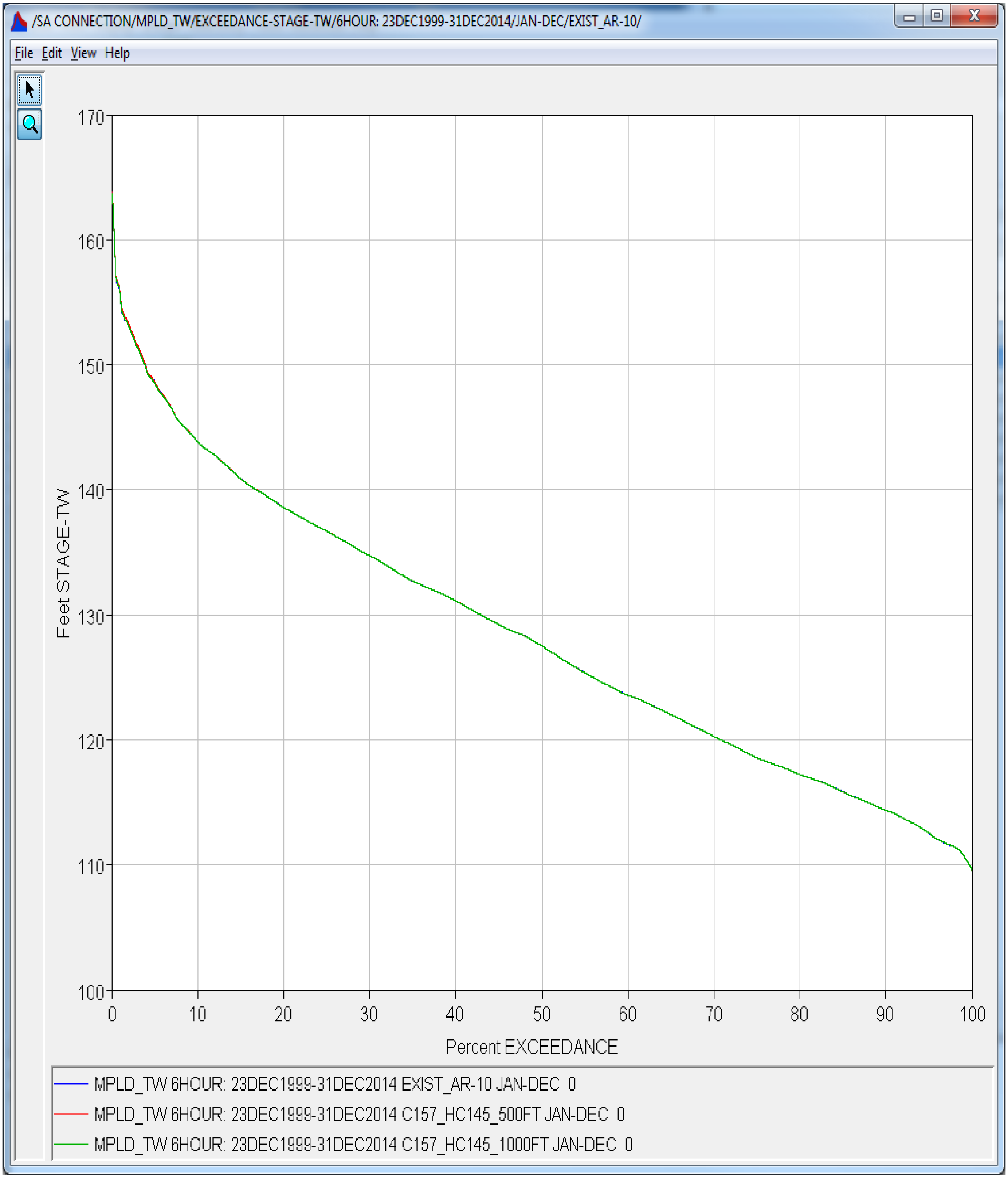
White River Downstream of Historic Cutoff

_____ Existing _____C157 HC145 500ft Wide ____C157 HC145 1000ft wide

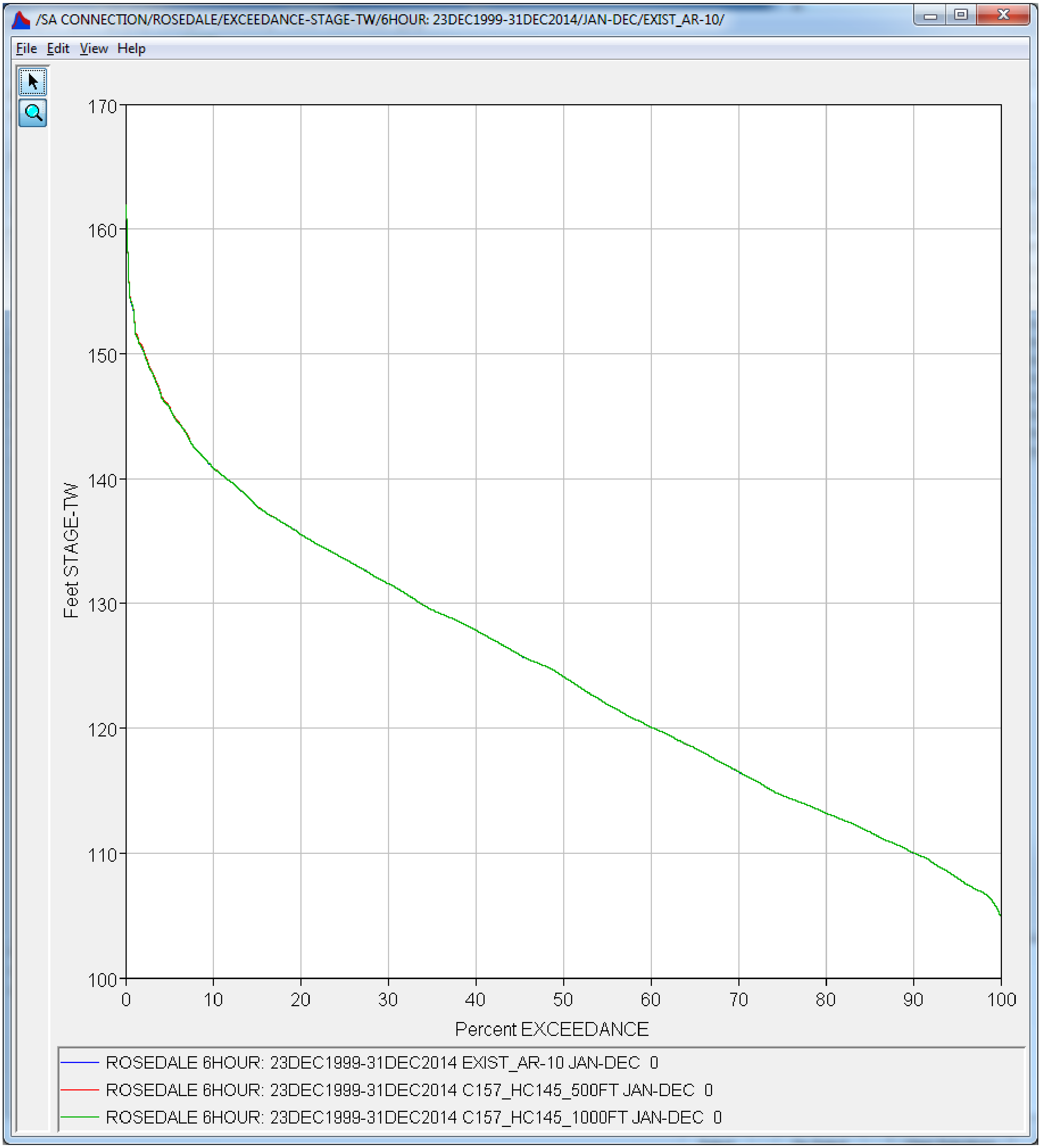


White River at Montgomery Point Lock and Dam Tailwater

______ Existing _____C157 HC145 500ft Wide ____C157 HC145 1000ft wide

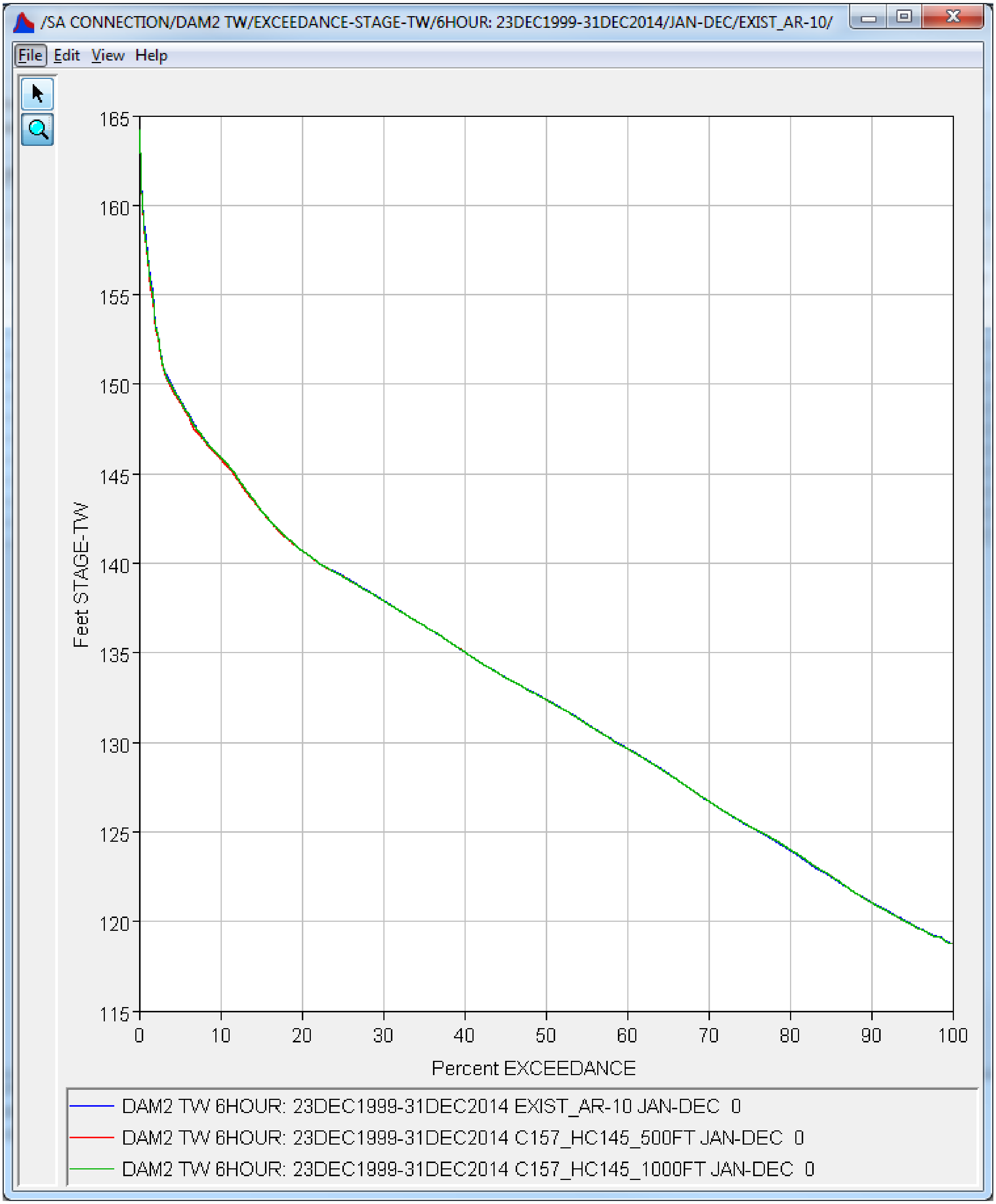


Mississippi River at Rosedale
______ Existing ______C157 HC145 500ft Wide ____C157 HC145 1000ft wide



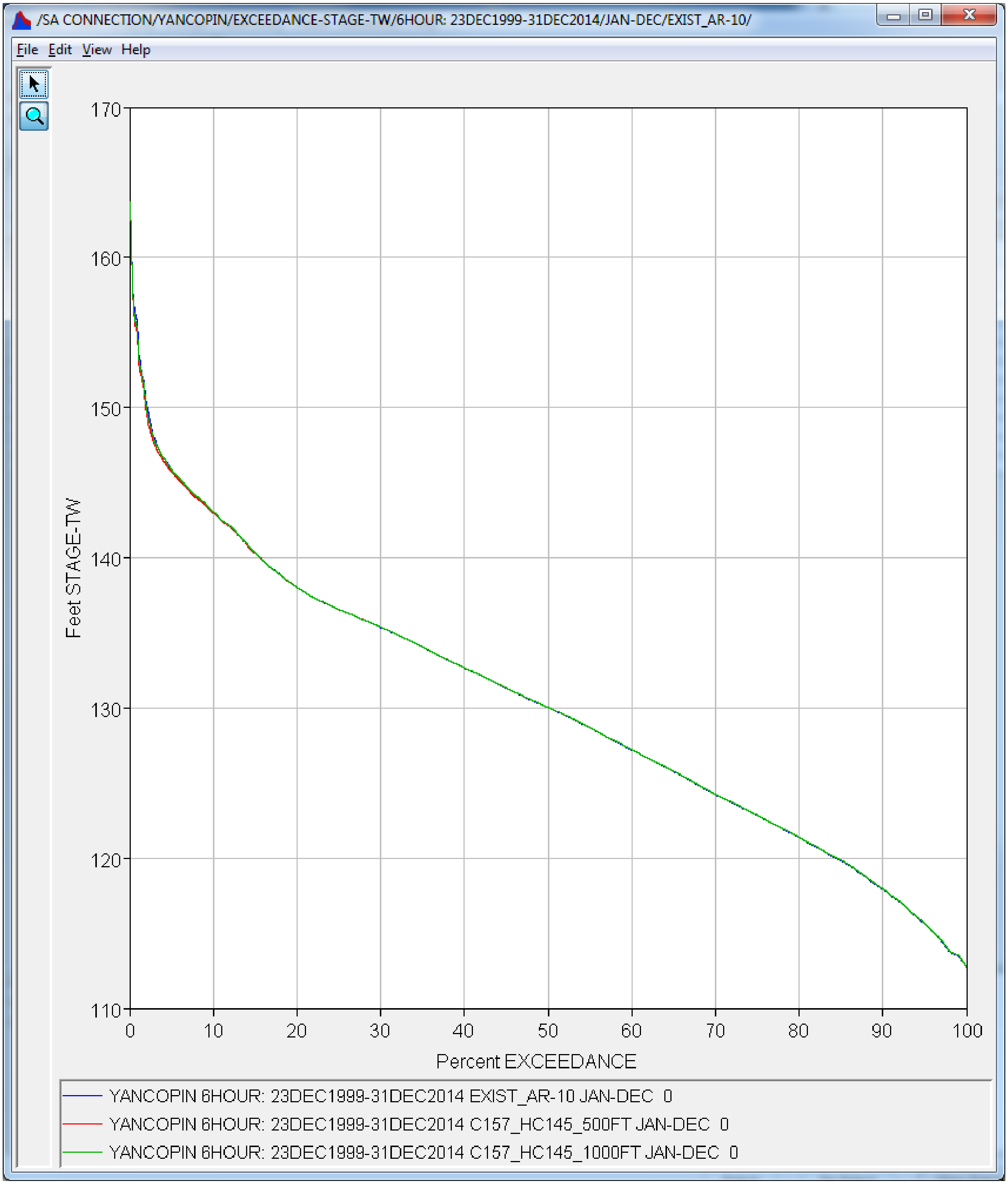
Arkansas River at Wilbur D. Mills (Dam 2) Tailwater

_____ Existing _____C157 HC145 500ft Wide ____C157 HC145 1000ft wide



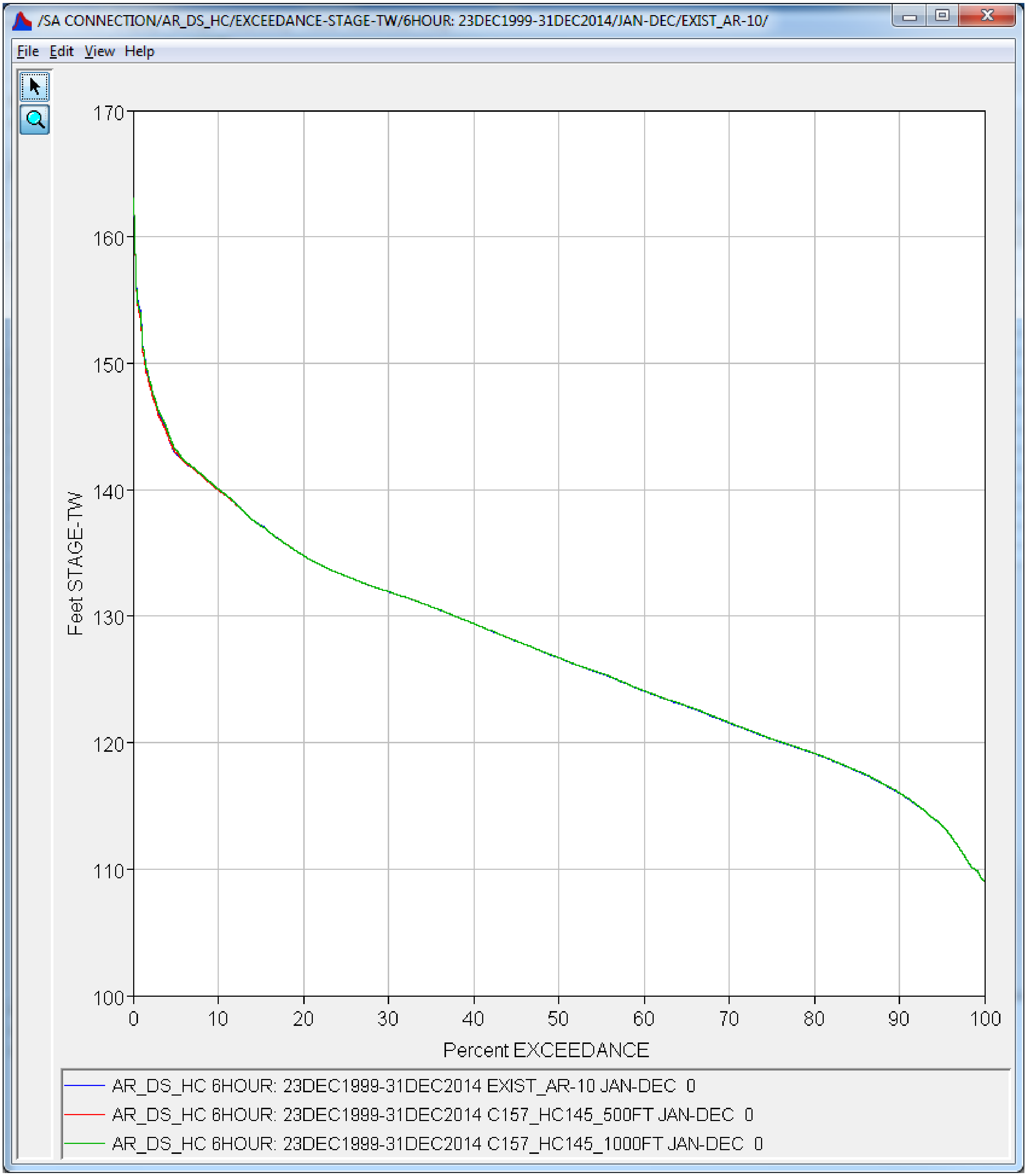
Arkansas River at Yancopin Stage Gage

______ Existing ______C157 HC145 500ft Wide ____C157 HC145 1000ft wide



Arkansas River Downstream of Historic Cutoff

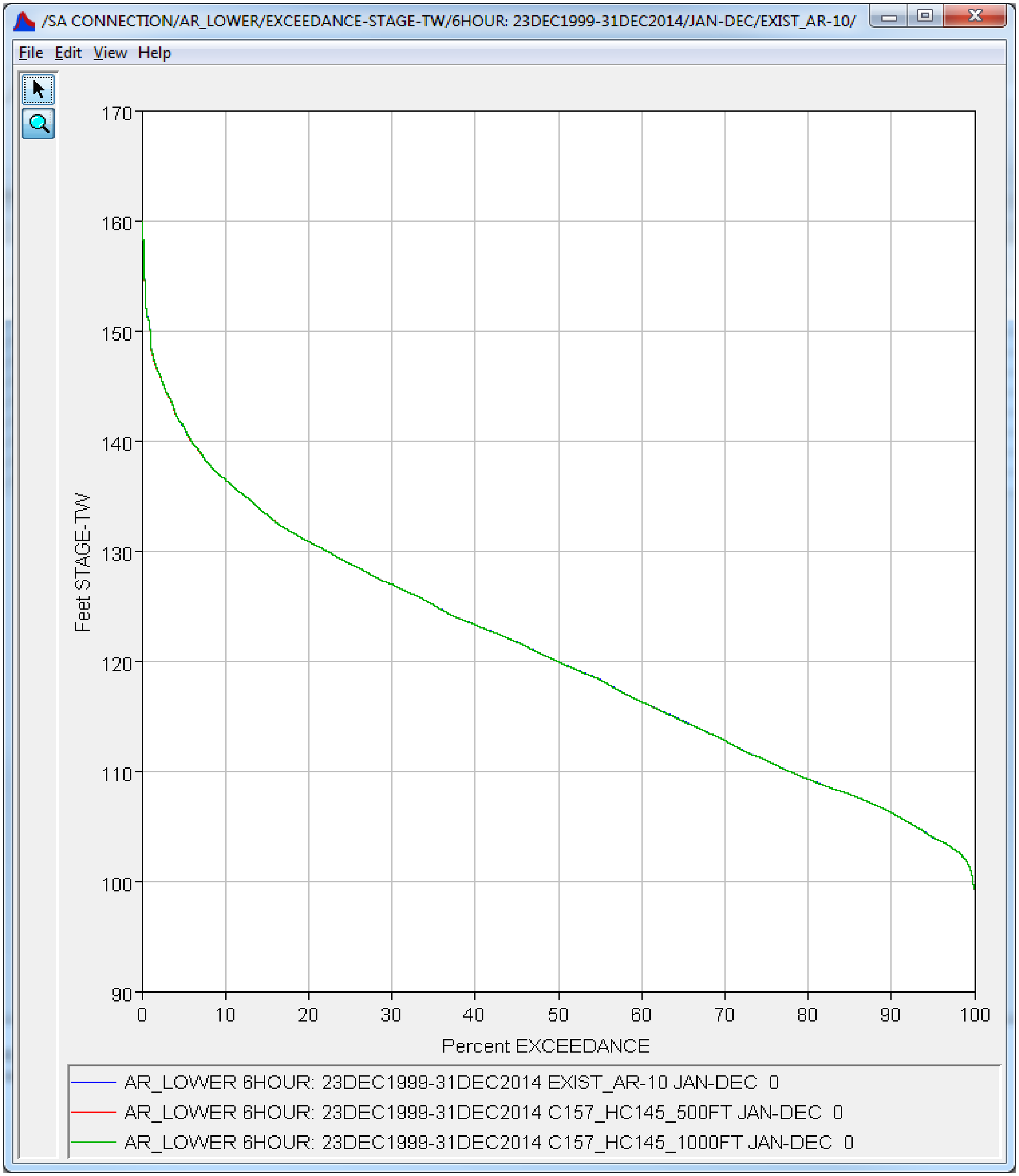
_____ Existing _____C157 HC145 500ft Wide ____C157 HC145 1000ft wide



Arkansas River Lower

Arkansas River approximately 5 miles above confluence with Mississippi river

______ Existing ______C157 HC145 500ft Wide ____C157 HC145 1000ft wide



/SA CONNECTION/AR_LOWER/EXCEEDANCE-STAGE-TW/6HOUR: 23DEC1999-31DEC2014/JAN-DEC/EXIST_AR-10/
File Edit View Help
Feet STAGE-TW
170
160
150
140
130
120
110
100
90
0 10 20 30 40 50 60 70 80 90 100
Percent EXCEEDANCE
AR_LOWER 6HOUR: 23DEC1999-31DEC2014 EXIST_AR-10 JAN-DEC 0
AR_LOWER 6HOUR: 23DEC1999-31DEC2014 C157_HC145_500FT JAN-DEC 0
AR_LOWER 6HOUR: 23DEC1999-31DEC2014 C157_HC145_1000FT JAN-DEC 0